



(RESEARCH ARTICLE)



## Design a solar power air conditioning system for the engineering building at Mutah University

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### Abstract

Jordan like the other non-oil countries, spend significant amount of its budget on importing foreign energy. Also, the power demand increases due to, the population growth, in addition to hosting high number of refugees, from neighboring countries, and the enhancement of the citizen life style. The objective of this study, is to define the cooling load requirement, for the engineering building, at Mutah University, in order to analyze suitable cooling system, to cater the required cooling load. Energy analysis carried out, using the climate variables tabulated data, and Cooling Load Temperature Difference (CLTD), and Cooling Load Factor (CLF). The required power, to drive the cooling system was defined. Climate data shows that the average temperature was 33.2 °C, 32 °C and 33.3 °C in 2015, 2016 and 2017, respectively. The maximum temperatures was 38 °C registered in 2015. In this study the implementation of renewable energy, was considered by analyzing the viability of using, photovoltaic system, to provide power for the cooling system. Two options, to provide power for the system analyzed, the first option is supply the power from the grid, and the second option is, to supply the required power using photovoltaic power plant. The results show that, the cooling load of the building is 560 kW, and the required electrical power, to operate the cooling system is 224 kW electrical power. In addition, the results show that, the cost of power from PV system is, 40 % less than the cost of power from grid for the first 10 years. In addition, the payback period for the designed system is 5 years.

**Keywords:** Solar power; Air conditioning; Design; Renewable energy

### 1. Introduction

Energy is the driving media of technology. Absent of energy, will create huge impact, on the whole societies. In a country for short period, one would explain, the level of importance of the power, and how much the societies, depend on the useful energy form. As global populations grow by average 1.4%, the persistent need for more, and more energy is exacerbated [1]. The industrial and developed economies, consume 75% of the world's energy supply, on the other hand, 75% of the world population consume 25%, of the total energy [2].

Power production, using fossil fuel associate, with various environmental problems, like global warming, and many environmental concerns, as emission of radioactive materials. In addition, it can create weather problems, like air pollution, and acid rain, as well as, ozone layer demolition, and forest annihilation. These problems are, serious and deserve spending a lot of efforts, at the global level to reduce the fossil fuel burning, and find alternative green source of energy, to minimize the impact of traditional power generation on the environment. There are many indicators, shows that the future of the environment will be, unfavorably affected if the world dose's change, the energy production and consumption behaviors. [3, 4].

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Renewable energy, become attractive technologies, for the energy consumers, in the last few decades, because of its green environmental effect. It is sustainable cheap, and clean power source. In Jordan many projects, where established to utilize the renewable energy, in order to cater the energy demand in Jordan. Renewable energy technology, is one of the important alternative solutions, for using of electricity generators, using diesel and the generation of electricity using solar energy by, Photovoltaic panels. Diesel electricity generator, usually used in the areas, which not covered by local grid, or for temporary used, as the case of construction projects.

A Comparative study, for three options to supply electricity power, to remote area in Cote d'Ivoire [5]. The first option was, the use of PV, electricity generator using diesel, and finally the Grid Extension. In order to find the most effective option, for remote area, the authors implement life cycle analyses techniques in their study. The main factors were, the distance from local grid, and amount of needed energy. The results of the study show that, the cost of power generated by diesel generators, is significantly higher than, the cost of the power generated by PV, and the power supplied from the local grid. On the other hand, the PV panels is more cost effectiveness.

In a recent study [6], it was concluded, that the supplying of power to the remote area, in Côte d'Ivoire keeps on being serious issue. A financial correlation between Photovoltaic, Diesel Generator and the Grid power, was examined. The parameters used utilized for reenactment, were power demand and distance. The outcomes indicated that, Diesel Generator could be, impressively more costly than PV system. Contrasted with Grid, PV cost adequacy would both daily load request, and separation to Grid subordinate. More than 50 kW h a day burden request, the network augmentation separation ought to be up to 6 km. The outcomes demonstrated that PV, is the financially savvy alternative, for low force vitality request, in provincial regions, and furthermore, when the territory is exceptionally a long way from framework.

In another study [7], the comfort states measured by a device, for the normal human body, especially in hot, and humid days in summer was discussed. The problem stated that generating electricity, is the reason for humid conditions, and heat because of global warming, and the use of non-renewable energy such as fossil fuel and coal. The objective of study was, to make a conscious about non-traditional energy sources, to decrease the environmental defilement. In this study, appropriate solution for villages, where electricity, is cut (face many electricity cut problems). The study problem, was the high electricity bills, comes from refrigeration, and air conditioning system, and the need for designing a solar power air conditioning system. The study focused in using of solar power, to produce a cold air.

