SEBHA UNIVERSITY JOURNAL OF PURE & APPLIED SCIENCES VOL.24 NO. 1 2025
DOI: 10.51984/JOPAS.V24I1.3860

مجلة جامعة سبها للعلوم البحتة والتطبيقية
Sebha University Journal of Pure & Applied Sciences

Journal homepage: www.sebhau.edu.ly/journal/jopas

Enhancing Energy Efficiency in Libyan Residential Buildings: Selecting Optimal Insulation and Integrating Renewable Energy Technologies

Awad Bodalal[a], Salah Mashiti[a], Omer Aladwli[a], Ayman Alkezza[b]*

[a]Department of Mechanical Engineering, University of Benghazi, Benghazi, Libya.
[b]College of Mechanical Engineering Technology-Benghazi ،Benghazi, Libya

Keywords:
Energy Efficiency.
Insulation Optimization.
Renewable Energy Integration.
Residential Energy Consumption.
Solar Energy.

ABSTRACT

The rising electricity demand in Libya, particularly from the residential sector, underscores the urgent need for sustainable energy solutions. This study investigates the potential of integrating energy-saving technologies, including solar water heating systems, photovoltaic (PV) cells, optimized insulation materials, and compact fluorescent lamps (CFLs), to enhance energy efficiency in Libyan households. A comprehensive methodology was employed, combining theoretical analysis and simulation-based evaluations across diverse climatic zones in Libya. Key findings reveal that adopting these integrated technologies can significantly reduce energy consumption, lower greenhouse gas emissions, and achieve considerable cost savings. For instance, optimizing insulation material thickness led to annual energy savings of up to 30% with payback periods between 4 to 6 years, while leveraging Libya's abundant solar resources further amplified these benefits. This research provides actionable insights for policymakers and stakeholders to promote sustainable practices and reduce the country's dependence on fossil fuels, aligning with global efforts to combat climate change and enhance energy security.

تحسين كفاءة الطاقة في المباني السكنية في ليبيا: اختيار العزل الأمثل ودمج تقنيات الطاقة المتجددة

عوض بودلال[a]، صلاح المشيطي[a]، عمر العدولي[a]، ايمن الكزة[b]*

[a]قسم الهندسة الميكانيكية، جامعة بنغازي، بنغازي، ليبيا.
[b]كلية تقنية الهندسة المكانيكية، ، بنغازي، ليبيا.

الكلمات المفتاحية:
كفاءة الطاقة.
تحسين العزل.
دمج الطاقة المتجددة.
الاستهلاك السكني.
الطاقة الشمسية.

الملخص

تزايد الطلب على الكهرباء في ليبيا، خصوصاً من القطاع السكني، تسلط هذه الدراسة الضوء على الحاجة الملحة إلى حلول طاقة مستدامة. الدراسة تحقق في إمكانية دمج تقنيات توفير الطاقة، بما في ذلك أنظمة تسخين المياه بالطاقة الشمسية، الخلايا الكهروضوئية (PV)، مواد العزل المثلى، والمصابيح الفلورية المدمجة (CFLs)، لتعزيز كفاءة الطاقة في المنازل الليبية. تم استخدام منهجية شاملة، تجمع بين التحليل النظري والتقييمات القائمة على المحاكاة عبر مناطق مناخية متنوعة في ليبيا. تكشف النتائج الرئيسية أن تبني هذه التقنيات المتكاملة يمكن أن يقلل بشكل كبير من استهلاك الطاقة، ويخفض انبعاثات غازات الاحتباس الحراري، ويحقق وفورات كبيرة في التكلفة. على سبيل المثال، أدى تحسين سمك مادة العزل إلى توفير طاقة سنوي يصل إلى 30٪ مع فترات استرداد للتكلفة تتراوح بين 4 إلى 6 سنوات، بينما زاد استغلال الموارد الشمسية الوفيرة في ليبيا من هذه الفوائد. توفر هذه الدراسة رؤى قابلة للتنفيذ لصانعي السياسات وأصحاب المصالح لتعزيز الممارسات المستدامة وتقليل اعتماد البلاد على الوقود الأحفوري، بما يتماشى مع الجهود العالمية لمكافحة تغير المناخ وتعزيز أمن الطاقة.

*Corresponding author.
E-mail addresses: aymankhaalifa@gmail.com, (A. Bodalal) awad.bodalal@gmail.com, (S. Masheiti) Salah.Masheiti@uob.edu.ly, (O. Aladwli) Omar.Aladoli@gmail.com.
Article History : Received 09 March 25 - Received in revised form 05 May 25 - Accepted 24 May 25

1. Introduction:

The global energy landscape has undergone significant changes in recent decades, driven by the twin challenges of rising energy demand and the urgent need to mitigate climate change. Fossil fuel depletion, escalating energy costs, and environmental degradation have collectively underscored the necessity for transitioning towards renewable and energy-efficient solutions. Among these, solar energy has emerged as a particularly promising option due to its abundance, sustainability, and minimal environmental impact. Libya, with its favorable geographic location and substantial solar radiation levels [1] averaging between 7.1 kWh/m²/day in coastal regions and 8.1 kWh/m²/day in southern areas [2] is exceptionally well-positioned to harness solar energy. Despite this potential, the nation's energy infrastructure remains heavily reliant on conventional sources, resulting in inefficiencies, high greenhouse gas emissions, and increasing energy costs for residential consumers. Residential buildings in Libya consume approximately 40% of the country's total electricity [3], making them a critical sector for implementing energy-saving measures. Technologies such as solar water heating systems, photovoltaic (PV) cells, compact fluorescent lamps (CFLs), and insulation materials have shown significant promise in enhancing energy efficiency. However, their adoption remains limited due to economic, infrastructural, and cultural barriers. Additionally, most existing research in the Libyan context has focused on isolated energy-saving technologies or specific geographic regions, leaving a notable gap in understanding the combined effects of multiple solutions across diverse climatic zones. This lack of integration and comprehensive analysis presents a critical research gap that this study aims to address.
The primary objective of this research is to evaluate the combined impact of solar energy systems, optimized insulation materials, and energy-efficient lighting on energy consumption and greenhouse gas emissions in the Libyan residential sector. By integrating diverse methodologies, including the calculation of cooling and heating degree days (CDD and HDD), field measurements of water and electricity usage, and cost-benefit analyses of insulation materials and renewable energy systems, the study seeks to provide actionable insights for sustainable energy management in Libya. Furthermore, it aims to contribute to global efforts in climate change mitigation by demonstrating how a developing nation with abundant solar resources can transition towards energy sustainability.
The existing body of literature highlights the potential of energy-saving technologies in reducing energy consumption and minimizing environmental impact. For instance, studies by Dombayci and Bolatturk [14] have demonstrated the effectiveness of calculating CDD and HDD to optimize insulation thickness, leading to significant reductions in heating and cooling energy demands. Similarly, Duffie and Backman's research on flat-plate solar collectors underscores their economic and environmental advantages for water heating, identifying them as one of the most cost-effective methods for harnessing solar energy. Comakli and Yuksel's investigations into insulation materials revealed that optimizing insulation could reduce CO2 emissions by up to 50%. These findings provide a robust foundation for understanding the technical and environmental benefits of energy optimization.
However, the Libyan context presents unique challenges and opportunities. The country's diverse climatic zones ranging from coastal Mediterranean climates to arid desert regions—require tailored approaches to energy efficiency. Despite this diversity, empirical data on the economic feasibility and environmental impacts of integrated energy-saving solutions in Libyan households remain scarce. Existing studies often overlook the synergistic benefits of combining technologies such as PV cells, solar water heaters, and insulation optimization. Additionally, the limited availability of high-quality data on energy consumption patterns and the underdeveloped state of Libya's energy infrastructure further complicates the implementation of sustainable solutions.
This study addresses these gaps by conducting a holistic evaluation of energy-saving measures tailored to Libya's climatic and economic conditions. It integrates theoretical modeling and cost-benefit analyses to quantify the potential reductions in energy consumption, costs, and greenhouse gas emissions achievable through the adoption of renewable and energy-efficient technologies. By leveraging Libya's abundant solar resources and optimizing insulation materials, the research aims to provide policymakers and stakeholders with evidence-based recommendations to enhance energy efficiency, reduce environmental impact, and promote sustainable development.
In conclusion, the research contributes to the growing body of knowledge on sustainable energy practices by addressing critical gaps in the literature and demonstrating the feasibility of integrated energy-saving solutions in a developing country context. It not only highlights the technical and economic benefits of these technologies but also underscores their potential to transform Libya's residential energy landscape, aligning with global objectives for a sustainable and low-carbon future.

2. Methodology:

The methodology employed in this study is designed to systematically evaluate the potential of integrated energy-saving technologies in enhancing energy efficiency and reducing greenhouse gas emissions in the Libyan residential sector. This section outlines the governing equations, analytical techniques, and the rationale behind the chosen methodologies, ensuring their alignment with the study's objectives

2.1. Research Design and Approach:

A multimethod approach was adopted, integrating theoretical analysis, field measurements, and simulation-based evaluations. This comprehensive methodology enabled the assessment of the combined impact of solar water heating systems, photovoltaic (PV) cells, optimized insulation materials, and compact fluorescent lamps (CFLs) on energy consumption and environmental outcomes across diverse Libyan climatic zones. The inclusion of multiple analytical techniques provided a robust framework for addressing the research objectives and filling existing gaps in the literature.

