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# Energy Saving Measures of Residential Buildings in North Africa: Review and Gap Analysis

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***Abstract--*** **This paper is a part of a research project aiming at developing and validating a computational code for multi-objective thermal building performance optimization by linking an evolutionary algorithm and a building simulation software in a powerful cluster. EnergyPlus simulation software/engine with SketchUp and OpenStudio software packages are employed. A common style case study as a typical residential building in Libya is studied. Single and combined energy efficiency measures were applied. These include, upgrading the specifications of building envelope and/or lights, installation of solar water heater and/or photovoltaic solar panels. In each scenario, the data and advantages are evaluated, analyzed and discussed.**

**The base style outcomes lead to an electricity demand of 163.6 kWh/m$^2$/year, where the space cooling load is devoted to be 4 times heating load, with the priority is to insulate roofs than walls. Improving the envelope thermal behavior reduces the energy consumption by 14.0 %. Lights represents a quarter of the total energy demand while upgrading interior lights leads to an annual saving of 7.7 %. Water heating strongly shares in the presence of peak demands for 9 months. Considering solar water heaters, reduces the required annual demand by more than 12 %. Using Photovoltaic Solar Panels, reduces the annual consumption by 19.3 %. Combining these energy efficiency practices results in savings of more than 54%, corresponding to a total energy reduction of 88.4 Wh/m$^2$/year.**

**For saving of 54% in residential buildings will result in a reduction of 19% of the national demand. This represents a very encouraging indicator for achieving energy and environmental sustainability, that overcomes the electricity generation crisis in many similar case countries.**

***Keywords--*** **Residential Buildings, Energy Loads, Energy Efficiency Measures, EnergyPlus, Electricity crisis.**

***Short Abstract (150 words)--*****A common style case study as a typical residential building in Libya is studied. Single and combined energy efficiency measures were applied. The base model consumes 163.6 kWh/m$^2$/year, where the space cooling load is devoted to be 4 times heating load, with the priority is to insulate roofs than walls. Improving the envelope thermal behavior reduces the energy consumption by 14.0 %. Upgrading interior lights leads to an annual saving of 7.7 %. Water heating strongly shares in the presence of peak demands for 9 months. Considering solar water heaters, reduces the required annual demand by more than 12 %. Using Photovoltaic Solar Panels, reduces the annual consumption by 19.3 %. Combining these energy efficiency practices results in savings of more than 54%, corresponding to a total energy reduction of 88.4 kWh/m$^2$/year. For saving of 54% in residential buildings will result in a reduction of 19% of the national demand.**

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CONTENTS



## I. INTRODUCTION

Since 2013, Libya has been experiencing a shortage of electricity supply. The state-owned electricity company (GECOL) has failed for the past four years to bring electricity demand and supply into balance. Daily power cuts (load shedding) and in particular during the heating and cooling seasons can last for up to seven - twelve hours in Tripoli, the capital, and up to 30 hours in the outskirts. It is well documented in Libya and elsewhere that the residential sector represents a significant energy consumer.

Over the next few years, Libya is expected to experience an unprecedented construction boom.

Therefore, it is felt essential to seize this opportunity to curb the energy consumption in buildings. To put this into perspective, it is worth mentioning that buildings are responsible for more than 36% of the national electricity use [1,2] (refer to Figure 1). A breakdown of buildings energy consumption is crucial in determining the influencing key parameters. As it is clearly shown in Figure 2, the top 4 electricity consuming end-uses in a typical Libyan home are: electrical appliances load at 30%, followed by domestic water heating load at 30%, lighting loads at 22%, and heating and cooling loads accounts for 18%.

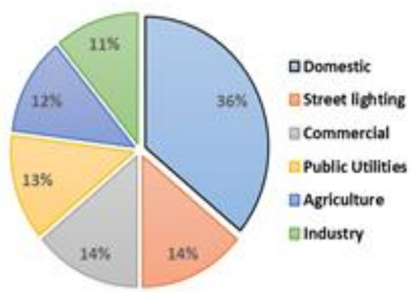


**Figure 1: Percentages of electric energy consumed in Libya in 2012 [1]**

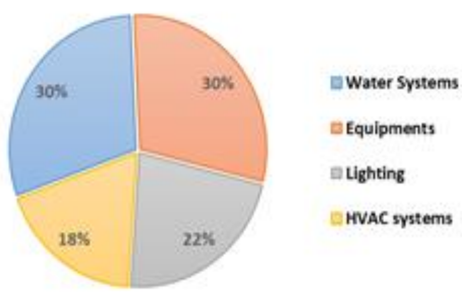


**Figure 2: Percentages of residential energy use in Libya [2]**

Optimization of energy consumption in residential buildings will in-no-doubt result in saving a sizable amount of energy and, therefore, have positive reflection on the national economy, personal expenses and environment. Reducing the energy consumption of the domestic electric appliances requires the adoption of energy efficiency measures and standards such as ENERGY STAR. The other three items (heating and cooling, domestic water heating and lighting), which are targeted in this paper, are mainly influenced by the prevailing weather conditions along with the life style and behavior of the people. There are a number of cost-effective energy-saving technologies and practices, including, among others, design strategies, construction materials and methods, operational techniques. For new constructions, in particular, there is a unique opportunity to incorporate integrated renewable energy technologies and improved site-specific design strategies among multiple building systems for maximum overall building efficiency and operating cost reductions.

An extensive amount of research work has been paid to the issues of energy consumption in residential buildings [3-8]. It is well documented that worldwide residential, commercial and public buildings consume up to 50% of total energy produced while this figure is 40% in the EU [3,8] and nearly approaches 50% in Libya according to the data collected and developed by the authorities for 2012 and 2008 [1,2]. Here, we can say that energy efficiency measures necessary to be considered in Libya in order not only to save the environment and national economy but also to support the Libyan contribution to the international efforts in saving the climate change and toward sustainable environment.