The design and execution, of solar powered air conditioning framework, inserted with (PV) system was presented in [8]. This system consists of, solar charger, batteries, inverter and the PV panels. The aim of designing this conditioning system was to utilize it in places that doesn't have any electricity, or in areas where the cost of electricity, is very expensive.

Reducing electricity consumption, of air conditioning system up to 45%, by integrating and designing a solar-hybrid air conditioning system, which gives the same cooling load, was presented in [9]. Placing the solar compressor before electrical compressor, resulted with less to no energy saving, because of high refrigerant temperature requirement. It was found that, if solar compressor is put after electric compressor, the refrigerant temperature entering, the condenser is dramatically lower, which converted to smaller size condenser. In this research, energy saved, raises with the refrigerant temperature.

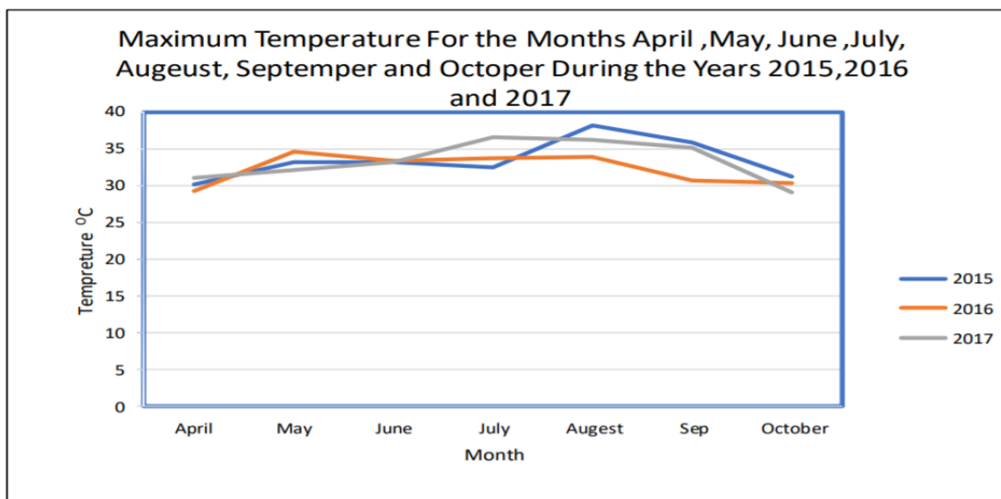
Jordan, is facing a real challenge in securing its energy demand, due to no indigenous energy resources, and high dependency, on imported energy, and instability of fuel prices. Due to population growth, and enhanced lifestyle, the demand on energy will significantly increase, this will pose new challenge lead, to huge deficit and consumed most of the foreign exchange. Conventionally, photovoltaic solar systems, were used, to produce electrical power, to cater cooling demands for buildings and facilities. This electrically driven system consumed considerable amount of power. Therefore, the search for available and feasible alternative power system, has become a pressing issue in Jordan. Utilize the photovoltaic solar system, is one of the available alternative solution, which can be used, to reduce the electricity power bill. A cooling system using air cooled chiller, will be selected and analyzed to, size and define its components. Two option to energize the cooling system should analyzed, the first to use the on-grade power, and the second option, use the photovoltaic solar system. The overall scheme is evaluated on the basis of energy and cost saving.

The objective of this study, is to select, and use solar photovoltaic panels system, with operating parameters, to produce enough electrical power, to energize a cooling system, to supply coolant, for the engineering building, at Mutah University. In addition, to minimize the electric consumption, from the local grid, and contribute in carbon dioxide emission reduction, and to calculate the cooling load value, for the classrooms and offices, for the engineering building in Mutah University, and size suitable cooling system. The designed system performance will be evaluated, over sun shining period from 8:00 AM to 5:00 PM, for the faculty working days in May, through September. During those months

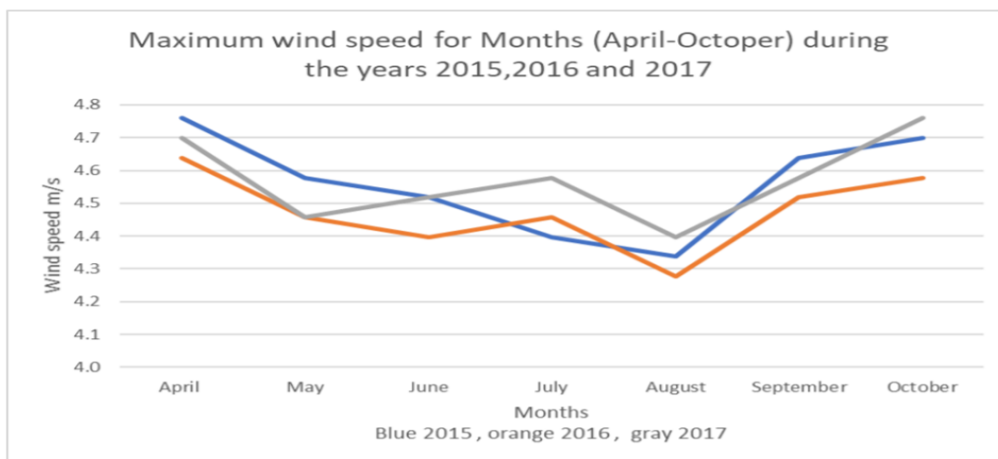
the climate in Jordan is hot, and the cooling become required inside the building. The engineering building, is located, in Mutah - Al Karak, south of Jordan, and it is at 35.43 E longitude and 31.05 N latitude, the elevation of the building from sea level is about 1100 m.

