Zero Energy and Low Water Schools: Case Study-Building of Garaboulli Engineering Faculty-Libya

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ABSTRACT

The current paper presents the design methodology for reducing the water consumption to reach a zero energy building. The building of the Garaboulli Engineering Faculty (GEF), Libya was chosen as a case study. The required energy will be supplied by renewable energy. In order to meet the required loads, solar energy is used in the design to generate heating, cooling, and electric power by using different techniques such as solar thermal collectors and photovoltaic panels. Moreover, rain water is used as a source of water supply for the building. To reach the low water and Zero Energy aims, different techniques such as recycling of greywater and solar cooling were adopted. Finally, the proposed system will be feasible for a long term of operation.

Keywords: Zero energy, Low water, Renewable energy, Rain water.

1   Introduction

The daily required of energy used increases continuously with a growing population. New buildings are constructed faster than old ones and thus increase the consumption of energy. On the other hand, the load on government supply of electricity or water increases over time. In the educational buildings, the increasing of consumption is depends on increase of student number.

Recently, water and power outages have increased as a result of increased demand of energy and water, and poor production capacity. From this perspective, alternatives ways are needed to find water and energy and ensure constant supply without interruption. Introducing of zero energy principle with rationing the water and energy uses into school buildings are particularly necessary when the supply of energy and water are intermittent. The zero energy is defined by the annual of the total energy amount used by the building that renewable energy sources. In general, a net zero energy is a building with highly reduced energy needs through efficiency gains such that the renewable technologies can supply the energy needs. In this paper, Garaboulli Engineering faculty building has designed to be low water

consumption and zero energy building. Solar panels can generate the required amount of electricity that consumed by the faculty building every year.

The large area of the building's roof allows collecting an ample amount of rainwater. Reuse of greywater for some purposes throughout the building will also save extra water.

2   Description and Aims of the Project

The building of Garaboulli Engineering Faculty is located at the north of the Garaboulli city on total area 17000 m². The surface area of the main and attachment buildings is about 2100 m². The green area is more than 2000 m². The main building has four toilets with four sinks in each of six parts in two stories with total of 24 toilets and 24 sinks. A small kitchen is also including in the building. There are another toilet and kitchen in the gate building. The construction has 15 class rooms, 1 theatre, 2 electronic labs and 16 offices. Figure 1 illustrates the plan of the building and surrounded garden area. The project aims to benefit of the large surface area to generate the energy (electric, heating and cooling) from the solar and to collect the rain water to reduce the dependency on the general city network.
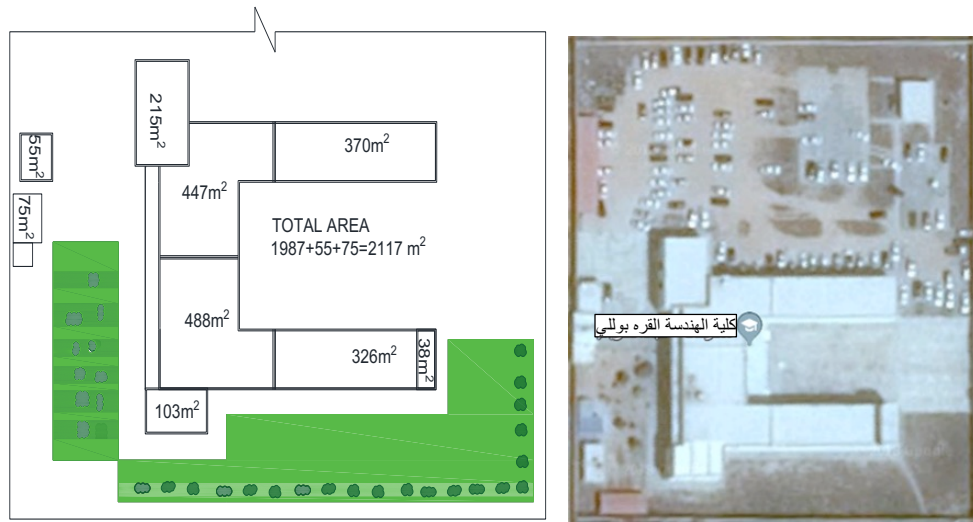

Figure 1: *Garaboulli Engineering Building, Plan (left) and air photo (right)*

3   Design Methodology

The current research attempts to find a suitable design to minimize the usage of water consumption from the city network by collecting the rain water and recycle the grey water or dispense on the network electricity by designing solar panels and heaters to generate the energy.