Energy efficient buildings should maintain an optimum environmental condition for human comfort under minimum cost for the required energy. Many energy efficient modeling approaches were developed heading towards achieving energy-efficient buildings. Jaber [9] studied the effect of various factors affecting the energy-related behavior of residential buildings. Improving and optimizing the thermal insulation has received a great deal of interest [10-13]. Also, integrating mature renewable energy technologies in buildings could potentially have tremendous positive effect on energy usage [14]. El-Darwish [15] focused on developing retrofitting strategy for building envelopes in order to achieve energy efficiency. Fluorescent lamps, solar-water heaters, and upgrading the thermal envelope were crucial in terms of energy use reduction in the long term [16].

Energy efficiency practices were further manifested and used by Yang et al. [17] as a key performance indicator in the assessment of residential buildings in China. A regression model was created by Brounen et al. [18] to analyze the physical characteristics of residential units and their energy consumption of gas and electricity in Dutch residential sector. A set of design guidelines augmented by the principles of energy efficiency for buildings in Saudi Arabia were developed by Al-Shaalan [19]. Alghoul, et al [20] studied the influence of electricity pricing in the residential sector on the thermal insulation thickness in Libya. In addition, the study aimed at quantifying the opportunities and potential of energy savings by estimating the energy losses related to space heating and cooling. A correlation for the estimation of energy saving related to windows were established by [21]. That correlation relates energy consumption with both window to wall ratio and window orientation.

Probably, the biggest successful achievement related to the applications of energy efficiency in buildings is realized in the State of California [22]. Over the last 40 years, California buildings enjoy a very low energy use intensity. This is attributed to the enforcement of energy efficiency standards for residential and non-residential buildings that were established in 1978 in response to a legislative mandate to reduce California's energy consumption. California new homes that meet the Standards are approximately 4.5 times more efficient than homes built prior to 1960 [23]. This does not count the potential for those homes that exceed the standards strategy.

In Libya, residential buildings have a high cost of construction, service, and maintenance. Still, energy auditing is not practiced till now. Energy efficiency and thermal performance are rarely validated after construction or renovation. As energy efficiency becomes important aspect of building design there is a need for accurate energy auditing tools both before and after building construction. Every building is different, and energy use in a specific building will depend on a range of factors such as the building fabric, how and when the building is used, and the heating and/or cooling systems and appliances that are being used.

While buildings are ubiquitous and a number of aspects are well researched and documented, such as engineering aspects, perhaps there is a shortage in understanding about their energy use and thus how problems related to their energy demand can be mitigated – both at the micro and macro levels.

This paper intends to provide a detailed overview and criticism of the current status of the Libyan residential building sector in terms of energy consumption and space thermal comfort. The research methodology adopted along with the base common building style in this research is also presented. A critical assessment of energy and hot water use within such building style is then provided, followed by well-established and presented suggested modifications with the application of renewable energy sources, and predicted potential improvements derived from commercial computer software packages. Here, different scenarios are considered targeting towards an energy efficiency building style. Finally, conclusions are summarized suggesting residential energy pinch marks, recommendations are enumerated to enhance the sustainability level within the Libyan residential sector which could mostly be taken as an indicator for North Africa region.

## II. Residential Energy Efficiency Measures

Buildings are complex physical objects, as there is a close relationship between the indoor and outdoor air conditions. The way a building behaves and performs is affected by the choices made in selecting building materials and components while designing the building envelope (walls, windows, roofs), and different systems like lighting, appliances and heating / cooling equipment. Buildings provide comfortable indoor environment conditions like thermal, visual, acoustical and an acceptable indoor air quality by consuming energy. Since the building sector is a major user of electricity, it is essential to evolve energy efficient building designs to insure thermal comfort and financial benefits through reduced electricity bills and have a role in reducing total societal energy use.

Energy actions/saving can be classified into three or four levels (refer to Figure 3): assessment, energy conservation, energy efficiency and renewable energy. They must be implemented together to achieve energy saving, clean energy and sustainability goals. Although renewable energy is important, energy efficiency and energy conservation have the most opportunities. The focus in this research will be on examining some aspects of energy efficiency and renewable energy while no attention will be given to energy conservation.

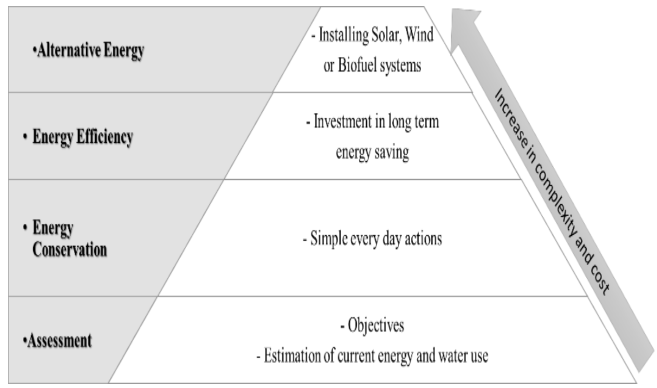


**Figure 3: Energy saving pyramid.**

Several building systems and components are common to most residences that can be investigated for energy efficiency potential; building envelope, landscaping, lighting, mechanical heating and cooling systems, appliances, operation and maintenance optimization. Building envelope includes every component separates the interior of a building from the outdoor environment. Envelope insulation should have a thermal value optimized for the microclimate zone of the home and encapsulates the entire occupied space that is air conditioned. This employs foam-filling cavities or using an exterior-applied insulation system [24-26]. A study carried out by Taleb and Sharples [24] shows that replacing the air gaps of the external walls by a foam insulation could reduce the air leakage by 15 times resulting in a reduction of the U-value (i.e. thermal transmittance) of the external wall by as much as 25%. Doors and windows in particular represent a major air infiltration and leakage component and, therefore, should weather stripping and caulked.

