International Journal on Recent Researches in Science, Engineering & Technology (IJRRSET)
A Journal Established in early 2000 as National journal and upgraded to International journal in 2013 and is in existence for the last 10 years. It is run by Retired Professors from NIT, Trichy. Journal Indexed in JIR, DIIF and SJIF.
Research Paper
Available online at: www.jrrset.com

ISSN (Print) : 2347-6729
ISSN (Online) : 2348-3105

Volume 6, Issue 10
October 2018.
JIR IF : 2.54
SJIF IF : 4.334
Cosmos: 5.395

Received on: 04.09.2018 Published on: 30.10.2018 Pages : 1 - 15

ZERO ENERGY BUILDING FOR A TYPICAL HOME IN AMMAN

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ABSTRACT

During the recent few decades, researchers as well as politicians are more concerned with the concept of low energy buildings. This is not a new concept since old houses and historical places were built taking into consideration the local climatic conditions. Today such approach is gaining more attention worldwide and new codes and regulations are introduced in this regard. In this work, a comprehensive techno-economic feasibility study of a new small independent house (with a total area of about 100 m2) in Amman is conducted using a commercial software package for calculating heating and cooling loads (HAP). A special tailored program to examine the techno-economic feasibility was developed for this purpose. This house is totally dependent on solar energy for supplying electric power and thermal energy. Consequently, gaseous emissions, including GHG, were reduced significantly. It was found that, with using appropriate energy storage system, there is no need to neither withdraw electrical power from the grid nor buy fuels for heating purposes. The expected monthly savings in energy cost may reach JD 260 with a payback period of about 8 years.
Keywords: Zero Energy Building, Solar Energy, PV, Solar Water Heating, Cooling and Heating, Ventilation.

1. INTRODUCTION

Large number of publications and reports conducted in the field of energy in buildings concluded that the existing energy systems in the residential and commercial sectors are not sustainable due to full dependence on conventional fuels combustion. This is mainly because of high energy consumption as a result of migration to main cities and better living standards. Consequently, the negative environmental impacts were substantial especially in urban areas and poor districts.

Environmental pollution is no more a fiction story, it is becoming a reality and threatening the international eco-system. The most impacted countries are poor and less developed countries. Thus, there is an increasing appreciation towards energy conservation and higher energy efficiency through management and control and employing highly efficient appliances and machines. Equally important the utilization of renewable energy sources when applicable. During the past few years most countries in the Middle East and North Africa (MENA) region, including Jordan, witnessed a significant shift towards the utilization of renewable energy sources in all applications including the housing sector.

Based on published literature, building sector is estimated to consume about 40-45% of primary energy in developed countries, such as USA and Europe [1], while in Jordan the ratio is slightly less [2]. Promotion of energy management and conservation in the household sector would have a good potential to improve efficiency and reduce energy consumption as well as greenhouse gas emission

[3]. Low or zero energy buildings is not new in the MENA region and represents one of most promising solutions to control energy and environmental problems. In this context the national codes ofGreen Building [4],Energy Efficiency in Buildings [5], Solar Energy and other related guidelines are introduced by the National Building Council, in Jordan, with the aim of increasing efficiency and reducing emissions: have zero carbon emission. The low energy or zero energy buildings are not new, and they fully depend on local conditions and utilization of renewable energy systems to achieve energy balance but with no fossil fuels [6]. This energy, needed for lighting and electrical appliances, space heating and cooling as well as ventilation,is covered by renewable energy systems and suitable energy storage .In this case such system is called off-grid system, i.e. there is no need to connect to the electrical grid nor supply petroleum products. In the current study, the thermal and electrical performance of a small house in Amman was analyzed and evaluated. The following section presents the literature review of zero or low energy buildings.

2. LITERATURE REVIEW

According to the latest survey of energy demand in the residential sector in Jordan, conducted by the Ministry of Energy and Mineral Resources, in [7], it was shown that space heating and domestic hot-water heating are still based on petroleum products: mainly LPG and Kerosene. Type of fuel used for space heating depends on the family income: rich houses use central heating systems in winter and air conditioning units, where poor families rely on kerosene. In this regard, a previous study [8] showed that in main cities almost all dwellings are using electricity and LPG fuel, which are considered clean compared with other conventional energy sources. The use of firewood is limited to some rural areas due to the fact that it is rated as low-quality fuel. In suburb and rural districts LPG is still considered the prime energy source for families, while other fuels such as Diesel is not popular because central heating systems are not widely used in rural districts. Kerosene consumption is the highest and represents about two-thirds and three-quarters of all fuels used for heating in both urban and rural areas, respectively [9].