3.1   Low Water

Rainwater exploitation may not be sufficient to cover the total consumption of water, as this requires a very large area of water storage. Annual rainfall in some areas is also insufficient.

The best ways are: rainwater exploitation to relieve the consumption from the public network, rationalize the consumption of water and recycling the grey water.

3.1.1 Rain Water Collection

In general, Libya has a dry climate with intense rain storms and short in duration. Along the north of Libya, the rainfall months are from September to May, with most severe from October to January. The annual rainfall for Garaboulli city is taken a similar of the average of annual rainfall of the two nearest cities, Tajura and Tripoli, which have recorded data. The average of annual rainfall of these cities were similar in two different studies, 288 mm/year, where the results of Tajura was based on 40 years [1] and in Tripoli was based on 30 years of data [2]. The catchment area of the main building of the college (2000 m²) has considered. For the runoff, it is estimated that 15% of the rain water volume is released during the time required to fill the detention facility [1]. This is due to unavoidable any leakages or a possible overflow in the gutter downpipe system, or in the case of the downpour is too light to produce sufficient runoff. However, the total volume of detention facility is designed on 85 % of the total rainwater collected as in Equation 1.

$$q = 0.85 \times 288 \times 2000 = 489.6 \times 10^3 \, l/year = 489.6 \, m^3/year \tag{1}$$

3.1.2 Water Consumption

There are many studies and standards determine the varying amount of consumption in the universities and schools, such as 4.86 -6.3 litters / student / day for secondary schools [3] and 125 - 180 $l/capita/day$ for Universities [4]. The large amount of the consumption at universities is due to use of larger this amount in laboratories, gardens and other facilities, while in the school case, the consumption only for drinking, washing and toilet flushing. The water consumption can be divided into:

1. Toilet flushing which make up about 30% of overall water consumption which produce the black water.
2. Wash basins, and floor cleaning that produces grey water as well as bidet faucets which mix with toilet sludge.
3. Water used to irrigate the garden.
4. Laboratory consumption such as concrete labs

Gray water can be recycled to use in the toilet flushing and irrigate the garden after a filtration and treatment process. Figure 2 illustrates the cycle of rain and city network water.

There are no reliable data for the water consumption in the target Faculty. Since the water consumption in the Faculty is limited to: *i.* washing; *ii.* toilet flushing; and *iii.* a small Garden, the consumption in our study for i and ii is estimated to be *6 $l/capita/day$*. If we consider that the consumption rate is limited to school days only and the number of annual school days is 280, the quantity required for annual consumption of water is 280 x 6 = 1680 $l/capita/year$.
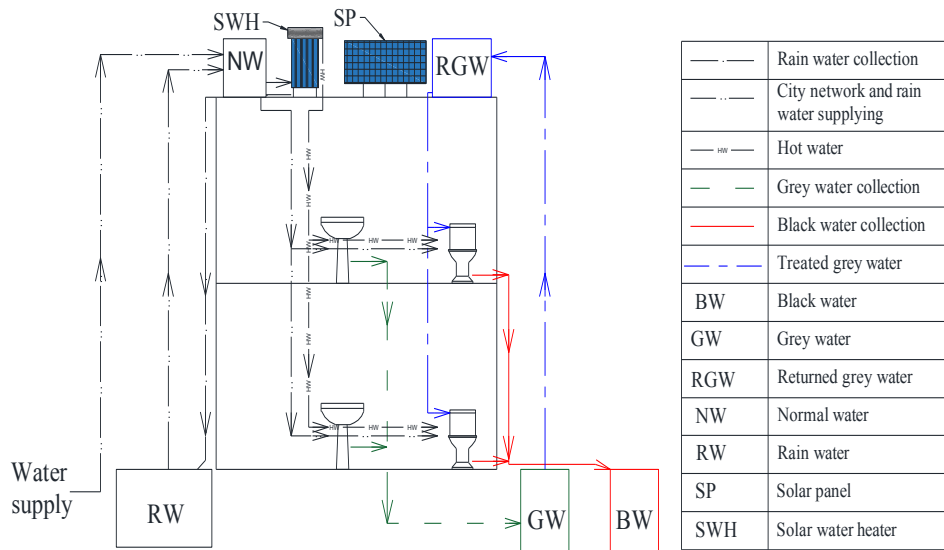
Figure 2: *General section of water cycle*