Windows, glazed doors and skylights, with high-performance reduce heating and cooling energy costs, improve occupant comfort and enable greater utilization of floor areas on perimeter zones, improve noise control and condensation resistance, minimize fading of interior furnishings, and increase the resale value of the property. Spectrally-selective glazing uses a low-emissivity coating to minimize ultraviolet transmission, maximize the visible light admission, and reduce solar heat gain in the summer and heat loss in the winter.

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This type of glazing typically lowers solar gain and heat loss by 25-45% with only a 10-15% reduction in visible light transmission – while tinted glass or reflective coatings can also be used for additional solar control [19].

Exterior shading systems such as fixed overhangs, fins, awnings, operable, louvers, shutters, and weave screens block the solar gain before it enters the fenestration assembly. Integral and interior shading systems are secondary options for solar gain, glare and heat loss control. Solar screens resemble standard window screens and can block up to 85% of the sun's heat from entering the home [26]. Such shading control can lower the space temperature in spaces adjacent to windows by as much as 20 degrees Fahrenheit on a hot day [26].

Strategically placing vegetation and trees adjacent to the building envelope, incoming solar heat gain and glare through fenestration are reduced. Cold prevailing winds are obstructed. Thereby lowering cooling and heating loads while improving occupant comfort. Deciduous trees offer one of the best year-round ways to save energy by blocking the summer sun for solar control and dropping their leaves in the winter to admit more solar gain through fenestration [26].

As stated above, lighting accounts for about 22% of the residential electricity use in Libya. Indoor and outdoor lighting fixtures need to be designed in a manner appropriate to the task to prevent illumination levels higher than necessary at any time throughout the day. It is worth mentioning that reducing the lighting load could be realized if it's carefully considered in the early planning stages of the building. Al-Shaalan et al [19] reported that a reduction in the heating loads of 5 - 7% could be achieved through the use of natural light. They found that 7% of the wall and 3.25% of the roof area should be glass with 0.77 reflectance. However, increased interior daylight generates heat and therefore may influence the cooling load.

Skylights provide additional daylight and they can be augmented with electrical lighting for nighttime illumination. Efficient indoor lighting systems also reduce heat gain to the space that in turn lowers air conditioning loads. High efficacy lamps offer the highest Lumens per Watt. Compact fluorescents use up to 75% less energy and last approximately 10,000 hours [27]. Halogen lights are considered an alternative selected lighting of the future. However, the new compact fluorescent Torchieres is far safer than the halogen ones because they do not operate at the same high temperatures [27]. In addition to that, interior automated lighting controls typically save 20-40% through the use of occupancy sensors to turn off the lights when spaces are unoccupied. Exterior lights better to be controlled by motion sensors.

Low energy-consuming mechanical heating and cooling systems are possible through the use of thoughtful building envelope design, sitting and orientation, followed by high-efficiency equipment, automated controls, improved duct systems, and various advanced technologies. Space Heating-Cooling Systems should be properly zoned, sized and installed. Furnaces, heaters and air-source heat pumps should meet a preset Appliance Efficiency Standards [27]. Ductwork should be insulated adequately and unobstructed with well-worked joints. Ventilation and Exhaust systems should be well recognized. Exhaust flue waste heat recovery systems are considered successful projects for numerous sites. Such systems reduce heating costs while recovering up to 85% of the exhausted heat [28], likewise, recovery in cooling systems reduce operating costs and improve indoor air quality and humidity levels. Programmable Setback Thermostats typically saves 15-75% of air heating and cooling costs [28].

Energy-efficient domestic water heating systems combined with water-efficient appliances and fixtures save water and energy. Proper sufficient insulation should be taken seriously on storage tanks and pipe runs. It has been proved in the field that solar domestic water heating systems could provide as much as 72% of the water heating load [29]. Solar photovoltaic systems could also provide the necessary electric loads for lights and water pumping.

## III. METHODOLOGY

In this paper, a local residential building is considered as a case study. The building is introduced below and it is located in the city of Tripoli, Libya (Lat. 32.68°N, Long. 13.5°E). Hourly, monthly, and yearly electrical energy consumption of the building are simulated, presented, compared, and discussed.

The steps considered in the study is schematically shown in Figure 4 below. Firstly, the base case simulation of building parameters was carried out by a suitable set up of the relevant parameters, including, drawing and creating the model geometry, constructions details, materials, people, interior and exterior lights, electrical appliances, air infiltration, water heating systems, and HVAC systems. Three specific software packages are employed to achieve the objectives; EnergyPlus simulation software/engine, SketchUp and OpenStudio software. A detailed description of the software used in this paper was presented by one of the authors in other work [30].

Secondly, energy efficiency related scenarios were developed by subjecting the building under consideration to modifications that are known to reduce the energy consumption.

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For each scenario developed, an energy consumption of the modified (desired) building was estimated through the building energy simulation. The energy consumption estimation for the different scenarios was analyzed and compared with each other as well as with that of the base case scenario with aim of obtaining the most energy efficient case.

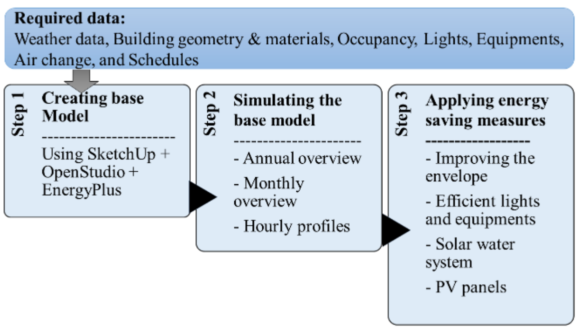


**Figure 4: Steps of Methodology used in this work.**

## IV. Building Description

A house located in the city of Tripoli, Libya, is selected as a case study. It is a two-floor building as shown in Figures 5 and 6 with a total floor area of 280 $m^2$ (net conditioned building area). The ground floor contains a kitchen, bathrooms, guest rooms and living area, while the first floor is a sleeping floor that contains bedrooms and bathrooms. This type of houses is deemed representative of the current energetic quality of the residence build environment in Libya and considered a contemporary house widely found in Libya.