Such behavior is attributed to the use of burning kerosene stoves, followed by kerosene or diesel stove with ducted chimney. These stoves, in addition to LPG stoves or heaters, provide space heating and used for cooking at the same time, especially by low-income families. Such heating systems contribute significantly to the problem of in-door air quality and increasing concentration of gaseous pollutants in the atmosphere. In the open literature, there are many definitions for Low or Zero Energy Buildings [10- 15]. But all share that such building should have low energy consumption thereby reducing the final resulting emissions. At present large number of developed and developing countries, including Jordan, around the world have considered the importance of establishing ZEBs as future solution to meet energy and environmental targets. Recently, in 2016, a new Green Building Code was introduced and enacted by the National Building Council [16]. In this voluntarily code, there are a punch of legal and financial incentives for developers and investors in the residential and commercial building sectors. Other leading countries such as USA and Europe, do have a a special building technology schemes as part of the governments' energy strategy [17].European Union has introduced a new and special directive on energy performance of existing and new buildings [18-21]. There are long list of case studies,in all regions of the world, confirming the high potential of ZEBs to assist in reducing current rates of energy consumption which will lead to longer span of the depleted energy resources.

Hence, slowing the deterioration of our environment [22-30]. The Low or Zero Energy Buildings primary aim is to reduce energy consumption for different applications. These include but not limited to space cooling and heating, ventilation, lighting, and other electrical needs such as appliances. Currently, there are many systems based on renewable energy that can be used in such buildings to achieve Low or Zero energy building. These include solar thermal collectors and photovoltaic (PV)

modules, hybrid photovoltaic–thermal systems, geothermal energy, wind energy, hydro electrical generators.
In the Middle-East regain, in particular Jordan enjoys high solar radiation intensity, which makes the use of solar systems (both thermal and PV) an attractive option for residential applications [31,32].This study will focus on harnessing solar energy as clean and free renewable energy source. The proposed renewable energy system is based on employing solar water heaters and off-grid PV array with suitable storage battery.This work will focus on designing a zero-energybuilding and studying the economic features of the house with optimization.

3.METHODOLOGY

The adopted methodology in the current study is based on simulating a small residential house by applying the following procedure:

1- Data collection (weather, solar radiation and local conditions).
2- Estimating heating and cooling loads using the hourly Analysisprogram (HAP).
3- Applying passive design strategies that can be used in this house such as orientation and shading.
4- Defining energy demand profiles.
5- Thermal load of domestic hot water (DHW).
6- Electrical power demand for lighting and appliances.
7- Selection of suitable A/C split units for space heating and cooling.
8- Sizing required buttery.
9- Environmental analysis.
10- Economic analysis.

4. LOCAL WEATHER AND SOLAR RADIATION DATA

Published weather data by the Dept. of Metrology including average temperatures, daily solar radiation, wind speed, etc., are used in the study in hand. In general, it is dry and hot in summer and cold in winter. Rainy days are becoming less and late in the season. Table1 shows monthly clear days and average sunshine hours in Amman. It is found that the minimum monthly average clear days and hours of sunshine in January and the maximum in August.

Table1. Clear days and sunshine hours average numbers in Amman [32]

Month	Average of clear days	Average of hours of sunshine
JAN	20	232
FEB	22	260
MAR	24	296
APR	25	275
MAY	25	348
JUN	30	405
JUL	31	380
AUG	31	390
SEPT	29	334
OCT	25	280
NOV	26	264
DEC	22	233

Fig .1 Illustrates the monthly distribution of global daily solar radiation and average sunshine hoursin Amman [33]. It was found that the values of solar radiation were high during the months of March –

October. It is evident from the figure that Jordan has one of the highest solar radiation values. The annual maximal dry bulb temperature in Amman is 32.9 °C while the minimal temperature is 4.2 °C [34]