Assuming that the total daily number that can be presence in the college is a maximum of 700 people, thus, the annual consumption required is 700 x 1680 = 1176 x10³ $l/capita/year$ or 98 $m^3/month$. The use of grey water in the flushing will save about 30% of the consumption amount, thus, the needed consumption will be 68.6 $m^3/month$. The garden consumption (iii) is estimated to be 30 $m^3/month$, therefore, the monthly amount of water consumption is 98.6 $m^3/month$ or say 100 $m^3/month$. Figure 3 illustrates the monthly average collected from rainwater [2] compared to the total monthly consumption as a percentage. The total rain water collected is 489 $m^3/year$ and the total consumption requirement 1200 $m^3/year$, thus, the needed water from the city network is 711 $m^3/year$ with save more than 40% of the consumption.

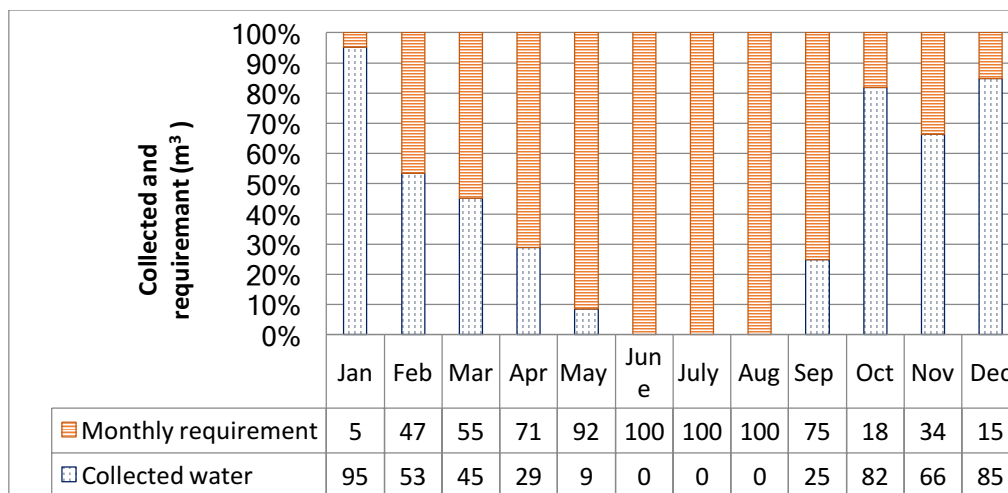|	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Monthly requirement	5	47	55	71	92	100	100	100	75	18	34	15
Collected water	95	53	45	29	9	0	0	0	25	82	66	85