The whole window to wall ratio (WWR) of the building is 15.64% distributed as 11.75%, 0.0%, 18.64%, and 16.42 % of North, East, South, and West faced walls, respectively. The eastern walls of the house are considered adiabatic walls as the house is a semi-detached with the eastern walls adjacent to neighbors' walls. The values of overall heat transfer coefficients of external walls, roof, ground, windows and doors are 2.5, 2.3, 3.0, 5.9, 1.8 $W/m^2.K$, respectively.

**Figure 5: A 3D drawing of the building**

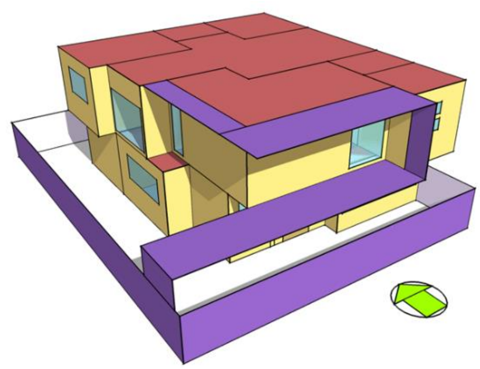

**Figure 6: SketchUp Model**

## V. Simulation Setup

This section presents the main simulation parameters, the specifications of HVAC system considered in this work and the specifications of the electrical water heaters. Table 1 contains the main assumptions for design parameters that were applied in the simulation.

**Table 1:**
**General simulation parameters**

| Parameter | Value |
|---|---|
| Number of people | 0.02 people/$m^2$ (6 People) |
| Heat gain from | 120 W/person |
| Interior light | 11 $W/m^2$ |
| Exterior light | 500 W |
| Equipment | 7 $W/m^2$ |
| Infiltration | 0.5 ACH (tight and well-sealed |

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The water main temperature is estimated by using a correlation described in [31], with necessary ambient parameters obtained from [32]. By using the above formula, the water mains temperature is found to fluctuate between 18 and 29 °C. The parameters related to the water heating system are given in Table 2.

**Table 2:**
**Water heating system parameters**

| Parameter | Value |
|---|---|
| Tank volume | 60 L |
| Number of water heaters | 5 |
| Set point temperature | 60 °C |
| Target temperature | 43 °C |
| Heater thermal efficiency | 80% |
| Dead band temperature difference | 2°C |
| Hot water peak flow rate | 0.000073 $m^3/s$ |

HVAC system parameters are outlined in Table 3. Cooling and heating supply air temperature set to be equal to 14°C and 40°C, respectively. While ventilation was ignored for all the scenarios considered in this paper.

**Table 3:**
**HVAC system parameters**

| Parameter | Value |
|---|---|
| HVAC Type | Packaged Terminal Heat Pump |
| Heating set point | 22°C |
| Cooling Setpoint | 24.5 °C |
| Fan efficiency | 0.7 |
| Motor efficiency | 0.9 |
| Heating Rated | 5 |
| Cooling Rated | 3 |

## VI. Results And Discussions

The results of this work can be classified into two main branches; firstly, results that consider the original specified building without any modifications (as built). This covers hourly, monthly, and yearly electrical energy consumption giving the share of heating, cooling, interior and exterior lights, interior electrical equipment and fans, and water heating system. Secondly, results for single or combined measures with the use of renewable energy applications, according to figure 3, which leads to energy-efficient upgraded building.

Each scenario should have consumption details for different main energy end-use as indicated below.

### *6.1 Annual Overview*

The methodology described above was applied by using the prevailing weather conditions in Tripoli-Libya (Lat. 32.688N) shown in Figure 7. Although, Figure 7 shows monthly average values of the ambient conditions, but the building and systems simulation was carried out on hourly basis. That means, the hourly variation of the ambient conditions throughout the year (8760 hours per year) was taken into account.

Referring to the methodology described above, the calculations begin with the evaluation of different main end-use item energy consumptions. The results presented below focuses on the electricity consumption by the systems of the original building that have the full details of the specifications indicated earlier. The details of the total building energy consumption are shown in Figure 8 for different building systems. The total annual energy consumption is estimated to be 45,624 kWh, 163 $kWh/m^2$, equivalent to 7,604 kWh/person. Among the others, the interior equipment has the peak annual consumption of 11,247 kWh, while minimum consumption is recorded for fans with 969 kWh per year. Interior lights and water heating systems have comparable annual consumption of 8,822 and 8,972 kWh, respectively. The annual cooling consumption comes with almost four times of that annual heating consumption, with 10,694 and 2,731 kWh, respectively.