2.2. Governing Equations:

a. Equations for the Wall:

The second aim of this study is to calculate the optimum insulation thickness and perform a cost analysis study. This subsection is devoted to illustrate energy and cost analysis calculations. In order to lower the heat flow from outside to inside buildings that have air conditions, an insulation material is usually used. This material has a very low thermal conductivity. In this case, a suitable insulation material with its optimal thickness is necessary in order to obtain optimum air conditioning system. The insulation thickness increases the investment cost, but the cost of energy will decrease, until at a point, the thickness of the material is optimum and will give the highest overall cost savings. This can be done by conducting life cycle cost or cost-benefit analysis due to the installation of insulation material. To calculate cost-benefit, it is necessary to know the total cost of the insulation (Ci) which can be calculated from the following:

$C_i = Ax * C_A$ ………………………… (1)

Where
A: Surface area (m^2).
x: Insulation thickness (m).
C_A: Cost of insulation per unit volume (LD/m^3).
Annual saving (S) can be calculated as follows:

$S = C_{f0} - C_w - C_i$…………………………………………(2)

Where:
C_{f0}: Total cost of energy consumption annually without insulation (LD/m^2).
C_w: Total cost of energy consumption annually with insulation (LD/m^2).
C_i: Total cost of insulation (LD/m^2).
While the total cost of energy consumption can be calculated as follow:

$C_{f0} = E_w * C_w * P$ …………………………………………..(3)

Where:
E_w: Total amount of energy consumption for air conditioning.

$E_w = \frac{Q_w}{Cop}$………………………………………………… (4)

Where:
Q_w: Heat transmission through the building envelope (W/m^2).
Cop: Coefficient of performance.
Figure (1) show a cross-sectional view for typical external walls in Libya and a cross-sectional view for the insulated external walls.

(i) Reference wall (uninsulated) (ii) Wall with insulation

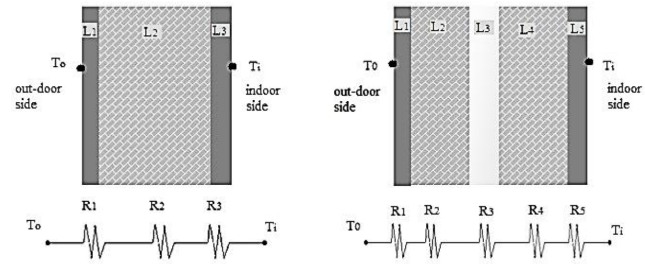

Fig1: The reference and the insulated walls

Table (1) The thermal and some other important information for the two walls illustrated above.

Table 1: Structure of the walls (reference and insulation)

Wall layer	Reference wall	Insulation wall
L1	Plaster (20 mm)	Plaster (20 mm)
L2	Hollow concrete block (200mm)	Hollow concrete block (100mm)
L3	Plaster (30 mm)	Insulation layer
L4	---	Hollow concrete block (100mm)
L5	---	Plaster (30 mm)

This thermal transmission process through the wall can be calculated by the following equation:

$Q_w = 0.024 * U_w * CDD$ or HDD …………………......……. (5)

CDD: Cooling degree day (℃day).

HDD: Heating degree day (℃day).

U_w: Overall heat transfer coefficient with insulation.

$U_w = \frac{1}{R_{wt}+\frac{x}{K_{ins}}}$…………………………..……………….... ….(6)

$U_0 = \frac{1}{R_{wt}}$ …………………………………… …...…….. (7)

U_0: Overall heat transfer coefficient without insulation.

Substitute equation (5) into equation (4) we get:

$E_w = \frac{0.024*U_w*CDD}{Cop}$……………………….....……….….…….. (8)

Substitute equation (8) into equation (3) we get:

$C_{f0} = \frac{0.024*U_0*CDD*C_E*P}{Cop}$………………………..………..……. (9)

And

$C_{fw} = \frac{0.024*U_w*CDD*C_E*P}{Cop}$……………………..……… ……… (10)

Sub. equation (9) and (10) into equation (1)

$S = \left[\frac{0.024*U_w*CDD*C_E*P}{Cop}\right] * (U_0 - U_w) - xC_A$………… ..…… (11)

S: Annual saving (LD/m^2).

The optimum insulation thickness is obtained by maximizing the net saving (S). Therefore, derivative at (S) with respect to (x) and equate it with zero [22].

$\frac{\partial S}{\partial x} = 0.$

$\frac{\partial S}{\partial x} = \frac{R_{wt}^2*K_{ins}*(0.024*CDD*C_E*P)}{Cop*(R_{wt}^2*K_{ins}+R_{th}*x)^2} - C_A.$

Solve for x (x=X_{opt}) we get:

$X_{opt} = \frac{\left\{\left(\frac{R_{wt}^2*K_{ins}*0.024*CDD*C_E*P}{C_{A*Cop}}\right)^{1/2}\right\}-(R_{wt}^2*K_{ins})}{R_{wt}}$ ……….….… (12)

where;

X_{opt}: The optimum thickness of insulation (m).

C_A: Cost of insulation per unit volume (LD/m^3).

R_{wt}: Thermal resistance of the composite wall (m^2°C$/W$).

P: Life cycle parameter (assumed 25- 30 years).

CDD: Cooling degree day (°C day).

K_{ins}: Thermal conductivity of the insulation ($W/m.$℃).

C_E: Cost of electricity (LD).

To get the payback period use equation (11) with $(U_0 - U_w) = \Delta U$

$\Delta U = \frac{x}{R_{wt}^2*K_{ins}+R_{wt}*x}$………………………...………… (13)

Sub. equation (13) into equation (11) and equal it with zero and solve for P we get

$P = \frac{C_A*Cop*[R_{wt}^2*K_{ins}+R_{wt}*x]}{(0.024*C_E*CDD)}$……………………………...... (14)

P: The payback period (year).

b. Equations for Energy Consumption for Water Heating:

The most important parameter that needs to be considered in the design of a water heating system is the hot water demand over a certain period of time (hourly, daily or monthly).

$Q_{rq} = V * \rho * C_p * (T_w - T_m)$………………………….. (15)

Where:

Q_{rq}: The heat energy required for heating water in (KJ/Day).

V: The volumetric consumption.

ρ: The density of water (kg/m^3).

C_p: The specific heat of water (KJ/Kg ℃).

T_m: The temperature of the cold water supplied by public mains (℃).

T_w: The temperature water distribution (℃).

Using the suitable conversion factor ($1/3.6 * 10^6$) to convert from (J/day) to (KWh/day) we can get the amount of electricity required to heat a specific amount of water from T_m to T_w.

$E_{rq} = \frac{Q_{rq}*10^3*30}{3.6*10^6}$ ……………..……….......…………(16)

If the two temperatures in Eq. (15) are known for a particular application, the only parameter on which the energy demand depends is the hot water volumetric consumption. This can be estimated according to the period of time investigated.

For example, for the monthly water demand, the following equation can be used:

$V = N_{day} * N_{persons} * V_{person}$……………………….. (17)

Where:

N_{day}: The number of days in a month.

$N_{persons}$: The number of persons served by the water heating system.

V_{person}: The volume of hot water required per person.

The volumetric consumption varies considerably from person to person and from day to day. For instance, the habits of users, the weather conditions of locality and various economic conditions.

c. Equations Used to Calculate Electricity Consumption of Water Heating:

Based on the solar hot water collector theory The thermal efficiency.

$\eta_{th} = \frac{Q_u}{A_c \overline{H_t}}$ ………………………………..………….. (18)

η_{th} : The solar collector thermal efficiency

Q_u: The amount of useful energy collected (J/day).

A_c: The surface area of the collector (m^2).

$\overline{H_t}$: The solar intensity of a specific location (MJ/m^2).

Using the suitable conversion factor ($1/3.6 * 10^6$) to convert from (J/day) to (KWh/day) we can get the amount of electricity required to heat a specific amount of water from T_m to T_w.

$E_u = \frac{(Q_u*10^{-3})*10^3*30}{3.6*10^6}$ ……………..……..……… … (19)

$E_{WH} = E_{rq} - E_u$ ……………………..……….… (20)

E_{WH}: The difference between energy demand in Regular home and contribution of solar collector (KJ/KWh) energy consumed by the Integrated home from the electrical grid due to water heating ($KWh/month$).

d. Equation Used for Calculating the Total Amount of Energy Consumption for Lighting:

$E_{light} = \frac{30* \ Bulb \ power * \ n * \ Average \ operation}{1000}$…………….. (21)

Where:

E_{light} : Total amount of energy consumption for lighting ($KWh/month$).

$Bulb\ power$: The wattage per lamp ($watt$).

n: The total number of lamps in the home.

$Average\ operation$: The average operating hours per day in the house (Hr).

e. Equation Used for Calculating the Total Amount of Energy Consumption for Appliances:

The first step is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system.

$E_{CR} = 30 *$ $Electrical\ energy\ consumption\ due\ to\ appliance\ (\frac{KWh}{day})$ …. (22)

Where:

E_{CR}: Electrical energy consumption due to appliance in a regular home ($KWh/month$).