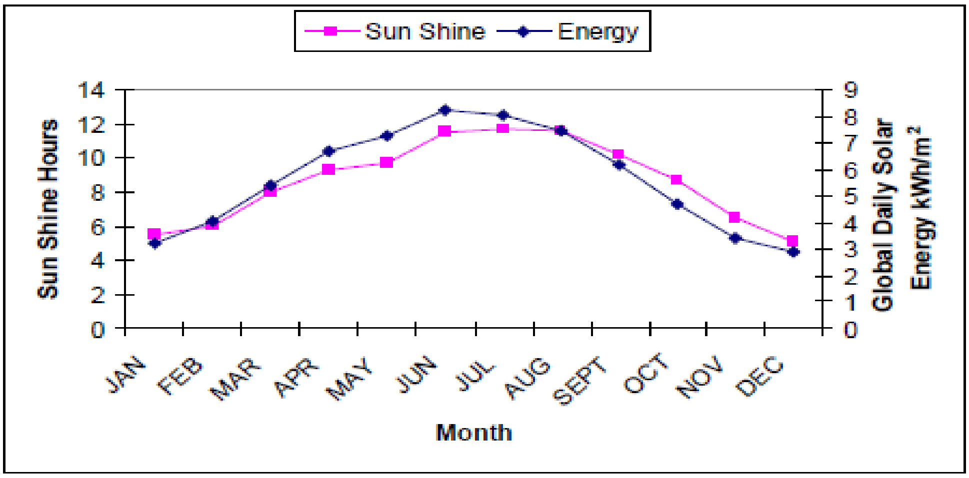


Fig.1. Average sunshine hours and global daily solar energy[33].

Figure 2 demonstrates the results of monthly solar radiation as a function of the tilted angle θ, showing that during the summer season there are small optimum tilted angles due to the sun's high location in the horizon, on the other hand, in the winter season, there are large optimum tilted angles due to the low location of the sun in the horizon. For the whole year, the optimum angle is **27°**

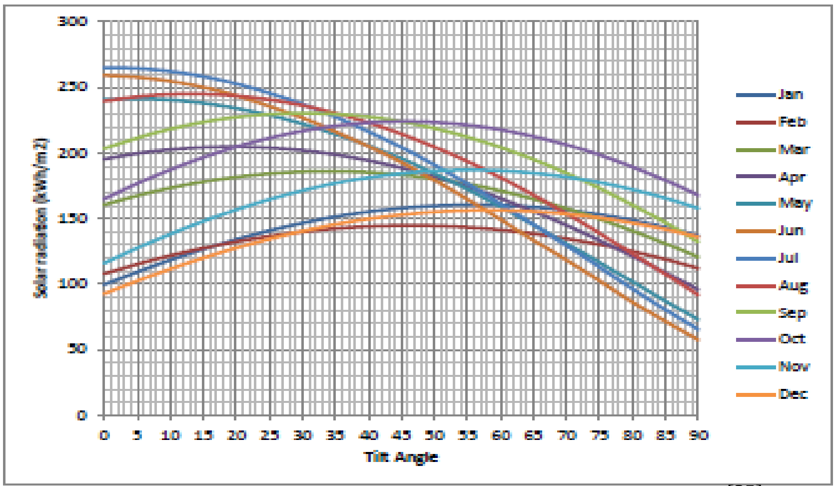


Fig 2 Monthly global solar radiation with tilt angle [35]

5. SOLAR PASSIVE DESIGN

Basic principles in passive design are dependent on using natural means to satisfy comfort of residence inside the house. These include lighting, ventilation, space heating and cooling. Moreover, by using highly efficient energy consumption appliances we can optimize the energy consumption in this house. The house orientation in passive design should take into account maximizing incoming solar energy during winter and less gains during summer time. This could be achieved by allowing daylight and thermal energy from the sun to penetrate through openings in the southern direction where living room and kitchen located. Bedrooms and the bathroom are located on the northern side. Such arrangement would reduce energy consumption for heating and cooling. All windows are shaded using external roller shading, being the most popular and efficient type, since it can diminish cooling load up to 70% [36]. In addition, the selected local building materials with sound thermal insulation material are used in the envelop. Thus, the value of overall heat transfer coefficient (U) was low and meeting the requirements of the National Code of Thermal Insulation.

Fig.3. shows the construction of external walls, celling and floor. Construction properties for the house are listed in table 2. This presents the requirements of related building codes in Jordan.