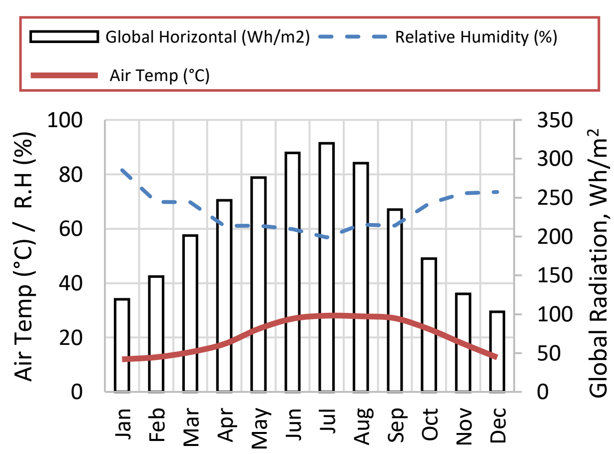


**Figure 7: Prevailing Weather Conditions in Tripoli-Libya.**

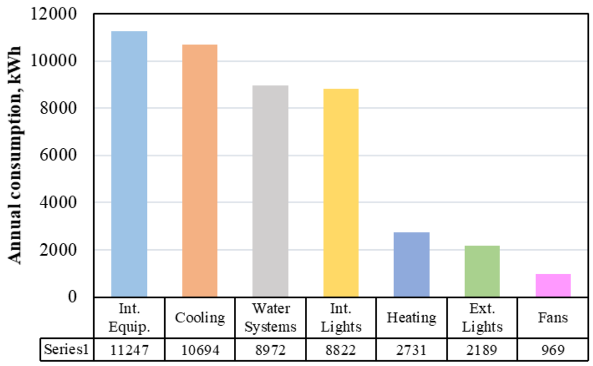


**Figure 8: Building-systems annual energy consumption, kWh.**

The simulation results for the base case shown in Figure 8 is further manifested to identify the dominant energy consuming item. The pie chart shown in Figure 9 gives the share of each energy consuming item. Clearly, the internal electrical appliances consume a quarter, 25 %. Interior lights and water heating systems have estimated equal shares of one fifth, 20 %, from the total annual consumption of the building. For such buildings under the specified conditions, the annual energy consumption required for space cooling is generally much greater than that needed for air heating with a ratio of 4:1. This is attributed to the fact that the cooling season (summer) is much longer than the heating season (winter), in addition to the high ambient air temperature during the summer. Also, the COP of the cooling system ($COP_{Cooling} = 3$) is much less than that of the heating system ($COP_{Heating} = 5$). Interior equipment and lights, and air cooling and water heating, represent the four main categories with a total share of 87 %. Air heating and cooling, with water heating systems, have totally share of approximately half, 49 %, of the total annual consumption, while the other systems share the other half.

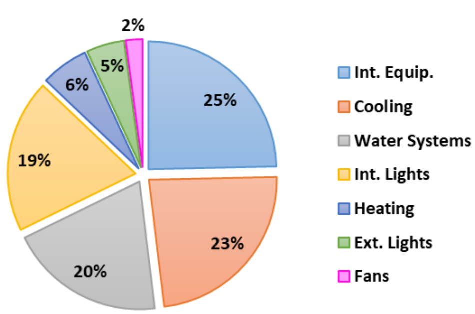


**Figure 9: Share of each energy consuming item in the simulated building (base case) from the total annual energy consumption,**

*6.2 Monthly Overview*

Considering more details through monthly-consumption bases presented in Figure 10, summer months have the beak consumption with a maximum value of about 5,000 kWh in July due to the required high cooling load. One can notice that the share is mostly constant along the year in 4 categories, interior, and exterior lights, interior electrical equipment, and water heating. The discrepancy in the energy consumption along the year comes mostly from both air heating and cooling which are functions of the season. April and November have the least energy consumption, each below 3,000 kWh, due to the limited heating and cooling loads. An air cooling process is needed from March to November with a maximum load in July, while air heating process is required along the period from November to April with a maximum in January. The general view of the monthly total energy consumption pattern seems to have a roughly incomplete sine wave.

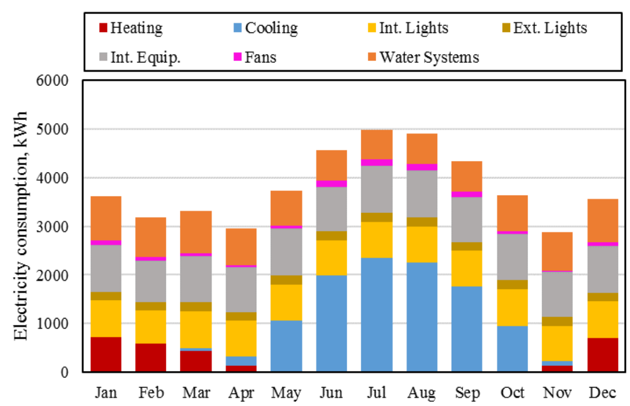


**Figure 10: Monthly Building electricity consumption, kWh.**

In terms of the power required to cover the load, Figure 11 shows the monthly peak demand in kW. It can be clearly seen from Figure 11 that the peak power demand is almost uniform ranging between 14 and 16 kW except for the months of June and July. In June and July, the peak power reached a high value of 20 kW for the building under simulation. This is in-line with the shortage of electricity and inability of the electricity power generation company (GECOL) to meet the demand in the summer season rather than the winter season. Also, surprisingly, water heating load has always the upper hand in terms of the power peak around the year except for 3 months, June, July, and October in which air cooling has the peak.

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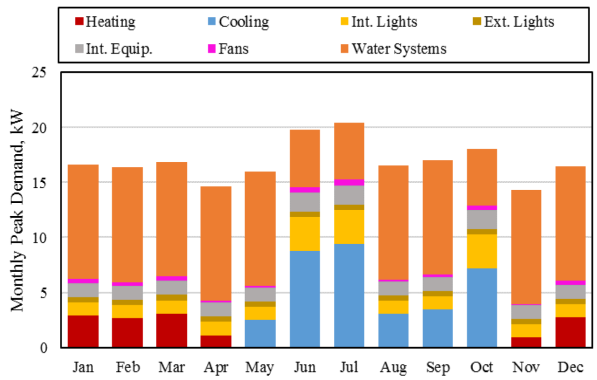


**Figure 11: Monthly peak power demand, kW.**

### *6.3 Comparing Energy Consumption With Other Studies*

For the sake of validation of the simulation results, the results obtained in this study were compared with results of other study [33] as well as the published reports of the local power company (GECOL) [2]. Figure 12 shows such comparison in terms of energy consumption share, the three studies agree on the interior equipment consumption of about a quarter, 25 %, of the total annual consumption. While for HVAC load (heating and cooling), the results of the current study is in good agreement with that of the results published in reference [33] accounting for 31% and considered to be far from HVAC load share of 20% recorded in GECOL report [2]. With respect to the internal lights, the current study estimated a high value of 24% as compared to 17% and 22% in other two references.