$E_{CI} = \frac{30* \ PGF * N_{PV} * PV \ Cell \ Watts}{1000}$…………………… (23)

Where:
E_{CI}: Total amount of (KWh) heat PV cell going to each month $(KWh/month)$.
PGF: The power generation factor in a specific location.
N_{PV} : The number of PV cell panels used (w).
$PV\ Cell\ Watts$: The watts of each PV cell (w).

$E_{App} = E_{CR} - E_{CI}$……………………… ……… (24)

Where:
E_{App}: The difference in $(KWh/month)$ between the actual need (monthly) and contribution of PV cell panels (monthly).

Total electrical energy consumed $(Kwh/month)$ = total electrical energy for hot water + lighting + Appliance.…. . (25)

f. Equations for Savings in Electricity Bills:

The cost of the electricity bill can be calculated as follows:

Cost of electricity bill $(LD/month)$ = Electricity Consumed$(KWh/month)$ * Electricity Price (LD/KWh)…… . (26)

Therefore, the saving is the difference between the two scenarios.

$C_{WH} = E_{WH} * C_E$ ……………………….… ..………… (27)

Where:
C_{WH}: The cost of electrical bill from hot water $(LD/month)$.
C_E: The electricity cost (LD/KWh).

$C_{light} = E_{light} * C_E$ …………………… ...…… .. (28)

C_{light}: The cost of electrical bill from lighting $(LD/month)$.

$C_{App} = E_{App} * C_E$ …………………………… ….…….. (29)

C_{App}: The cost of electrical bill from Appliance $(LD/month)$.

Total electrical energy consumed $(Kwh/month)$ = total electrical energy for (hot water + lighting + Appliance) ……………………………..….………. (30)

$$Pb = \frac{the\ cost\ of\ the\ equipment}{Anually\ saving\ electrical\ energy} \text{ ….… …..………. (31)}$$

Pb: Total payback period (year).

g.Equations for Environmental Impact Assessment:

The reduction in greenhouse gas emissions is quantified using the following:

The amount of greenhouse gases emitted from power station can be summered by the following table (2).

Table 2: Emissions amount of green gases by power plants [23].

EMISSION FACTOR (KG/KWH)				
FUELS	CO_2	SO_2	NO_X	CO
COAL	1.18	0.0139	0.0052	0.0002
PETROLEUM	0.85	0.0164	0.0025	0.0002
GAS	0.53	0.0005	0.0009	0.0005

Therefore, the emitted greenhouse can be calculated as follows:

Total $CO_2 = 0.53 * Electricity\ saved\ (KWh)$ …………………………… (32)

Total $CO = 0.0005 * Electricity\ saved\ (KWh)$ ……………………....…… (33)

Total $NO_X = 0.0009 * Electricity\ saved\ (KWh)$ ……………..…...….…… (34)

Total $SO_2 = 0.0005 * Electricity\ saved\ (KWh)$ ……………..…..…...…… (35)

Thermal pollutant $= (Total\ amount\ CO_2\ saved/$ 0.001016..….......……… (36)

Number of trees $= (Total\ amount\ CO_2\ saved/1000)/\ 12$ ……………………....…… (37)

This equation is based on that, every 1 fully grown tree consumes 12 kg of CO_2 annually.

Where:
CO_2 : The amount of CO_2 emission$(Kg/\ year)$.
CO: The amount of CO emission$(Kg/\ year)$.
NO_X : The amount of NO_X emission$(Kg/\ year)$.
SO_2 : The amount of SO_2 emission$(Kg/\ year)$.
Thermal Pollutant: Thermal energy Emitted $(KCal/year)$.

h. Equations for Home Energy Rating Standard (HERS) Calculations:

The HERS index is a measurement of a home's energy efficiency and there are a lot of great reasons why a home energy rating should be performed on houses. The HERS index score indicates how well the home performs in regards to energy. The HERS report outlines the energy features of the home and the expected cost of utility bills. You will be provided with invaluable information about the house you live in, like how efficiently it's operating and areas where modification can be made for greater energy saving.

The *HERS index* equation:

HERS Index =

$$PE_{frac} \frac{(E_{WH}+E_{light}+E_{App}+E_{Cooling}+E_{Heating})\ Integrated\ home}{(E_{WH}+E_{light}+E_{App}+E_{Cooling}+E_{Heating})\ Regular\ home} * 100 \text{ .(38)}$$

PE_{frac}: Energy fraction

$$PE_{frac} = \frac{E_{used}-E_{produced}}{E_{used}} \text{ …… ……..….(39)}$$

- A home that produces no power ($E_{produced} = 0$) has a PE_{frac} = 1 and doesn't affect the HERS index score.
- A home producing an amount of energy equal to half of what it uses ($E_{produced} = 0.5 * E_{used}$) will have a $PE_{frac} = 0.5$, which will cut the HERS index by half.
- A home producing the same amount of energy as it produces ($E_{produced} = E_{used}$) will have a PE_{frac} = 0, producing a HERS index score of 0. This is a net-zero energy home.
- A home producing more energy than it used ($E_{produced} > E_{used}$) will have a negative PE_{frac}, and therefore a negative HERS index score.

The methodologies are grounded in established academic practices, ensuring validity and reproducibility. By integrating multiple approaches, this study not only addresses the identified research gaps but also contributes novel insights into the sustainable energy practices required for developing nations.

3. Results:

The results of this study highlight the significant potential of integrated energy-saving technologies in improving energy efficiency and reducing greenhouse gas emissions in Libyan residential buildings. This section presents key findings in an organized manner, discusses their implications, and identifies areas where clarification or optimization is needed to enhance the interpretability and utility of the results.

3.1 Results for Wall Insulation:

a. **Optimization of Insulation Thickness*:*** The analysis of insulation materials across different climatic zones demonstrated a direct correlation between Cooling and Heating Degree Days (CDD/HDD) and the optimum insulation thickness. For instance, in Benghazi, with a CDD of 1089.725 °C·day, polyurethane was identified as the most cost-effective insulation material, offering an annual energy savings of 30% with a payback period of approximately 5.4 years. Expanded polystyrene and fiberglass also showed significant savings but were less efficient than polyurethane under similar conditions.

Table 3: Results of insulation material calculations for the city of Benghazi (CDD = 1089.725℃ day).

Description	Insulation material		
	Fiberglass	Polyurethane	polystyrene
Thermal conductivity, K $(\boldsymbol{W/m}$℃)	0.050	0.025	0.032
Cost of insulation, $\boldsymbol{C_A}$ $(\boldsymbol{LD/m^3})$	142	156	170
Optimum thickness, $\boldsymbol{X_{op}}$ (m)	0.0536	0.04	0.0412
Annual energy consumption, $\boldsymbol{E_w}$ $(\boldsymbol{KWh/m^2year})$	8.5906	6.3669	7.5196
Insulation cost, $\boldsymbol{C_i}$ (LD/ m^2)	7.6112	6.24	7.004
Payback period, (year)	7.2731	5.3904	6.3663
Amount of $\boldsymbol{Co_2}$ emission $(\boldsymbol{Ton/m^2\ life})$	0.5235	0.5790	0.5502
The annual saving per unit area (LD/m^2 year)	3.8134	4.6664	4.2135

b. **Development of Empirical Correlation:** In the order to get a complete view of parameters affecting the thermal performance of the wall, the relationship between the optimum insulation thickness of the insulation material (X_{op}) and the (CDD/HDD) has to be investigated. An empirical correlation for the optimum thickness is proposed in this study. The rest of this branch section will be dedicated to developing this empirical correlation. Thermal transmission in a certain material depends upon its thermal properties (in this case the thermal conductivity) and the thickness of that material. The lower the thermal conductivity, the lower the thermal transmission. Likewise, the thicker the insulation material, the less thermal transmission. Therefore, there is an expected relationship between the thermal conductivity and optimum thickness for an energy insulation material. To our knowledge, this relation has not been discovered yet for the climate of Libya. This study will propose an empirical correlation between the optimum thickness (X_{op}) and the (CDD/HDD) for the temperature values usually experienced in Libya.

As shown in Fig:2 the relationship between (X_{op}) and the (CDD/HDD) is a non-linear relation. The best-fit equation describing this non-linear behaviour is:

$$X_{op} = a + b\,(CDD)^{0.5} \quad \ldots\ldots\ldots (40)$$

Where: a = - 0.0132285 b = 0.0010887 and X_{op} : is the optimum insulation thickness (m).

CDD: is the Cooling Degree Day (or HDD) (°C day).

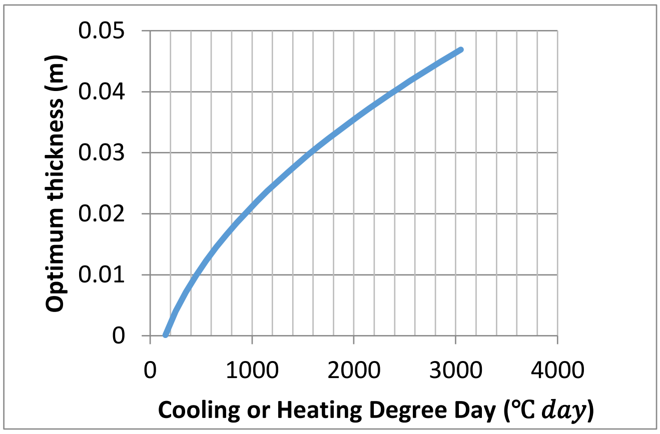

Fig 2: Development of Empirical Correlation

This empirical correlation will be very important in the future. It estimates the optimum insulation thickness easily without any long analysis. It has been revealed that the proposed correlation is valid for a wide range of thermal conductivity ($0.02 \leq K \leq 0.035$) which covers most of the commonly used wall insulation available in the market.