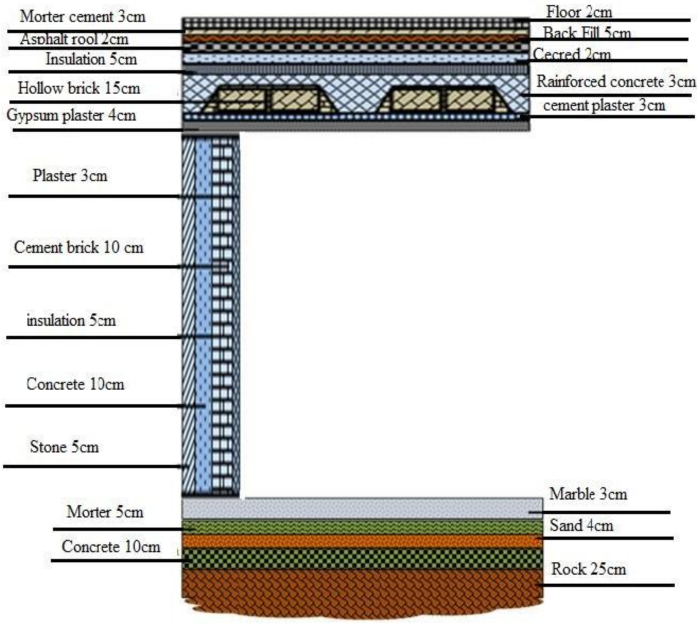


Fig.3. External walls, ceiling and floor construction.

6.CASE STUDY HOUSE

In this study the building has an area of 100 m^2, with a flat rooftop, and an internal height of 3m. A single-story house with three bedrooms, living and dining rooms, kitchen, and two bathrooms. The orientation and area of each room with the building plan are presented in Fig. 4.

Table 2.Building construction materials

<table>
<tr><th colspan="2">Building elements</th><th>Materials</th><th>U values (W/m^2 K)</th></tr>
<tr><td colspan="2">outside walls</td><td>Soft stone, Light weight concrete, Polyurethane boards, Cement brick, Cement Plaster</td><td>0.437</td></tr>
<tr><td rowspan="2">Ceiling</td><td>with brick</td><td rowspan="2">Floor, Morter Cement, Backfill, Asphalt Roll Roofing, Cecred, Polyurthane, Reinforced Concrete, Hollow Brick, Cement Plaster, Gybsum Plaster</td><td>0.392</td></tr>
<tr><td>without brick</td><td>0.4</td></tr>
<tr><td rowspan="2">Windows</td><td>For rooms</td><td>Wood double glass with air gab 6 mm</td><td>2.5</td></tr>
<tr><td>For bathrooms</td><td>Aluminum double glass with air gab 6 mm</td><td>3.2</td></tr>
<tr><td>Doors</td><td>Main door</td><td>wood storm doors</td><td>1.4</td></tr>
</table>