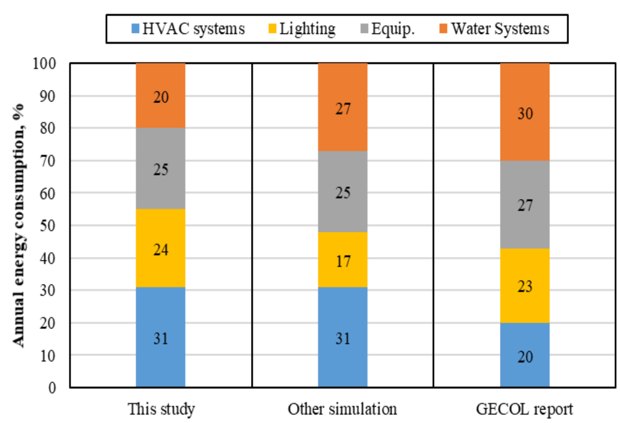


**Figure 12: Comparison of building-systems annual energy consumption, %.**

### *6.4 Hourly Load Profile*

For the sake of obtaining more insights into the obtained results, Figure 13 shows the building hourly power curve for two randomly selected days (21st of July and 21st of January) to represent summer and winter seasons. The minimum load period for both profiles during the early morning hours till 6:00 AM. As expected the load generally increases with people starting day activities. For these two days and most of the days of the year, the power curve shows two power peaks, one at 9 AM and another at 9 PM. The timing of these two power peaks is in good agreement with the data published by the local power company (GECOL) [34] which is totally based on actual measurements. The January power curve seems to be much more uniform than that of July. The fluctuation in July curve is expected due to the high load required by the cooling process. The morning power peak (at 9 AM) could be due to water heating load, while the evening peak (at 9 PM) is mainly due to the HVAC load (heating or cooling).

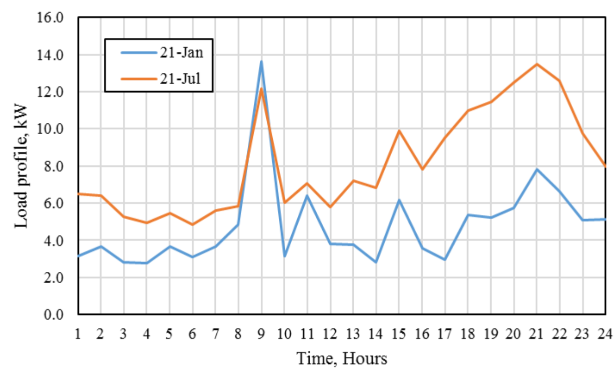


**Figure 13: Building hourly load profile for summer and winter design days, kW.**

Figure 14 shows the hourly average value of the total power demand. Just for clarification purposes, the bar chart given in Figure 11 above, gives a value of 20 kW for the month of July, while the power curve given by Figure 14 shows a maximum value of 16 kW. This could be explained as the results given Figure 10 is simply the peak demand of each month as an instantaneous value. Whereas, Figure 14 given the hourly average values. The dark and light areas of the curve in Figure 14 are due to the fluctuations of curve. During the winter season, although, the hourly average power demand reaches values of 14 kW, it is mostly between 4 and 8 kW.

The high values of the power during the winter time was found to happen at 9 AM which is attributed to high water heating consumption at this particular time. From the 3,600 hours (corresponding to around May 1st) to 6500 hour (corresponding to around the around the end of September) which is the cooling season (summer), the hourly average power reaches a value of 16 kW with power demand levels ranging between 6 and 10 kW most of the time. This power curve is very helpful to the control center operators and the power plant operational engineers in power demand forecast as well as setting the base load and peak load timing.

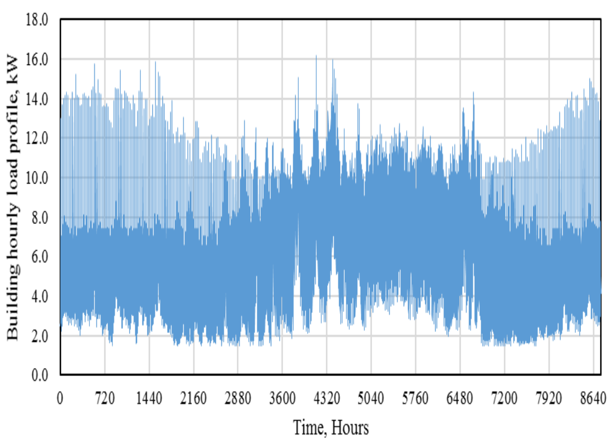


**Figure 14: Building hourly power demand profile around the year in kW.**

*6.5 Water Heating System*

As stated above, domestic water heating load represent a heavy burden on the national grid and accounts for 20% of the total annual residential electricity consumption. To put this into perspective, all the water heating systems used for domestic water heating in Libya are completely dependent on electricity. Therefore, it is felt essential to conduct a complete analysis of the water heating load with the aim of identifying the ways and means of reducing its share.