Figure 3: *Collected water and monthly requirement*

3.2   Cooling, Space Heating and SHW Loads

In order to a achieve Net Zero Energy (NZE), Combi-system is the highest prospective technology which can offer that. A solar Combi-system is providing space heating, Service Hot Water (SHW) and cooling stock by solar collectors and an absorption cooling cycle. In this paper, for the purpose of designing a solar heating system, f-chart method and ɸ-utilizability method are integrated together to merge the advantages and merits of the two methods to get more accurate and precise results[5],[6]. In order to start design process, relevant weather data required are shown in RetScreen software including local weather data, air temperature, latitude, tilt angle, daily solar radiation on horizontal surface...etc[8]. Moreover, Table 1 shows the input and design data for faculty of engineering at Garaboulli, includes the number of occupants, average daily service hot water consumption per capita in addition to other related data. In addition, Table 2 shows the proposed solar collector specifications. The first step in the design of solar thermal system is to determine the energy demand of the building by using RetScreen software, and assumption a faculty operation whole the year. Table 3 summarizes the different energy demands for the space heating, cooling, service hot water, and electric devises (Baseline energy) such as computers, lighting, surface pumps that calculated according to annual consumption of the faculty building. It should be noted that the total heating load requirement which covered by solar thermal system is calculated as following in Equation 2;

$$Total\ heating\ load\ =\ heating\ for\ cooling\ +\ space\ heating\ load\ +\ SHW\ load \qquad (2)$$

Total heating load = 3.65×10^{12} (J)

Table 1: *Input and design data for the faculty building*

S. No.	Item	Value	unit
1	Latitude	32	^{o}N
2	Tilt Angle	42	degree
3	Number of Students	700	
4	Average Service Hot Water Consumption	2.3	L/day/student
5	Water Service Temperature	60	^{o}C
6	Water Density	1000	kg/m^3

Table 2: *The proposed Solar Collector Specifications*

S. No.	Item	Value	unit
1	Type of Collector	Tubular	
2	Gross Area of collector	4.619	m^2
3	$(F_R U_L)$	-1.26	W m^{-2} ^{o} C^{-1}
4	$F_R(\tau\alpha)_n$	0.51	
5	Collector Flow Rate	0.566	L/s
6	Collector Fluid Specific Heat	3600	J kg^{-1} ^{o}C^{-1}
7	Collector Fluid Density	1034	kg m^{-3}
8	Heat Exchanger Effectiveness	0.8	
9	Storage Tank Capacity	1610	Litre

Table 3: *Energy demands for the faculty building*

Month	Cooling load demand (J)	Heating load for cooling demand (J)	Heating load (J)	SHW (J)	Total heating load (J)	Electric devices load (kWh)
Jan	0.00	0.00	2.15×10^{11}	8.95×10^{09}	2.23×10^{11}	10,477.3
Feb	2.69×10^{09}	4.21×10^{09}	1.91×10^{11}	8.37×10^{09}	2.04×10^{11}	9,463.4
Mar	3.32×10^{10}	5.19×10^{10}	1.85×10^{11}	9.22×10^{09}	2.47×10^{11}	10,477.3
Apr	4.67×10^{10}	7.30×10^{10}	1.67×10^{11}	8.53×10^{09}	2.49×10^{11}	9,225.6
May	1.57×10^{11}	2.46×10^{11}	9.00×10^{10}	8.18×10^{09}	3.44×10^{11}	9,533.1
Jun	2.22×10^{11}	3.47×10^{11}	3.39×10^{10}	7.21×10^{09}	3.88×10^{11}	9,225.6
Jul	2.48×10^{11}	3.87×10^{11}	2.08×10^{10}	6.86×10^{09}	4.15×10^{11}	6,308.8
Aug	2.49×10^{11}	3.89×10^{11}	2.08×10^{11}	6.53×10^{09}	4.16×10^{11}	6,308.8
Sep	2.26×10^{11}	3.54×10^{11}	3.11×10^{11}	6.37×10^{09}	3.91×10^{11}	6,105.3
Oct	1.27×10^{11}	1.98×10^{11}	9.62×10^{10}	6.98×10^{09}	3.01×10^{11}	9,185.6
Nov	4.04×10^{10}	6.32×10^{10}	1.75×10^{11}	7.39×10^{09}	2.46×10^{11}	8,889.3
Dec	0.00	0.00	2.15×10^{11}	8.35×10^{09}	2.23×10^{11}	9,185.6
Annual demand	2.11×10^{12}	1.44×10^{11}	9.29×10^{10}	3.65×10^{12}		104,386.40

Heating for cooling is defined as the heating energy which is required for absorption cooling system. It can be calculated as follows;

Heating for cooling = cooling load demand x COP

In this study, the absorption cooling system COP is equal to 0.64.