3.2.The Integration of Renewable Energy Technologies Results:

In this section, the following parameters will be studied:

1. The effect of variable collector thermal efficiency.
2. The effect of the number of PV cells employed.
3. The effect of the number of lighting lamps employed.
4. The effect of CDD (Cooling Degree Days) employed.
5. The effect of HDD (Heating Degree Days) employed.
6. The effect of electricity tariff.
7. The effect of insulation brick employed.

and their impact on the environment by calculating the following:

(i) The amount of CO_2 and other greenhouse gases emitted to the environment as a result of electrical consumption. (ii) The annual savings in the electricity bill. (iii) The cost and the payback period.

The results of the effects of the above-mentioned input parameters on electricity consumption and environmental pollution are presented in tables (4 to 5) and in figures (3 to 5).

As can be seen that all the trends are logical and as expected. The results are very informative and will have great values for researchers and home owners.

3.2.1. The Effect of Variable Collector Thermal Efficiency:

The results of the effect of the above-mentioned input parameter on electricity consumption and environmental pollution are presented in tables (4 & 5) and figures (3 to 5).

Table 4: The effect of collector thermal efficiency

Thermal efficiency of collector (%)	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
40%	18173.327	6579.752	908.666	328.988	11593.577	579.679
50%	18173.327	6013.352	908.666	300.668	12159.977	607.999
60%	18173.327	5446.952	908.666	272.348	12726.377	636.319
70%	18173.327	4880.552	908.666	244.028	13292.777	664.639
80%	18173.327	4314.152	908.666	215.708	13859.177	692.959

Table 5: The effect of collector thermal efficiency on other parameters

Thermal efficiency of collector (%)	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
40%	9631.864	9480180.600	3487.269	3432350.657	27.561	6.281
50%	9631.864	9480180.600	3187.077	3136886.110	24.157	5.988
60%	9631.864	9480180.600	2886.885	2841421.562	20.948	5.722
70%	9631.864	9480180.600	2586.693	2545957.015	17.932	5.478
80%	9631.864	9480180.600	2286.501	2250492.468	15.111	5.254

The effect of an increase in the collector thermal efficiency has on the electrical bill saving cost. Ascan be seen from the Fig (3) an increasing collector thermal efficiency results in an increase in financial savings

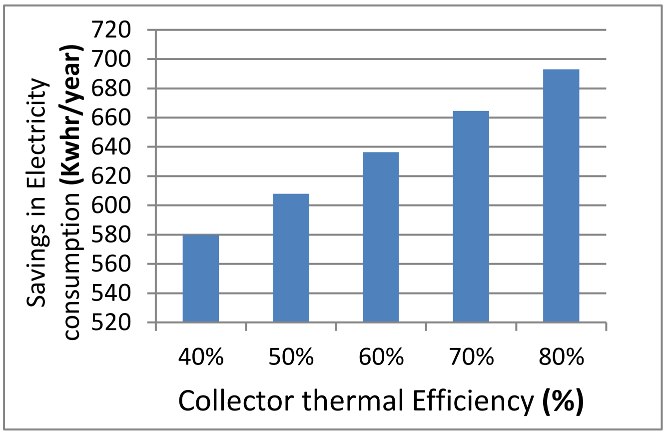

Fig 3: Collector thermal efficiency versus savings in the cost

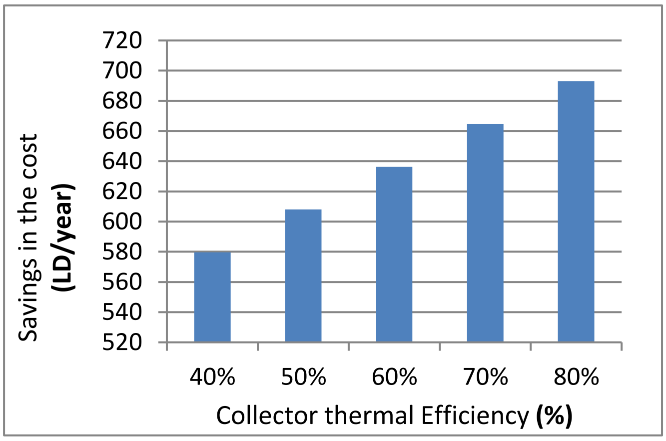

Fig 4: Collector thermal efficiency versus savings in electrical Consumption

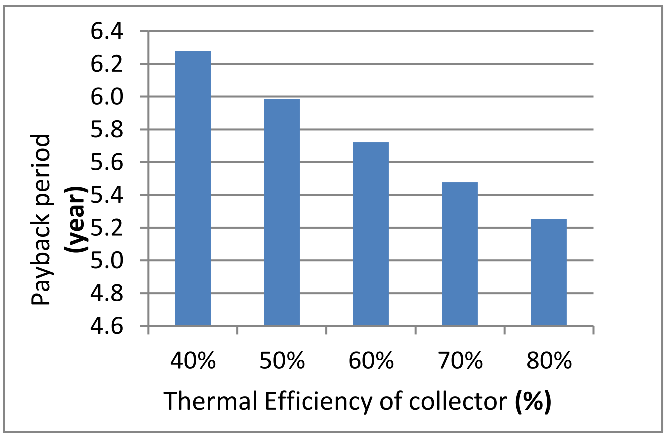

Figure 5: Collector thermal efficiency of collector versus Payback period

Illustration of the effect of an increase in the collector thermal efficiency has on electrical consumption saving. As highlighted in figure (4), an increasing collector thermal efficiency leads to an increase in consumption savings. Figure (5) shows the thermal efficiency collector versus the payback period. As the collector thermal efficiency increase the payback period decreases.

3.2.2. The Effect of the Number of PV Cell Employed:

The results of the effect of the above-mentioned input parameter on electricity consumption and environmental pollution are presented in tables (6 & 7) and figures (6 to 7).

Table 6: The effect of the number of PV cells.

Number of PV Cell	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
1	18173.327	6095.912	908.666	304.796	12077.417	603.871
2	18173.327	5577.512	908.666	278.876	12595.817	629.791
3	18173.327	5059.112	908.666	252.956	13114.217	655.711
4	18173.327	4540.712	908.666	227.036	13632.617	681.631
5	18173.327	4022.312	908.666	201.116	14151.017	707.551

Table 7: The effect of the number of PV cells on other parameters

Number of PV Cell	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
1	9631.864	9480180.600	3230.833	3179953.791	24.641	3.359
2	9631.864	9480180.600	2956.081	2909528.623	21.670	4.074
3	9631.864	9480180.600	2681.329	2639103.455	18.862	4.733
4	9631.864	9480180.600	2406.577	2368678.286	16.216	5.341
5	9631.864	9480180.600	2131.825	656433.118	13.734	5.905

The effect of an increase in the number of PV cell has on the electrical bill saving cost. As can be seen from Fig (6) an increasing number of PV cell results in an increase in financial savings

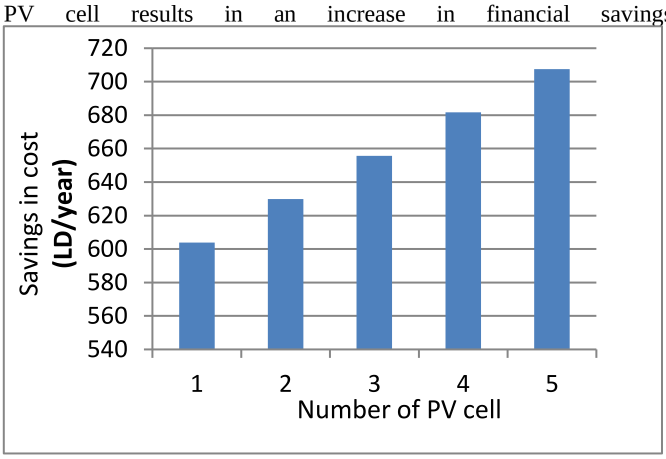

Fig6: Number of PV cell versus savings in cost

Illustration of the effect of an increase in the number of PV cell has on electrical consumption saving. As highlighted in Fig (7), an increasing number of PV cell leads to an increase in consumption savings

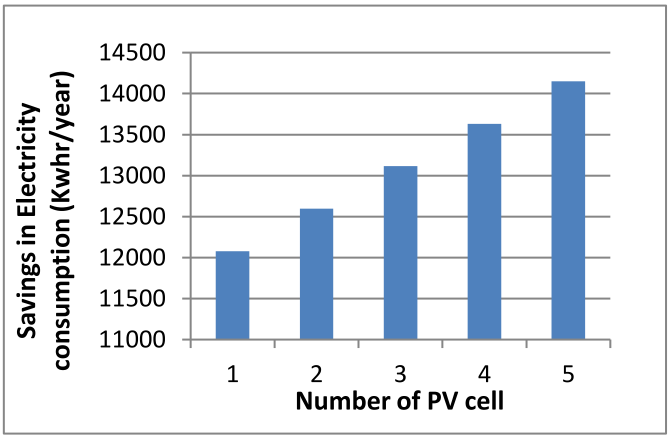

Fig 7: Number of PV cell versus savings electricity Consumption

Fig (7) shows the number of PV cell versus the payback period. As the number of PV cell increase the payback period decreases