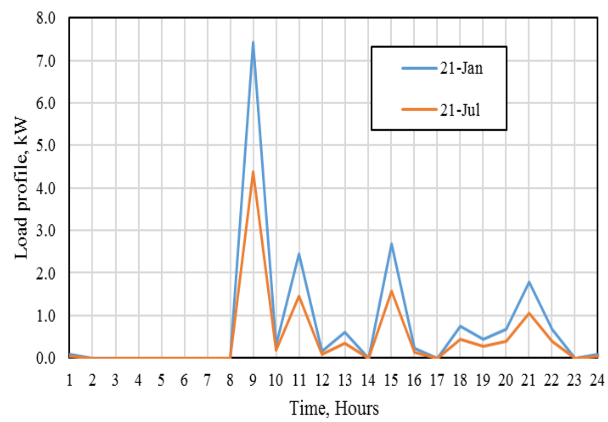


**Figure 15: Hourly water heating load profile for summer and winter design days, kW.**

For the sake of the analysis and in order to provide the necessary data to properly estimate the coincidence capacity factor, Figure 15 shows the computer simulation results for the hourly water heating load profiles for two days (January 21st and July 21st). As expected, due to the prevailing weather conditions, January trend is higher than that of July profile along the day. During the night and after 11 PM, the curve shows a zero-demand value till 8 AM at which time people will start their day activities.

*6.6 Rendering The Building More Sustainable*

In this section, the energy efficiency practices and the use of renewable energy are explored by upgrading or improving (in terms of energy) the building making it a more sustainable building. The first step is to insulate the envelope walls and/or roofs, and/or implementation of double glazed windows. The second step is to improve the technical specifications of lights, while the 3rd step is to upgrade water heating systems by replacing the electric water heaters by flat plate solar water heating systems, and finally installing photovoltaic solar panels to offset part of the electricity consumption. These steps represent implementation of energy efficiency measures, either single or combined improvement scenarios.

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*6.6.1 Improving the Envelope*

Table 4 below outlines the suggested values of the overall heat transfer coefficients for insulated walls, roofs and double-glazed windows as compared to the base case (original). That means upgrading the thermal performance of the building envelop results in $U_{wall}$ = 0.35 W/m$^2$-K and $U_{roof}$ = 0.37 W/m$^2$-K while for the double glass window $U_{Win}$ = 2.67 W/m$^2$- K. Table 4 also gives the predicted (simulation results) amounts of annual energy requirement for each case. The energy load for the base case was predicted as 45,624 kWh, this energy quantity is reduced to 43,044 kWh (5.7% reduction), as compared with the base case, just by insulating the walls. Insulating the roof results in reducing the load to 42,780 kWh (6.3% reduction), while using double glazed windows results in a lower energy reduction of about 1.3% only. The lower energy savings results from using double glazed windows as compared to both cases of insulated walls and insulated roofs, can be justified by the high U value for windows along with the smalls areas allocated for the windows. While insulated roofs gives the highest energy savings which are not far away from the case of insulated walls. This confirms the role of the high thermal loads due to building roofs.

Improving the building envelope will, of-course, reduce the energy requirements for space heating and cooling and will have no effect on the interior lights, equipment and water heating load. With this in mind, Table 4 gives the HVAC energy reduction for each case. Insulated walls resulted in the HVAC energy requirement reduction by 18% while insulated roofs reduce this energy value by 20% and only 4% reduction in case of using double glazed windows.

**Table 4:**
**Annual energy consumption with and without improvements**

| | Base | Walls | Roofs | (5 | Dbl |
|---|---|---|---|---|---|
| U(W/m$^2$.k | uninsul | 0.35 | 0.37 | | 2.67 |
| kWh | 45,624 | 43,044 | 42,780 | | 45,0 |
| Saving = | - | 2,588 | 2,852 | | 602 |
| Saving/To | - | 5.7% | 6.3% | | 1.3% |
| Saving/H | - | 18% | 20% | | 4% |

EP = Expanded Polystyrene found as optimum insulation for Libyan buildings [20]

Since upgrading the building envelope will result in lower heating and cooling loads, therefore, it will make a lot of sense to investigate the effect of each modification on the heating and cooling loads. Figure 16 shows such a comparison.

It can be clearly seen that insulating the exterior walls of the building will reduce the heating load by almost half (47%) while the cooling load was estimated to be only 10% less. On the other hand, insulating the roof reduces the heating load by 25% and cooling load by 18%. This result clearly indicates that it is better to insulate the external walls rather than the roof in case of the heating load. However, for the cooling load, it is more beneficial to insulate the roof rather than the walls. This could be attributed to the fact that the roof is a flat horizontal absorbed plane. During the summer season (cooling season) the high values of the solar heating gain from the horizontal plane (roof) is higher than that gained by the vertical walls. Even with the integration of the loads along the year data recommended the priority of insulating roofs in such case studies.