Next step, by using ϕ-chart method, the number of collectors and the solar monthly energy collected by collectors can be estimated with following Equation 3;

$$Q = F_R(\overline{\tau\alpha})\overline{H_T}\,\overline{\phi} \tag{3}$$

Where is:

Q, the monthly energy collected by collectors (J/m^2).

$F_R(\tau\alpha)_n$, is readily determined from collector specifications.

H_T, is the monthly average daily radiation on tilted surface on the collector.

ϕ, is the monthly average daily utilizability.

In order to calculate the required collectors' area in square meters and the available total annual solar energy (J/m^2) in site. First, the solar radiation on tilted surface on collector in (Kwh/m^2) should be calculated. Table 4 summarizes the estimated average monthly solar radiation on tilted surface on collectors. Furthermore, the monthly and annual solar thermal energy collected by collectors is also shown in Table 5. In view of the data shown in Tables 4 and 5, total annual solar thermal energy available $= 3.49 \times 10^{09}$ (J/m^2), and total annual thermal energy demand $= 3.65 \times 10^{12}$ (J), taken from Table 4. Then, total collector area required is determined by Equation 4;

$$Total\ Collector\ Area\ Required = \frac{Total\ Annual\ thermal\ energy\ demand}{total\ annual\ solar\ thermal\ energy\ available} \tag{4}$$

Table 4: *The average monthly solar radiation on tilted surface on collectors*

Month	$\overline{H_o}$ (J/m²) x10⁷	$\overline{H}$ (kWh/m²)	K_T (-)	H_d (J/m²) x10⁶	H_b (J/m²) x10⁷	R_b (-)	ϱ_g (-)	$\overline{H_T}$ (kWh/m²)	$\overline{H_T}$ (J/m²) x10⁷
Jan	1.99	2.9	0.53	3.83	0.661	1.90	0.2	4.50	1.62
Feb	2.42	4	0.60	4.39	1.00	1.60	0.2	5.61	2.02
Mar	3.06	5	0.59	6.28	1.17	1.24	0.2	5.67	2.04
Apr	3.63	6	0.60	7.40	1.42	0.96	0.2	5.72	2.06
May	4.00	6.5	0.58	8.23	1.52	0.78	0.2	5.43	1.96
Jun	4.14	7	0.61	8.32	1.69	0.70	0.2	5.49	1.98
Jul	4.07	7.1	0.63	8.02	1.75	0.73	0.2	5.69	2.05
Aug	3.79	6.5	0.62	7.54	1.59	0.86	0.2	5.80	2.09
Sep	3.30	5.5	0.60	6.69	1.31	1.10	0.2	5.76	2.07
Oct	2.66	4	0.54	5.62	0.878	1.44	0.2	4.96	1.79
Nov	2.12	3.1	0.53	4.08	0.708	1.79	0.2	4.59	1.65
Dec	1.85	2.3	0.45	3.69	0.459	2.01	0.2	3.52	1.27