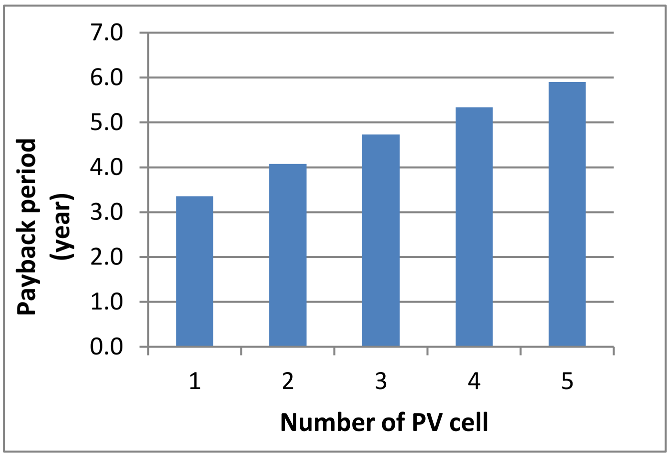

Fig 8: Number of PV cell versus Payback period

3.2.3. The Effect of the Number of Lighting Lamps Employed:

The results of the effect of the above-stated input parameter on electricity consumption and environmental pollution are given in tables (8 & 9) and figures (8 to 9).

Table 8: The effect of a number of lighting lamp

Number of Lighting Lamp	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
10	13853.327	2740.712	692.666	137.036	11112.617	555.631
20	16013.327	3640.712	800.666	182.036	12372.617	618.631
30	18173.327	4540.712	908.666	227.036	13632.617	681.631
40	20333.327	5440.712	1016.666	272.036	14892.617	744.631
50	22493.327	6340.712	1124.666	317.036	16152.617	807.631

Table 9: The effect of a number of lighting lamp on other parameters

Number of Lighting Lamp	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
10	7342.264	7226637.532	1452.577	1429702.008	10.675	6.336
20	8487.064	8353409.066	1929.577	1899190.147	13.680	5.788
30	9631.864	9480180.600	2406.577	2368678.286	16.216	5.341
40	10776.664	10606952.134	2883.577	2838166.426	18.364	4.970
50	11921.464	11733723.668	3360.577	3307654.565	20.196	4.656

Obviously, it can be seen from Fig (8), as the number of lighting lamps increases so does the financial savings

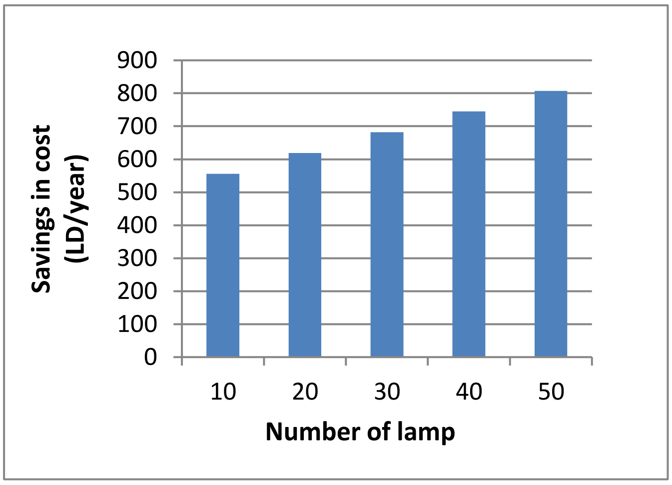

Fig 9: Number of PV cell versus savings in cost

Evidence of an increase in the number of lighting lamps as the consumption savings increases can be seen from the Fig (9).

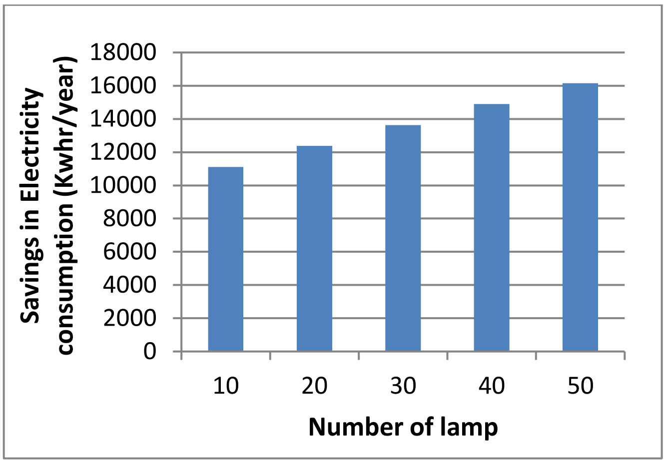

Fig10: Number of PV cell versus savings electricity Consumption

Fig (10) shows the number of lighting lamps versus the payback period. As the number of lighting lamps increases the payback period decreases.

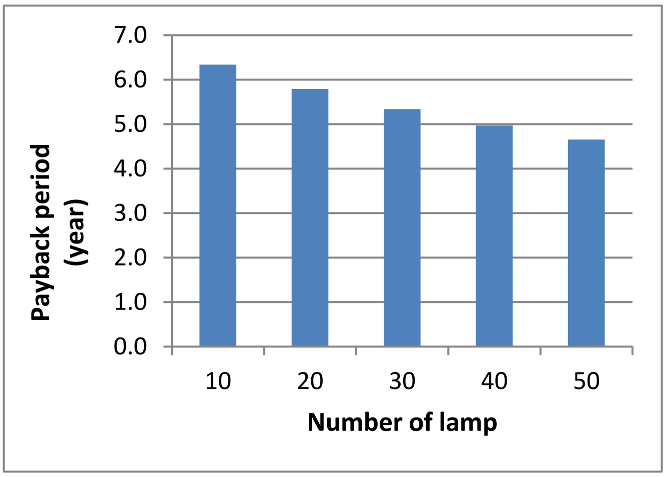

Fig 11: Number of PV cell versus payback period

3.2.4. 4.The Effect of CDD Employed:

The results of the effect of the above-mentioned input parameter on electricity consumption and environmental pollution are presented in tables (10 & 11) and figures (12 to 14).

Table 10: The effect of Cooling Degree Day (CDD)

CDD (°C/year)	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
300	16482.620	4177.307	824.131	208.865	12305.313	615.266
500	16910.797	4269.337	845.540	213.467	12641.457	632.073
1000	17981.239	4499.424	899.062	224.971	13481.815	674.091
1500	19051.680	4729.507	952.584	236.475	14322.173	716.109
2000	20122.122	4959.591	1006.106	247.980	15162.531	758.127

Table 11: The effect of Cooling Degree Day (CDD) on other parameters

CDD (°C/year)	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
300	8735.788	8598216.270	2213.972	2179106.605	15.537	5.917
500	8762.722	8821576.138	2262.750	2227116.149	15.724	5.760
1000	9530.056	9379975.807	2384.691	2347140.010	16.147	5.401
1500	10097.390	9938375.476	2506.639	2467163.872	16.514	5.084
2000	10664.724	10496775.145	2628.583	2587187.733	16.835	4.802

Fig (12) presents the effect of an increase in the CDD has on the electrical bill saving cost.

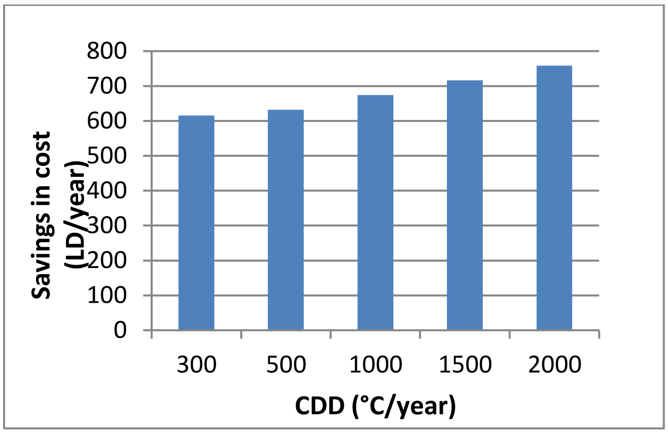

Fig 12: Cooling Degree Day (CDD) versus savings in cost

Fig (13) describes the effect of an increase in the CDD has on electrical consumption saving