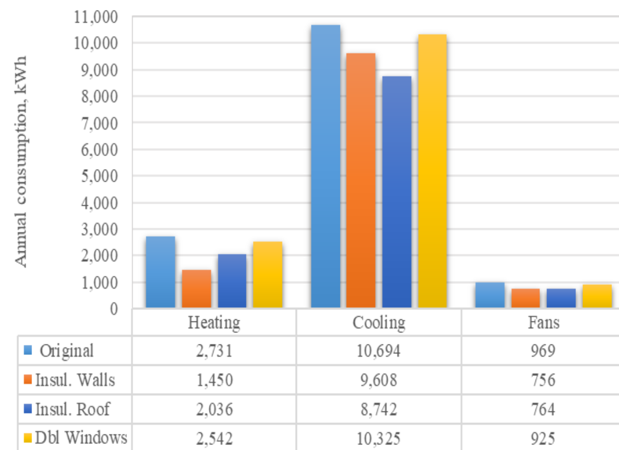


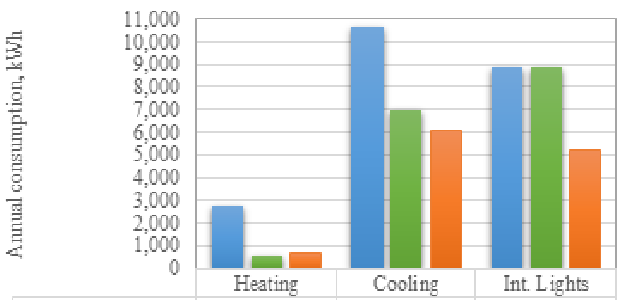

**Figure 16: HVAC annual energy consumption with and without envelope upgrading, kWh.**

For more details, refer to Figure 16 that concerning the consequences of the individual improvement on each specific category; heating, cooling, and fans. As it is mentioned above, installing double glazed windows does not help much in reducing the energy consumption related to all categories. Apparently, from the cooling results, insulating roofs is significant and more effective than insulating walls. For the cooling load, the amount of energy saved in case of insulating the roof is almost double that saved for insulating the walls (1,952 kWh as compared to 1,086 kWh). However, for heating season insulating walls is more effective than insulating roofs, 1,450 to 2,036 kWh, respectively. Qualitatively, fans are not affected too much by these scenarios.

Obviously, applying all improvements together leading to a significant energy saving for the considered building, with a total energy consumption of 39,221 kWh corresponding to a total saving of 6,411 kWh (14%) per year.

*6.6.2 Lights Improvement*

There are various scenarios for the improvements of this item, however, the considered assumptions represent; interior lights changed to 50 % incandescent and 50% fluorescent, with fluorescent power = 20% incandescent power, while exterior lights kept being 100% incandescent (no change). Referring to Figure 17, the energy consumption due to interior lights drops 40 % due to the assumed improvements, while it is independent of the implementation of envelope insulation.




| | Heating | Cooling | Int. Lights |
|---|---|---|---|
| Original | 2,731 | 10,694 | 8,822 |
| Envelope | 528 | 6,983 | 8,822 |
| Envelope & Lights | 703 | 6,128 | 5,292 |

**Figure 17: Heating, cooling, and interior lights annual energy consumption for original, upgraded envelope only and combined upgraded of envelope and interior lights, kWh.**

Figure 17 clearly shows, as expected, that improvement of lights has moderate favorable effects on the cooling energy consumption while it has adverse effects on the heating load. However, upgrading the interior lights will have a positive effect on the total HVAC load (heating and cooling) resulting in an energy reduction of about 680 kWh per year. Applying envelope and interior lights measures together lead to a total energy saving of more than 10,000 kWh per year. That means the energy required for the upgraded building will be 22% less than that required for the base case.

*6.6.3 Improving the Water System*

Installing flat plate solar collectors for domestic water heating becomes a worldwide sustainable energy efficiency practice.

The design procedure can determine the desired solar share in covering water heating energy demand which is a function of the specifications of the collectors including the required flat plate collector area and storage tank volume. Although the local solar insolation is encouraging where the solar share can attain high values and field studies have shown that the annual solar fraction can be as high as 72%, in this study a very conservative solar share of 60% was used. Accordingly, the reduction in the required annual building electrical energy for water heating is 5,383 kWh instead of 8972 kWh. In other words, using solar water heaters will reduce the energy demand of the base case building by 11.8%. Implementation of all energy efficiency measures, envelop insulation (walls, roofs and windows), lights, and water heating, comes with a total annual energy demand of 29,603 kWh with total savings of 16,029 kWh per year (35.1 %). These represent more than one-third of the required electrical energy for the building, which is a big achievement.

*6.6.4 Installing Photovoltaic Panels*

The last improvement suggested and evaluated in this study is the installation of solar Photovoltaic Panels to share in covering the required electrical annual building demand. Assuming the generated panel energy is devoted to cover 80 % of the total (interior + exterior) required lights. This means that the reduction in electrical energy consumed from the main general electricity grid is 8,809 kWh, equivalent to a reduction of 19.3 % of the base case annual consumption.

Considering implementation of all above improvement measures, the annual electrical consumption reaches only 20,794 kWh, with a total reduction of 24,838 kWh which equals to 54.4 % savings from the original annual electrical energy consumption. This outcome clearly indicates a very encouraging indicator that contributes in offsetting the crises of electricity generation shortage.

## VII. Conclusions And Recommendations

Referring to the outcomes for the typical base building, HVAC, interior equipment, lights, and water heating systems, account for 29, 25, 24, and 20 %, respectively, from the electricity demand of 163.6 kWh/m$^2$/year. Space cooling is much higher than heating load, where the priority is to insulate roofs than walls. Insulating the building's envelope reduces the consumption by 14.0 %. Lights represents a quarter of the total energy demand. Upgrading interior lights serves air cooling process than heating process, where applying this measure leads to save 7.7%.

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Water heating is required around the year and strongly shares in the presence of peak demands for 9 months. Considering a solar water heater with 60 % solar factor, reduces the required annual electricity by 12 %. Installing Photovoltaic Panels covering 80 % of the required lights, reduces the demand 19.3 %. Considering the implementation of all indicated improvement measures, the annual total reduction reaches 54.4 %. Which will result in a reduction of 19% of the national demand.

The implementation of energy saving measures in residential buildings is strongly confirmed and recommended, that contributes in solving the current electricity crises in many countries. In addition, referring to the demand growth, many policies and legislations should be formulated and activated. Conducting an economic feasibility study should be conducted for unstudied cases in different parts of the world.

## VIII. List Of Abbreviations

| **ITEM** | **DEFINITION** |
|---|---|
| ACH | Air Change |
| AM | Mornings |
| COP | Coefficient Of Performance |
| HVAC | Heating, Ventilation and Air Conditioning |
| GECOL | General Electricity Company Of Libya |
| PM | Afternoons |
| PTHP | Packaged Terminal Heat Pump |
| WWR | Whole Window To Wall Ratio |

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