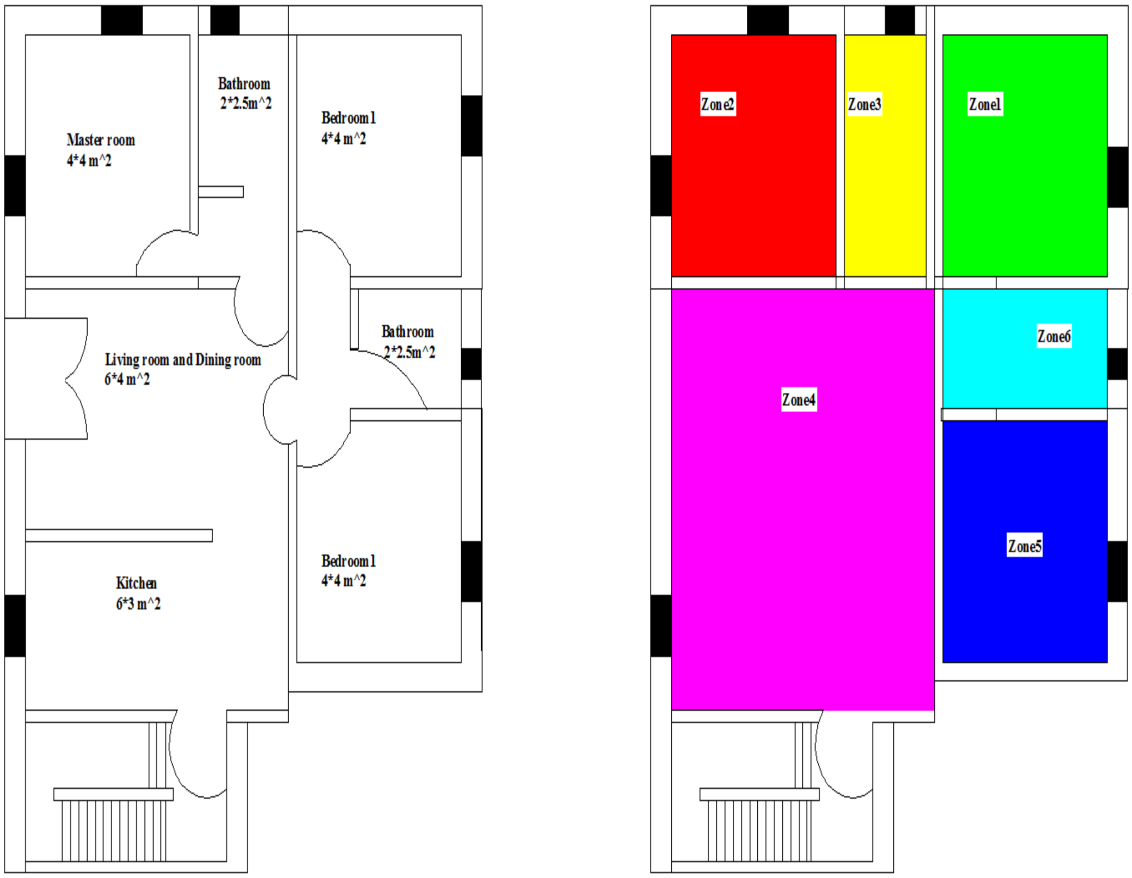


Fig. 4 Floor plan of the building: north (equator) at the right of the plan
(a) House plan, (b) House zones

7. HEATING AND COOLING LOAD CALCULATIONS

In Amman the heating period is considered to be from November to April and the cooling period is from June to September.

To estimate heating and cooling loads for this housewhich is located in Amman, the inside and outside design conditions are considered, according to the local code, and these conditions are summarized in Table 3.

Table 3 Inside and outside design condition in Amman [37].

Inside						Outside							
Winter			Summer			Winter				Summer			
T (ºC)	RH %	h (kJ/kg)	T (ºC)	RH %	h (kJ/kg)	T (ºC)	RH %	v(m³/kg)	h (kJ/kg)	T (ºC)	RH %	v(m³/kg)	h (kJ/kg)
23	35	38.5	22	48	47	4.2	67	0.7911	13.4	32.9	42	0.88	65

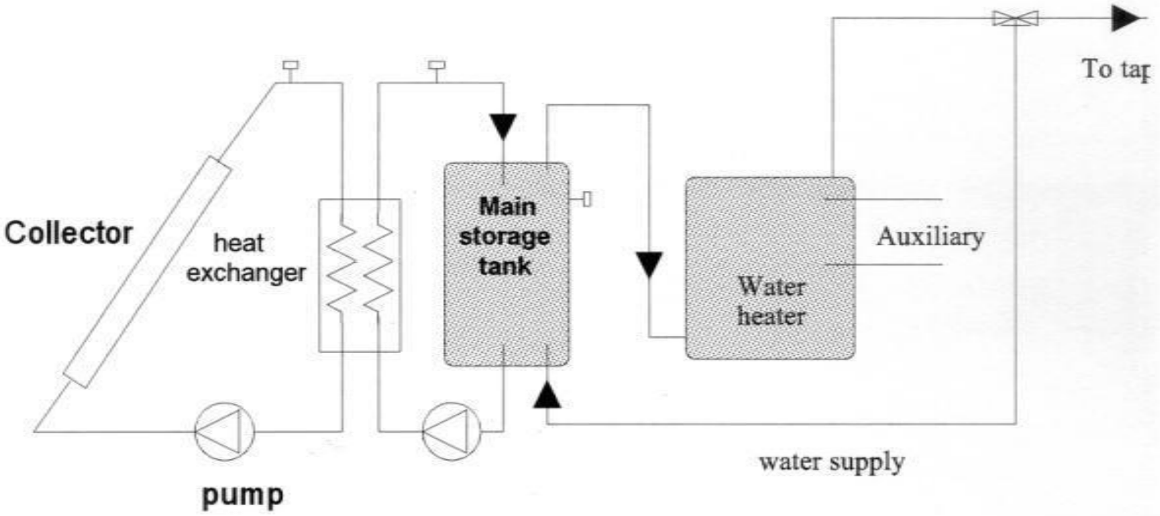
To calculate the heating load, the following should be considered, heat losses through outside walls, ceiling, floor, windows, door, and infiltration. However for cooling loads, the gain from walls, ceiling, floor, windows, door, light, occupancies, and infiltration should be considered, which their construction is shown in Fig 3 also their material of construction in addition to U values are clarified in Table 2.

As stated earlier, HAP was used to calculate thermal load for different zones (see Fig. 2) in the studied house.The results of HAP are shown in Table 4. The total space heating and cooling loads were4.30kW and 8.75 kW, repectivly.