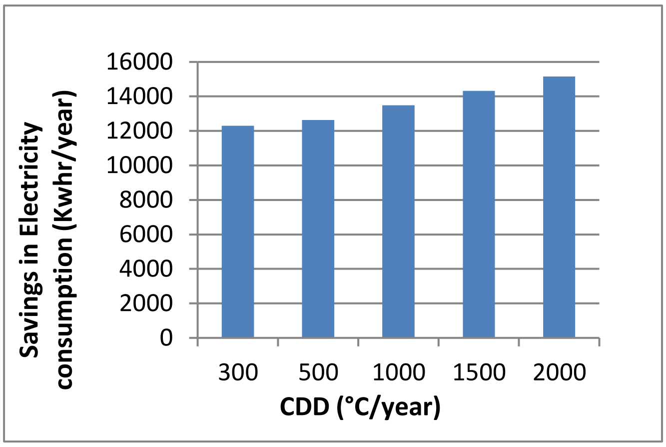

Fig13: Cooling Degree Day (CDD) versus savings electricity Consumption

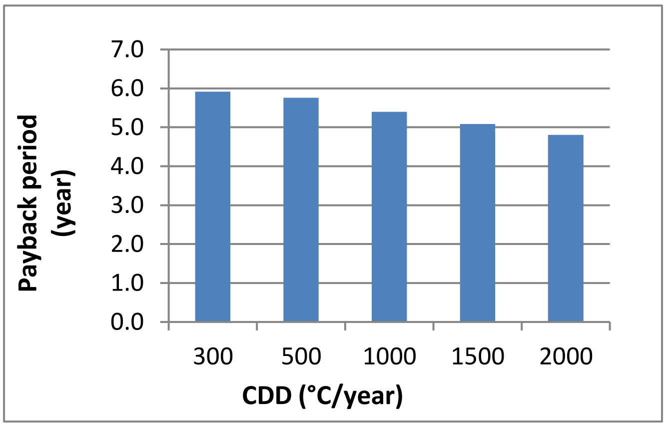

Fig 14: show the effect of varying the CDD with payback

Table 12: The effect of Heating Degree Day (HDD)

HDD (°C/year)	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
300	8863.155	8723576.996	2241.349	2206051.962	15.643	5.828
500	9090.088	8946936.864	2290.127	2254061.506	15.825	5.675
1000	9657.423	9505336.532	2412.067	2374085.367	16.234	5.326
1500	10224.757	10063736.201	2534.015	2494109.228	16.589	5.018
2000	10792.091	10622135.870	2655.959	2614133.089	19.901	4.743

3.2.5. The Effect of HDD Employed:

The results of the effect of the above-mentioned input parameter on electricity consumption and environmental pollution are presented in tables (12 & 13) and figures (15 to17).

The effect of an increase in the HDD has on the electrical bill saving cost. As can be seen from Fig (14) an increasing the HDD results in an increase in financial savings

Table 13: The effect of Heating Degree Day (HDD) with parameters

HDD (°C/year)	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
300	16722.934	4228.960	836.147	211.448	12493.970	624.699
500	17151.111	4320.994	857.556	216.050	12830.117	641.506
1000	18221.553	4551.077	911.078	227.554	13670.475	683.524
1500	19291.995	4781.161	964.600	239.058	14510.834	725.542
2000	20362.436	5011.244	1018.122	250.562	15351.192	767.560

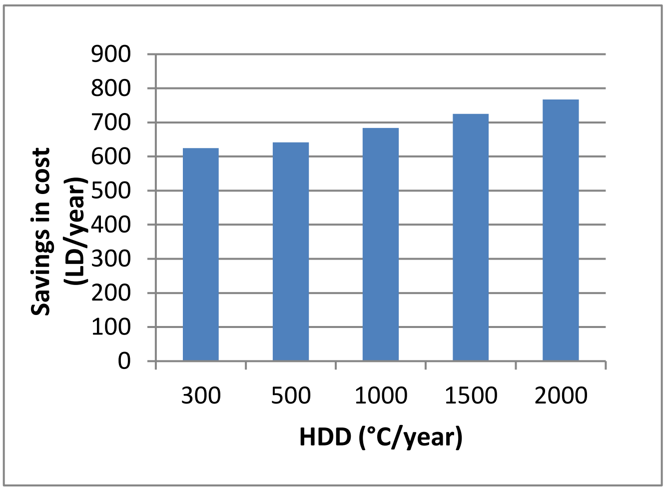

Fig 15: Heating Degree Day (HDD) versus savings in cost

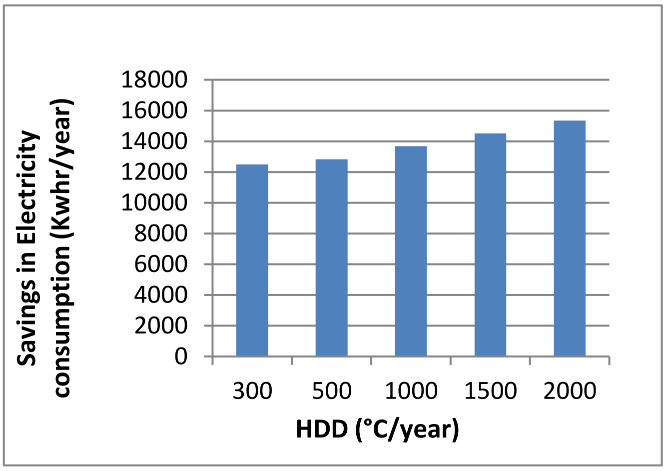

Fig 16: Heating Degree Day (HDD) with electricity Consumption

Fig (17): shows the HDD versus the payback period. As the HDD increases the payback period decreases.

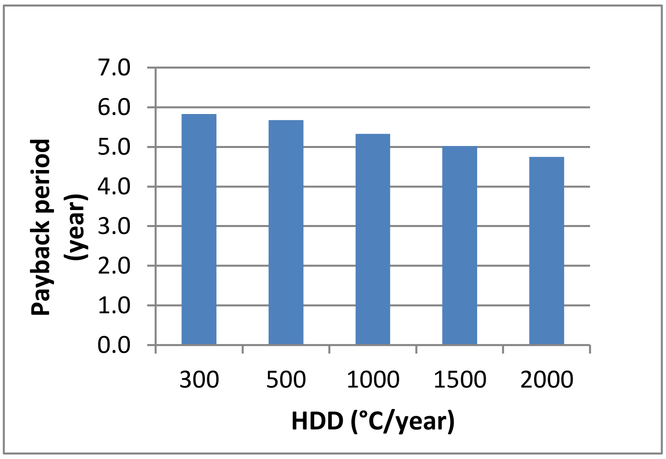

Fig 17: Heating Degree Day (HDD) versus Payback period

3.2.6. The Effect of Electricity Tariff:

The results of the effect of the above-stated input parameter on electricity consumption and environmental pollution are given in tables (14 & 15) and figures (18 to 20).

Table 14: The effect of electricity tariff

Electricity Tariff (DL)	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
0.02	18173.325	4540.712	363.467	90.814	13632.617	272.652
0.05	18173.325	4540.712	908.666	227.036	13632.617	681.631
0.1	18173.325	4540.712	1817.333	454.071	13632.617	1363.262
0.15	18173.325	4540.712	2726.000	681.107	13632.617	2044.893
0.2	18173.325	4540.712	3634.666	908.142	13632.617	2726.523
0.25	18173.325	4540.712	4543.332	1135.178	13632.617	3408.154

Table 15: The effect of electricity tariff on other parameters

Electricity Tariff (DL)	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
0.02	9631.864	9480180.600	2406.577	2368678.286	16.216	13.353
0.05	9631.864	9480180.600	2406.577	2368678.286	16.216	5.341
0.1	9631.864	9480180.600	2406.577	2368678.286	16.216	2.671
0.15	9631.864	9480180.600	2406.577	2368678.286	16.216	1.780
0.2	9631.864	9480180.600	2406.577	2368678.286	16.216	1.335
0.25	9631.864	9480180.600	2406.577	2368678.286	16.216	1.068

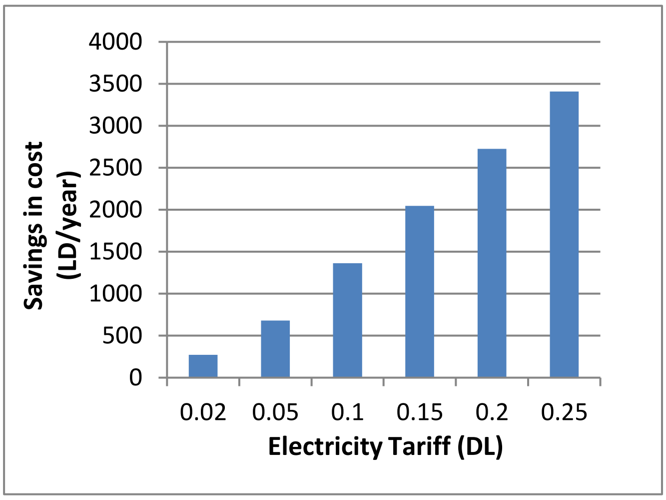

Fig 18: Electricity tariff versus savings in cost

Clearly, it can be seen from (18), as the electricity tariff increases so does the financial savings.

A proof of an increase in the electricity tariff as the consumption savings increases can be seen from the Fig (19).