Table 5: *The monthly and annual solar thermal energy collected by collectors*

Month	H_T (kWh/m²)	R	a	B	$r_{t,n}$	$r_{d,n}$	R_n	a	b	c	Ø	Q (J/m²) x10⁸
Jan	4.50	1.55	0.55	0.53	0.16	0.15	1.58	-0.82	-0.69	0.48	1	2.5
Feb	5.61	1.40	0.59	0.49	0.16	0.14	1.42	-1.15	-0.35	0.69	1	2.8
Mar	5.67	1.13	0.65	0.44	0.14	0.13	1.14	-1.11	-0.38	0.67	1	3.2
Apr	5.72	0.95	0.70	0.38	0.13	0.12	0.96	-1.15	-0.35	0.69	1	3.14
May	5.43	0.84	0.75	0.34	0.13	0.12	0.83	-1.10	-0.40	0.65	1	3.08
Jun	5.49	0.78	0.77	0.32	0.12	0.11	0.78	-1.21	-0.29	0.73	1	3.01
Jul	5.69	0.80	0.76	0.33	0.13	0.12	0.80	-1.29	-0.21	0.80	1	3.23
Aug	5.80	0.89	0.72	0.36	0.13	0.12	0.89	-1.25	-0.25	0.76	1	3.29
Sep	5.76	1.05	0.67	0.41	0.14	0.13	1.05	-1.17	-0.33	0.70	1	3.16
Oct	4.96	1.24	0.61	0.47	0.15	0.14	1.26	-0.89	-0.61	0.52	1	2.81
Nov	4.59	1.48	0.56	0.52	0.16	0.15	1.50	-0.82	-0.68	0.48	1	2.52
Dec	3.52	1.53	0.53	0.54	0.17	0.16	1.56	-0.40	-1.11	0.28	1	1.99
Total Annual solar thermal energy available												34.9

Total Collector Area Required $= 3.65 \times 10^{12}$ $(J) / 3.49 \times 10^{09}$ $(J/m^2) = 1046$ (m²)

The number of collectors required is calculated by Equation 5;

$$Number\ of\ collectors\ needed\ = \frac{Total\ Collector\ Area\ required}{Area\ of\ single\ collector} \tag{5}$$

Number of collectors needed = (1046/4.619) = 226.4 collectors approx. **227** collectors.

After that, the estimated solar fraction which is defined as the percentage of the energy requirements that can be met by a solar energy system. It is calculated by f-Chart method. Table 6 shows the energy met by the solar system and solar fraction. The solar collector combi-system proposed is collector type Tubular – with model SEIDO5-16 AS/AB and tilt angle of 42° with horizontal surface. The working fluid used in this collector is anti-freezing with water solution. For cooling, the absorption cycle is used to cover the cooling load with COP 0.64. All the process of working fluid inside the system between the hot region and cold region are controlled by sophisticated computerized system [7].

Table 6: *Energy met by the solar collector and the value of solar fraction*

Month	Total Heating Energy demand (J/month) x10¹¹	second per month	$\frac{(\tau\alpha)}{(\tau\alpha)_n}$	X (-)	Y (-)	f (-)	f actual (-)	Energy met by collector (J) x10¹¹
Jan.	2.23	2678400	0.96	-3.686	1.145	1.154	1.00	2.23
Feb.	2.03	2419200	0.96	-3.618	1.418	1.286	1.00	2.03
Mar.	2.46	2678400	0.96	-3.200	1.310	1.202	1.00	2.46
Apr.	2.48	2592000	0.9	-2.941	1.187	1.119	1.00	2.48
May	3.43	2678400	0.9	-2.087	0.844	0.850	0.85	2.92
Jun.	3.87	2592000	0.9	-1.709	0.732	0.747	0.75	2.89
Jul.	4.14	2678400	0.9	-1.614	0.732	0.740	0.74	3.07
Aug.	4.16	2678400	0.9	-1.597	0.745	0.748	0.75	3.11
Sep.	3.91	2592000	0.9	-1.687	0.760	0.765	0.76	2.99
Oct.	3.01	2678400	0.96	-2.380	0.939	0.933	0.93	2.80
Nov.	2.45	2592000	0.96	-3.029	1.029	1.036	1.00	2.45
Dec.	2.22	2678400	0.96	-3.642	0.898	1.003	1.00	2.22
Total	36.5	Annual solar fraction					0.87	31.7

3.3 Photovoltaic System Design

The Photovoltaic system is used to cover the electrical power demand for the faculty building. Two cases are considered; On-Grid design and off-Grid design. Table 7 shows the specification of module used to produce the electric power (kWh) [8].