Table 4 Design cooling and heating loads

Zone	Heating Load (W)	Cooling Load (W)
Zone 1	667.02	547.08
Zone 2	747.95	1527.32
Zone 3	198.36	82.8
Zone 4	1635	5236.278
Zone 5	667.02	1197.08
Zone 6	358.6	154.13

Fig 5 Schematic of the standard f-chart system for water heating only [38]



According to heating and cooling loads,based on desired thermal comfort,is covered by using wall mounted air conditioning units(A/C split units) ar for each zone. The main advantage of such system is that its capital cost much less than the capital cost of central chiller and boiler. The specs of selected AC type are shown in Table 5.

Table 5. Air Conditioning Selection.

	1 enoZ	***2 enoZ***	***4 enoZ***	***5 enoZ***
REE	*2.92*	*2.92*	*2.6*	*2.92*
POC	*3.12*	*3.12*	*2.73*	*3.12*
HQ	*3900*	*3900*	*6700*	*3900*
CQ	*3500*	*3500*	*6000*	*3500*

8. SOLAR SYSTEM

For the studied house, hot domestic water, electric power for different applications including lighting and home appliances and the storage system are supplied by using appropriate solar technology to achieve the main goal of this study: zero energy consumption.

8.1 Hot water

According to the local code of water supply and sewage in the residential sector, the maximum total daily domestic hot water usage for a small family of 4 persons is 250 liters per day at temperature of not less than 55°C [37].

Fig 5 illustrate the scheme of the standard f-chart for domestic hot water system, including the evacuated –tube solar collector facing south at a tilt angle of about 45°.This system has two small circulation pumps, a heat exchanger and 250 lit storage tanks. In the latter there is an embodid electrical hear to heat water in case needed.
Assuming the water heating collector characteristics are: Fr Ul (test slope) = 2.758 W/m^2°C, Fr(τα) n (test intersect) = 0.65
The solar water heating system is meant to contribute for offsetting the hot water demand load beside the auxiliary system over the year. The f-Chart method is used to evaluate the monthly system performance. The solar system simulation parameters which were used as input to the *f*-Chart software are summarized in Table 6.

Table 6. Solar Water Heater Simulation Parameters

Parameter	**Value**
Collector system area	4.142m^2
Slope of collector efficiency curve, $_R$×U_L	2.758 W/m^2°C
Intercept of collector efficiency curve, $_R$×τ×α	0.65
Number of Glazing	1
Collector azimuth	South
Collector slope	45°
Water set temperature	50 °C
Storage tank size/Collector area	37.5 L/m^2
Collector mass flow rate/area.	0.0261 kg/s-m^2

8.2Electricity

To determine the average daily &yearly load demand requirements as shown in table 7 in addition to common sense of energy saving techniques, the total daily electric load = 43.40267 kWh, multiplying by 10% safety factor, yearly electric load become = 17426.17 kWh, the assumption that's made is that the electricity produced by the PV module should cover the yearly electrical load, in addition to the storage. This is considered as an important point to achieve a zero energy house. The PV system consists of photovoltaic modules, inverter, AC and DC cables and switches, charging unit and batteries. Considering the estimated annual electricity consumption of various appliances as shown in table 7, the capacity of the needed PV system was determined.

Table 7. Household Appliances and Lighting Load

Appliance	**Power (W)**	**Quantity**	**Operation Hour**	**Energy (Wh/day)**
Laptop	50	4	3	600
LED TV 39´	68	1	4	272
Washing machine	350	1	0.714	249.9
Fridge	150	1	18	2700
Hair dryer	1800	2	0.214	770.4
Dish washer	1200	1	0.57	685.2
Microwave	1220	1	0.5	610

Vacuum cleaner		1200	1	0.285	342
Mixer		350	1	0.16	56
Oven Package		2150	1	4	8600
Iron		1000	1	0.21	210
Coffee maker		800	1	0.33	264
Electric shaver		2	3	0.28	1.71
Water pump		400	1	0.714	285.6
Toaster		1310	1	0.166	217.46
TV package		35	1	4	140
Backup heater		1500	1	1	1500
Light	2600L	28	3	6	504
	1600L	20	6	4	480
	800L	8	1	1	8
	450L	5	3	1	15
AC	Zone1	1250	1	4	5000
	Zone2	1250	1	4	5000
	Zone4	2450	1	4	9800
	Zone5	1250	1	4	5000
Water dispenser		35	1	9.6	336
Total		12619	-------	-------	43402.67