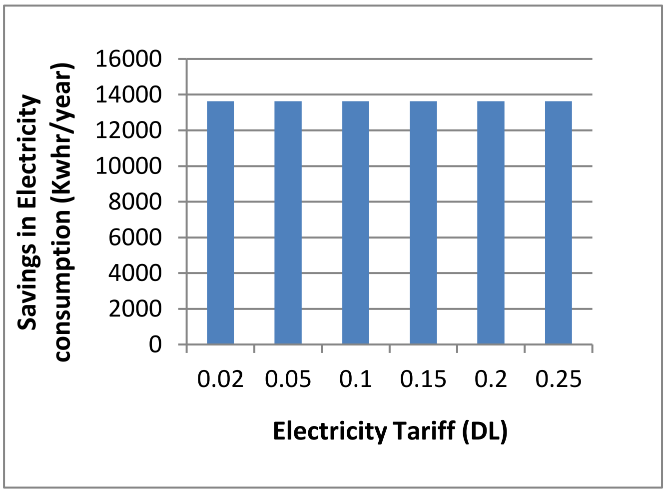

Fig 19: Electricity tariff versus savings electricity Consumption

Fig (20) shows the electricity tariff versus the payback period. As the solar collector area increase the payback period decreases

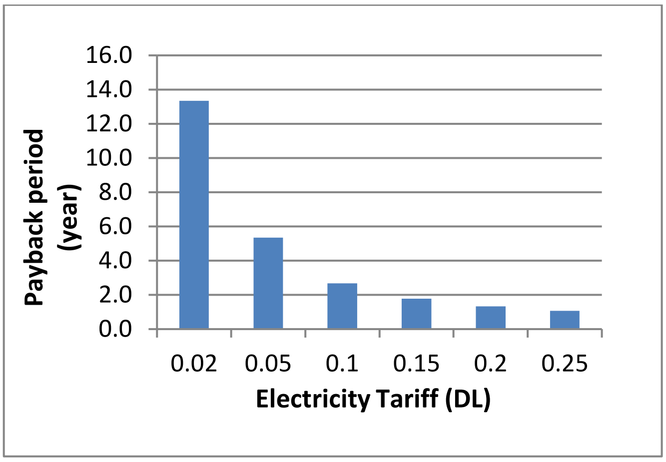

Fig 20: Electricity tariff versus Payback period

3.2.7. The Effect of Insulation Brick Employed:

It can be concluded from the obtained results from table (16 to 17) that no effect the variation in the cost of insulated bricks on other parameters except one parameter which is payback period, fig (21) Indicate the increase cost of insulated bricks it can be noticed the increase the payback period.

Table 16: The effect of insulated bricks cost

Cost of Insulation Brick (DL)	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
1.25	18173.327	4540.712	908.666	227.036	13632.617	681.631
1.5	18173.327	4540.712	908.666	227.036	13632.617	681.631
1.8	18173.327	4540.712	908.666	227.036	13632.617	681.631
2	18173.327	4540.712	908.666	227.036	13632.617	681.631
2.5	18173.327	4540.712	908.666	227.036	13632.617	681.631

Table 17: The effect of insulated bricks cost on other parameters

Cost of Insulation Brick (DL)	Environmental Pollution				HERS (%)	Payback Period (year)
	Regular home		Integrated home			
	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)	Co2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
1.25	9631.864	9480180.600	2406.577	2368678.286	16.216	4.512
1.5	9631.864	9480180.600	2406.577	2368678.286	16.216	4.857
1.8	9631.864	9480180.600	2406.577	2368678.286	16.216	5.272
2	9631.864	9480180.600	2406.577	2368678.286	16.216	5.548
2.5	9631.864	9480180.600	2406.577	2368678.286	16.216	6.239

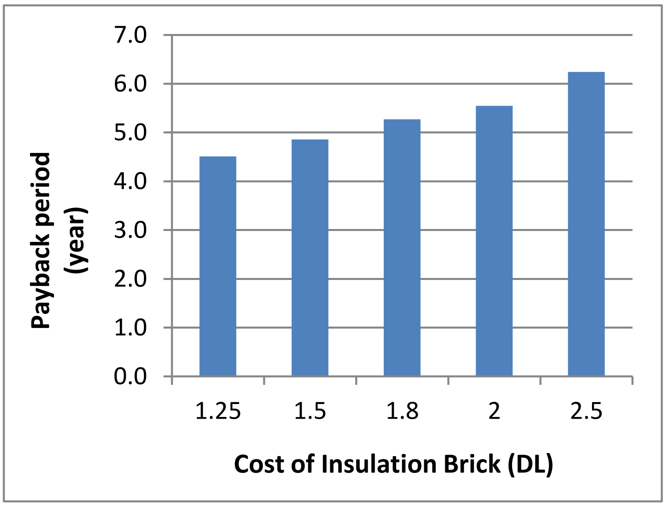

Fig 21: cost of insulated brick versus payback period

3.3 The Results of the Case Study:

The case study results indicate that Libya can achieve significant financial and environmental benefits by utilizing solar energy for domestic water heating, PV cell electricity production, thermal insulation materials in external walls, and replacing incandescent lamps with energy-efficient CFL lamps. The simulation of a 5000-housing project in Benghazi showed that these measures would save approximately 68.163 GWh/year and 3.408 million Libyan Dinars annually, with a payback period of 5.34 years. Additionally, these measures would prevent approximately 36.256 million tons of greenhouse gases from being emitted annually. The HERS index improved to 16.2% with the implementation of these technologies, as shown in Fig (26).

Table 18 Results of the case study

Case Study	Electricity Consumption (KWhr/Year)		Electricity Cost (LD/Year)		Saving Electricity Consumption (KWhr/Year)	Saving Electricity Cost (LD/Year)
	Regular home	Integrated home	Regular home	Integrated home		
5000 houses	90,866,646.3	22,703,560.3	1,140,777.8	1,135,178.03	68,163,086.01	3,408,154.3

Table 19: Results of the case study on other parameters

Case Study	Environmental Pollution		HERS (%)	Payback Period (year)
	Integrated home			
	Co_2 (Kg/Year)	Thermal Energy Emitted (KCal/year)		
5000 houses	12,032,886.3	11,843,391,432.2	16.2	5.34

Table 20: Results of the case study on other parameters

Case Study	Environmental Pollution				
	Regular home				
	Co_2 (Kg/Year)	Co (Kg/year)	Nox (Kg/ year)	So_2 (Kg/ year)	Thermal Energy Emitted (KCal/year)
5000 houses	48,159,319.9	45,433.3	81,779.9	454,33.3	47,400,903,000.8

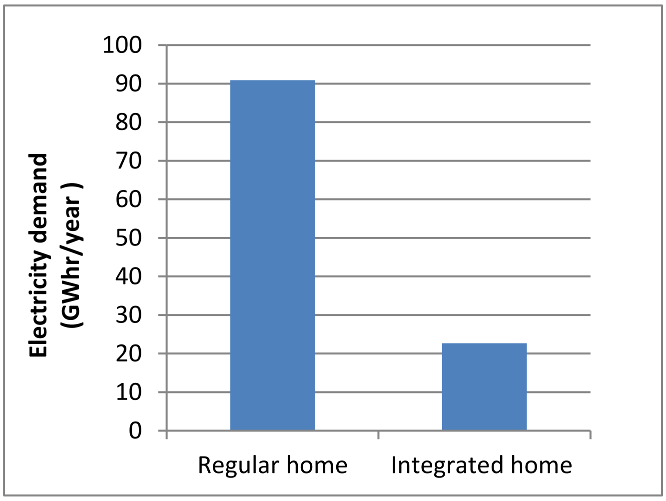

Figure 22: Electricity demand in regular homes and integrated homes (GWh/year).

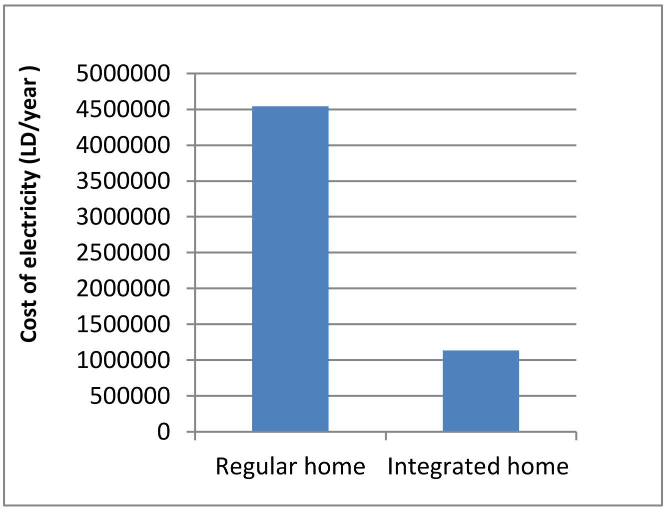

Fig 23: Cost of Electricity in regular homes and integrated homes (LD/year).