By using PVwatts program, the monthly power production output (kWh/month) can be estimated as shown in Table 8. It gives the monthly power production under the conditions; tilt angle 42°, the module face on south direction, and assuming 15% losses due to shadow, wiring and dust. It should be noted that the net total electric energy needed and sent to Grid is zero. In this sense, the electric design is net zero energy class.

Table 7: *Energy met by the PV system with* specifications of PV module used

Design PV System		
Efficiency of the inverter	0.9	AC to DC
Voltage DC system	49	volte
Peak Amp for module	7.86	
Peak sun hours	4	hr/day
Design module system	Mono-silicon module	
Type of Module	Grape Solar	Gs-S-385-TS
Power of module (W)	385	Watt
Area of a module m^2	2.56	m^2
Nominal voltage for module	49	Volte

Table 8: *Electric energy demand and PV power production On –Grid output data*

Month	Heating demand still not covered kWh	Electric device demand kWh	electric demand from PV system kWh	PV system Production kWh	Need from grid kWh	Send to grid kWh
Jan.	0.0	10,477.38	10,477.38	9,335	-1142.38	0
Feb.	0.0	9,463.44	9,463.44	9,385	-78.44	0
Mar.	0.0	10,477.38	10,477.38	11,716	0	1238.62
Apr.	0.0	9,225.6	9,225.6	11,985	0	2759.4
May	4,434.8	9,533.12	13,967.87	11,872	-2095.87	0
Jun.	5,415.7	9,225.6	14,641.29	11,894	-2747.29	0
Jul.	5,950.1	6,308.88	12,258.97	12,878	0	619.02
Aug.	5,789.0	6,308.88	12,097.87	13,284	0	1186.12
Sep.	5,071.5	6,105.37	11,176.84	11,968	0	791.15
Oct.	1,112.5	9,185.68	10,298.22	10,698	0	399.77
Nov.	0.0	8,889.37	8,889.37	8,922	0	32.628
Dec.	0.0	9,185.68	9,185.68	8,223	-962.68	0
Total			132,159.95	132,160.00	-7027	7027

In order to calculate the number of modules and total area meter square needed to cover the electric load, PVwatts program is used. The size of capacity for PV modules is (87.5 kW). Then, total number of PV modules can be calculated from Equations 6 and 7;

$$Size\ DC\ (KW) = Module\ Capacity \times No.of\ Modules \tag{6}$$

Thus, $No.of\ Modules = \frac{87.5 \times 1000}{385} = 227.27 = approx\ 228\ module$

$$The\ total\ area\ for\ PV\ modules\ =\ No.of\ modules\ x\ Area\ of\ module \tag{7}$$

$$= 228\ x\ 2.56 = 583.68\ m^2$$

Another method for design PV system called stand-alone system (off-grid system) in which the system is working without any auxiliary source or supply for electricity such as grid [9].

Stand–alone system use batteries to store a power replacing the grid, Table 9 show the specification of batteries. It should be noted that the total number of batteries used for the PV system in this study is 715 batteries with number of modules 426 covered $1091.61\ m^2$.

Table 9: *Specifications of the batteries for the stand-alone PV system*

PV system for Stand-alone system		Unit
Discharge limit	0.75	
Battery current Amp.hours	300	Ah/day
Battery Voltage	12	Volt
Efficiency of battery	0.8	
Anatomy days	3	Days

4   Conclusions

In this paper, the low and zero energy building design principles are applied to the faculty of engineering building at Garaboulli-Libya. Collected rain water and recycled grey water quantities are designed to be used for drinking, washing and toilet flushing or irrigation. The cooling, space heating and service hot water demand is determined. In addition, the total number and the area of the solar collectors are also evaluated. The electric demand for the building is also determined. Two design scenarios for covering electrical demands are adopted; Off-Grid and On-Grid. Total number of PV modules and total area are also calculated. Results show that the net zero energy design could be applicable for space heating, cooling and electricity demand. However, low energy design principle could be the case of rain water and grey water demand since the quantities are not sufficient to meet the required water demand. Finally, the issue of insulation, walls material, shading and other architectural measures are not taken into considerations in this study.

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