8.2.1 Solar Radiation Analysis

Amman has an abundance of solar energy which can be noticed from the annual daily average solar radiation intensity on a horizontal surface range between 4.5-5 kWh/m^2. Table1 Shows monthly clear days and average sunshine hours in Amman. [32] Fig 1Illustrates the monthly distribution of average sunshine hours and global daily solar radiation in Amman.[33] Fig 2 demonstrates the results of monthly solar radiation as a function of the tilted angle θ, from this figure, it can be concluded that the yearly optimum tilt angle is equal to 27°, approximately equals the latitude of the study house in Amman.[35]

8.2.2 Off-Grid Photovoltaic panels system design

The PV system components are the PV panel, battery, inverter, charger controller, etc....The PV system design is the main tool that aids in the selection of the system's required equipment's for an off grid connection. The PV system sizing is the result of calculation of the number and type of solar modules required to capture the solar radiation, the battery capacity will store the energy for cloudy days with no sunshine, and to ease the process of determining the characteristics for the rest of the components mentioned above.

8.2.2.1 Solar panel, battery and inverter sizing

-Photovoltaic array sizing

To produce the needed energy, we take into consideration the efficiencies of balances of the system; the table shows the typical efficiencies of these configurations, using the following equation we can calculate the needed energy that's must be generated by the modules per a day.

To calculate the needed power by the PV modules, initially the peak solar hour (PSH) in Amman must be determined, the PSH is about ***5.5 h/day*** and **321** clear day per the year as mentioned previously. After that the total energy demand is divided by the PSH to obtain the peak power as follow: $Ppeak = \frac{17426.17}{1.76} = 9901.2\,Wp \ldots\ldots\ldots(1)$

To define how many module is required, the needed power is divided by the rated power of the module, that was obtained from the manufacturer manual for polycrystalline modules with module efficiency rated between 14-16% for the panel .The selection of the PV modules does not depend only on the rated power, there are many factors should be taken into consideration such as: efficiency, area, operating conditions, and the price.

$$Number\ of\ PV\ panels = \frac{9901.2}{250} \approx 40\ panels \ldots (2)$$

8.2.2.2 Inverter Sizing

Inverters change direct current (DC) to alternating current (AC). Full feed in inverters can be used to convert DC directly from a module to AC to run electronic equipment, motors, appliances, etc. For this system, we need an inverter that its AC output equals to 220-240 V, 50 Hz.
Depending on the previous value 9901.2 Wp ,10 Kw inverter is appropriate

8.2.2.3 Battery Sizing

To determine the battery sizing, the following steps are done
Step A:Determine Average Watt-peak 9957.81 Wp
Step B: Determine battery bank capacity (Ah)
Battery Bank Capacity (Ah) =
Average Watt-Peak/Battery voltage ∗Days of Autonomy ∗Battery Temp Multiplier /Discharge Limit

$$\frac{\left(\left(\frac{9901.2Wp}{12V}\right) * 2 * 1.1\right)}{0.5} = 3631Ah \ldots\ldots\ldots\ldots\ldots(3)$$

Step C: Determine number of battery needed to cover demand :Battery Bank capacity (Ah)/battery capacity (Ah)

$$= \frac{3631Ah}{250Ah} = 14.5 \approx 16 \ldots (4)$$

Step D: Determine number of batteries in each series strings :DC system voltage/Battery voltage

$$= \frac{48V}{12V} = 4 \ldots (5)$$

8.2.2.4 Charge Controller Sizing

Regarding the panels which had been selected previously we pay attention for its **short circuit Current (Isc) to select a charge controller which will be appropriate for the PV configuration**.

Charge controller size = 8.87 Amps *4 = 35.48 A = 40A…………(6)

8.2.2.5 Selection and Assembly

Selection of the components begin with the poly-crystalline PV panels, **CS6P-250P 250W** model from CANADIAN SOLAR is selected,with an efficiency of 15.54 %% and 250W as maximum power, the model price is 271.25$ per panel. For this project, 40 panels are required, in order to mount it in a frame 40 panels need to be made.

To select the inverter it should be taken into consideration the rated peak power for the panels. for that **ABB PVI -10.0-I-OUTD-S-US-480-NG** 10.0 kW Inverter with high frequency transformer for more efficiency and MPPT feature is selected, the unit price is 3560 $.