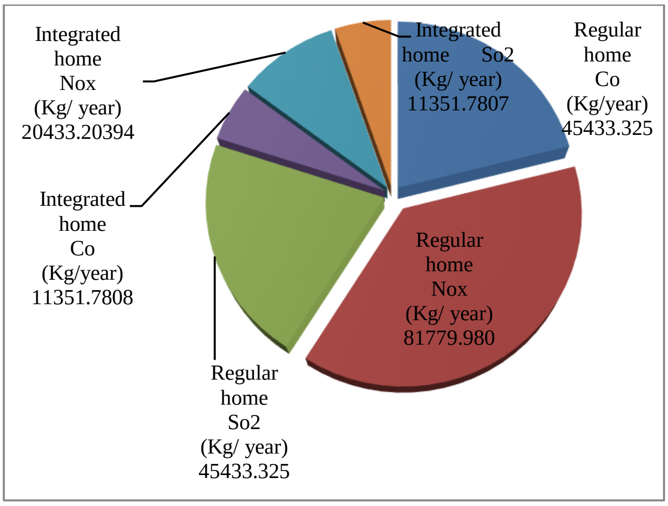

Fig 24: Total emission of environmental pollution (Kg/year) for Regular home and Integrated home

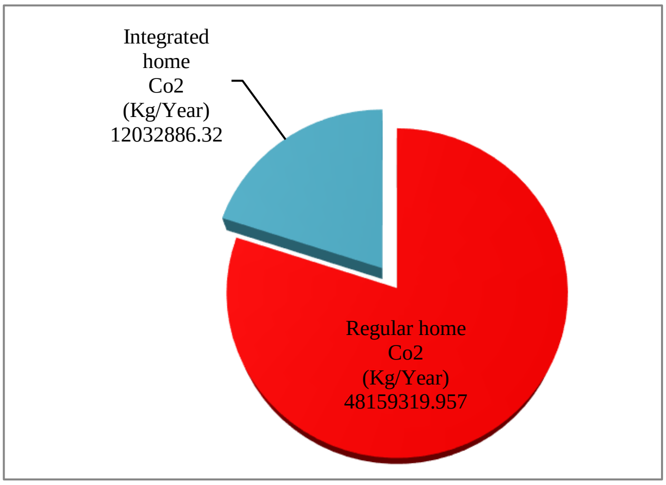

Fig25: Co_2 emission for Regular home and Integrated home

The case study for a 5,000-housing project in Benghazi highlights the benefits of integrating solar water heating systems and PV cells. Key findings include:

- Annual energy savings: 68.163 GWh
- Financial savings: 3.408 million Libyan dinars
- Payback period: 5.34 years
- Reduction in greenhouse gas emissions: 36.256 million tons annually

These results underscore the advantages of adopting renewable energy technologies in residential sectors.

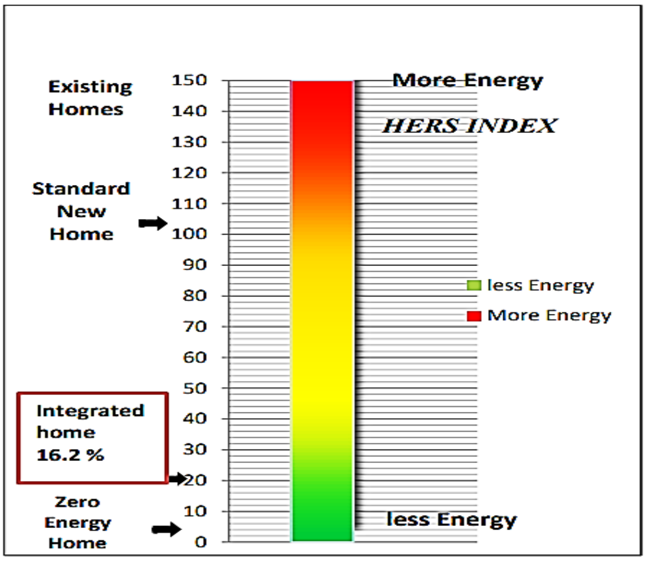

Fig26: Home energy rating system of the case study (Hers %)

By implementing an integrated approach combining solar collectors, photovoltaic (PV) systems, optimal insulation, and compact fluorescent light (CFL) bulbs, household carbon dioxide (CO_2) emissions were significantly reduced by 68% compared to the baseline scenario. Furthermore, adopting energy-saving measures yields substantial financial benefits, with the cost of implementing insulation and renewable energy systems being recouped through energy savings within a 5–6-year payback period. Households could achieve an average monthly electricity bill reduction of 45% under the integrated scenario compared to the baseline scenario.

4. Discussion:

This study explored integrated energy-saving technologies to optimize energy use and reduce environmental impact in Libyan residential buildings. Key findings show that excessive water and energy consumption, along with inefficient building practices, significantly contribute to Libya's energy challenges. The study highlighted the importance of region-specific interventions, optimizing insulation thickness, and integrating solar water heating and photovoltaic (PV) systems. A case study of a 5,000-housing project in Benghazi demonstrated a reduction of 68.163 GWh/year in energy consumption and a 36.256-million-ton annual decrease in greenhouse gas emissions. The findings emphasize the substantial impact of energy-saving measures, with calculated payback periods averaging 5.34 years, making these investments both environmentally sustainable and economically viable. Regional climate considerations and the integration of renewable energy systems showed significant environmental benefits, reducing CO_2 emissions by 68%. Robust policy support and public awareness are essential for successful implementation.

5. Conclusions, Limitations, and Recommendations:

5.1. Conclusions: This study highlights the transformative potential of energy-efficient technologies in addressing Libya's energy challenges. By integrating solar water heating, PV systems, insulation optimization, and efficient lighting, residential buildings can achieve significant energy and cost savings while mitigating environmental impacts.

5.2. Limitations: The study relies on simulated scenarios and field measurements from a limited sample size, which may not capture the full variability of household energy behaviors in Libya. The economic analysis assumes stable energy prices and does not account for potential fluctuations in installation costs or policy incentives.

5.3. Recommendations:

1. **Policies and Incentives:** Establish government-led initiatives to support the adoption of renewable energy technologies and insulation materials, especially in high-consumption areas.
2. **Public Awareness Campaigns:** Educate households on water and energy conservation practices to address excessive consumption behaviors.
3. **Further Research:** Expand the scope of field measurements to include diverse building types and regions, and explore the integration of advanced energy storage systems to enhance the reliability of solar energy solutions.
4. **Capacity Building:** Train local professionals in the installation and maintenance of renewable energy systems to ensure their long-term effectiveness and cost-efficiency.
5. **Energy Consumption for Heating and Cooling:** The integration of optimized insulation materials with PV systems and solar water heating significantly reduced energy demand for heating and cooling.
6. **Cost-Benefit Analysis:** The cost-benefit analysis showed that initial investments in energy-saving technologies might be high, but the cumulative savings over a 25-year lifecycle outweighed the costs.
7. **Environmental Impact:** The integration of renewable energy technologies significantly reduced greenhouse gas emissions, aligning with global sustainability goals

6. References:

[1]. Mohamed A, Al Habaibeh A, Abdo H, Elabar S. Towards exporting renewable energy from MENA region to Europe: An

investigation into domestic energy use and householders' energy behaviour in Libya. Applied Energy. 2015; 146:247-62.

[2]. Fathi N. Thermodynamic Analysis and Optimization Procedure for Domestic Solar Water Heating System. Am J Energy Power Eng. 2015; 2:92-99.

[3]. GECOL. General Electricity Company of Libya Report, Libya; 2010. Available from: www.gecol.ly.

[4]. Karshman H, Kaawan A. Achievement progress in the Great Man-Made River project. Engineering. 1985; 5:48-51.

[5]. Jwili R, Akilla S. Analysis of an Air-Conditioning System Assisted by a Parabolic Through Solar Collector Mounted in a Building in Benghazi-Libya. University of Benghazi. 2013;6-9.

[6]. Taylor B, Imbabi M. The application of dynamic insulation in buildings. Renew Energy. 1998;377-82.

[7]. Zaki G, Hassan K. Thermal performance of composite building components with periodic solar insulation and ambient temperature. Solar Wind Technol. 1986; 3:103-9.

[8]. Kossecka E, Kosny J. Influence of insulation configuration on heating and cooling loads in continuously used building. Energy Build. 2002; 34:321-31.

[9]. Al-Sanea S, Zedan M. Effect of insulation location on initial transient thermal response of building walls. Therm Environ Build Sci. 2001; 24:275-300.

[10]. Hassan A. Optimizing insulation thickness for building using life-cycle cost. Appl Energy. 1999; 63:115-24.

[11]. Dombaycı A. Degree-days maps of Turkey for various base temperatures. Energy. 2009; 34:1807-12.

[12]. Bolatturk A. Optimum insulation thickness for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey. Build Environ. 2008; 43:1055-64.

[13].Comakli K, Yuksel B. Environmental impact of thermal insulation thickness in buildings. Appl Therm Eng. 2004; 24:933-40.

[14]. Dombayci O. The environmental impact of optimum insulation thickness for external walls of buildings. Build Environ. 2007; 42:3855-9.

[15]. Mahlia T, Taufiq B, Masjuki H. Correlation between thermal conductivity and the thickness of selected insulation materials for building wall. Energy Build. 2007; 39:182-7.

[16]. Bolatturk A. Determination of optimum insulation thickness for building walls with respect to various fuels and climate zones in Turkey. Appl Therm Eng. 2006; 26:1301-9.

[17]. Comakli K, Yuksel B. Optimum insulation thickness of external walls for energy saving. Appl Therm Eng. 2003; 23:473-9.

[18]. Duffie J, Beckman W. Solar Engineering of Thermal Processes. 2nd ed. New York: Wiley; 1991.

[19]. ASHRAE Handbook. Heating, Ventilation, and Air Conditioning Applications. Atlanta: ASHRAE Inc.; 1991.

[20]. Naouel D. A Study on Optimum insulation thickness in Walls and Energy Savings in Tunisian Buildings Based on Analytical Calculation of Cooling and Heating Transmission Loads. Appl Energy. 2011; 88:156-64.

[21]. Kalogirou S. Solar thermal collectors and application. Appl Energy. 2004; 30:231-95. [22] . K. Murat and K. Kamola, "Energy saving potential in the residential sector of Uzbekistan," Energy Journal, vol. 32, pp. 1319–1325, 2007 .

[23]. Saidur R. Energy consumption, energy saving, and emission analysis in Malaysian office buildings. Energy Policy. 2009; 37:4104-13