To select the batteries it should be taken into consideration the rated peak power and system voltage that around 48V.for that **UNIVERSAL Ub8D 12V*250AH** SEALD AGM BATTERY was chosen, the unit price is509.61$

. The battery parameters in details are shown inTable8.

Table 8 Specs of Battery System

Battery parameters	
Nominal voltage	12 V
Capacity	250 Ah
Number of batteries	16
Total capacity	3652 Ah

8.2.2.6 PV System Simulation

In order to illustrate the effectiveness of the system, a simulation process has been made using **PV*SOL Expert softaware**which is the 3D design program for simulating photovoltaic performance. All the data in table 8 are determined using the simulation software to find the system output and its efficiency.

Table 9 PV parameters in the electricity system

Location	**AMMAN**	
Climate Data Record	AMMAN	
PV Output	10000	kWp
Gross/Active PV Surface Area	73.99/74.16	m²
PV Array Irradiation	174.746	kWh
Energy Produced by PV Array (AC)	22.737	kWh
Consumption Requirement	9.958	KWp
Solar Fraction	124.1	%
Inverter Efficiency	95.0	%
CO_2 Emissions Avoided	9.007	kg/year

9. ECONOMIC DISCUSSION

During the past few years the cost of the PV modules dropped to reach less than 0.35 USD/Wp as a result of higher rates of production andadvancement in technology. The investment costs for the system is the most pressing barrier for its use nowadays. The system costs consist of the sum of costs for the PV panels, batteries, inverter, charger controller, wiring, cables, and installation, which are shown in table 10.

Table 10 Total Cost for System

Component	Price (JD)	Number	Sub Total (JD)
Battery	360.88	16	5774.08
Panels	192.14	40	7685.6
Inverter	2524	1	2524
Charge Controller	119	2	238
Wires and Cables	250	-	250
Installation	5000	-	5000
Total Initial Cost (JD)	-	-	21471

For maintenance 25% of total initial cost = 21471$*\mathbf{0.25}$= 5367.75 JD
Total cost after maintenance = 26838.75 JD.
According to the calculated electrical load, cost of electrical consumption on monthly basis in Jordan was found to be equal 257 JD/month tabulated in this table, the total electricity bill is equal to what was mentioned in addition to a 14% tax on the cost.

Table 11 National Electric Power Company [39].

Price	Range (kW)
0.033	1 – 160
0.072	161 – 300
0.086	301 – 500
0.114	501 – 600
0.158	601 – 750
0.188	751 – 1000
0.265	1001 – 9999999

Based on the presented analysis and assuming a low interest rate of 2% supported by the GoJ and current electrical tariff, the expected simple payback period is about 8 years. In conclusion, the conducted sensitivity analysis proved that market price of electricity and low interest rate (less than 5%), would make the investment in zero energy house justified.

10. Conclusion

The main objective of the study in hand is to simulate thermal and electrical performance of a small house of 100 $m^2$and determine the required energy system to achieve zero energy. The heating and cooling analysis was based on HAP package, while the electrical load and consumption were calculated taking into account capacity, operation and diversity factors for various applications.
All appliances were selected to have high efficiency with clear energy star label and LED lighting used in all zones. Space heating and cooling were met by employing A/C split units that works as air condition in summer and heat pump in winter. Demostic hot water is supplied by an evacuated tube solar water heater.
The results of this study are promising, considering local conditions and availability of easy funding schemes, i.e. financial incentives by the government, represented by low interest rate on loans for building such houses.

The obtained results clearly showed that summer season, mainly July and August, are the most critical monthsin terms of energy consumption due to excessive use of A/C units for space cooling. Thus, large storage system that consists of sixteen batteries were used to provide needed electricity during night-time and/or cloudy days.

From the environmental point of view, it is possible to reach the zero energy goal and being totally dependent on solar energy all year round. Consequently substantial reduction in polluting emission incurred, including CO_2 emissions The economics of such house could be attractive when direct and indirect governmental incentives are provided to encourage developers and owners of houses to apply energy conservation measures and employ solar energy for water and space heating and cooling. The estimated monthly energy savings is about JD 260 JD, but with relatively long payback period of around eight years. It is recommended that GoJ should develop and enact targeted programs that include some incentives to encourage Jordanians expand in building new houses or refurbish old houses to be zero energy buildings.

Acknowledgments
We would like to express our gratitude toAl-Balqa Applied University (BAU) for providing this opportunity to perform this work during sabbatical leave granted to the author (Dr.Mamdoh Al-Busoul) in the academic year 2017/2018.

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