## 2. Weather conditions at Mutah University

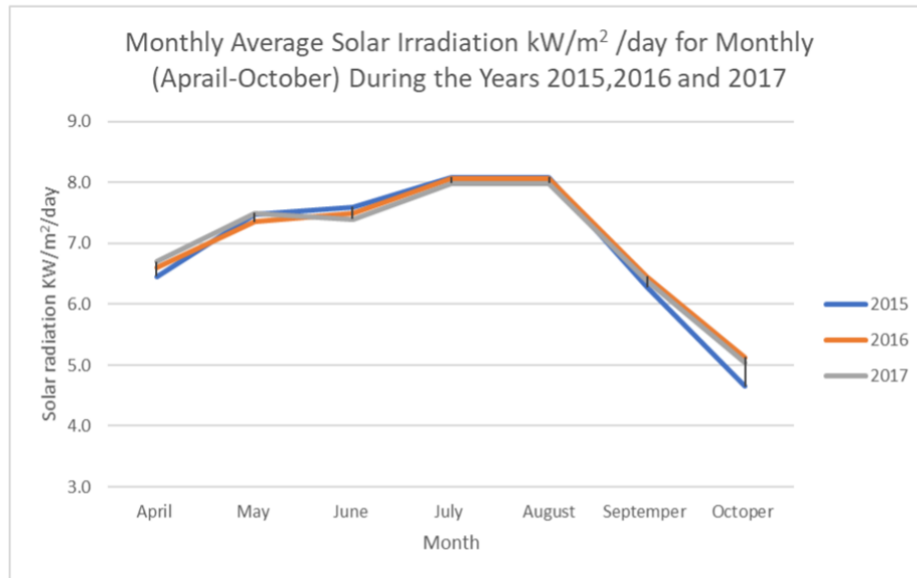
During spring and summer (April – October), the climate is relatively hot, with maximum temperature presented in figure 1. Maximum wind speed is shown in figure 2 and solar radiation as shown in figure 3. The data was obtained from prince Feisal Center at Mutah University. The temperature change through the months from April to October is presented in figure 1. The average temperature in 2015 was 33.2 °C, while in 2016 it was 32 °C and 33.3 °C in 2017, the figure shows, that the maximum temperatures was 38°C registered in August, 2015. The outdoor design temperature assumed is the maximum temperature registered (38 °C). This assumption considered to keep the results of this research up with expected climate change. Jordan climate is diverse from season to another, cold winter with minimum temperature touch zero Celsius, and hot summer with maximum temperature touch 40 °C. The climate in Jordan is affected by, its location, part of the country affected by subtropical aridity, where it's near to the arabian desert areas while the other part is affected by, the humidity of the eastern Mediterranean area.



**Figure 1** Maximum temperatures for the years 2015, 2016, and 2017.



**Figure 2** Maximum wind speed for the years 2015, 2016, and 2017.



**Figure 3** Monthly average solar irradiation during the years 2015, 2016, and 2017.

Wind speeds used in this study, were measured, by meteorological department station at Mutah University. Wind data covering periods ranging, from 2015 to 2017, were used in the study. The average wind speed for the year, 2015 was 4.5 m/s, in 2016 was 4.3 m/s, and in 2017 was 4.6 m/s. In addition, the average solar radiation for the year 2015 was 7 kW h/day, for 2016 was 7.1 kW h/day and, 7.1 kW h/day for 2017.

### 3. General description of the engineering building

The building composed from three floors; ground, first and second. There are 18 class rooms in the ground floor. The first floor has two classrooms and 40 offices. The second floor also has two classrooms and 40 offices,

Location: Mutah, Jordan

The area of each floor is 1102 m<sup>2</sup>

Area of each window, and type: 3 m<sup>2</sup> ( 2 m length x 1.5 m height), Double glass

Occupancy: 60 persons per classroom, 1 person per office

Working hours: 8:00 AM to 5:00 PM

(CLTD/CLF) method will be used to find the cooling for Mutah area.

Outdoor dry bulb: 38 °C

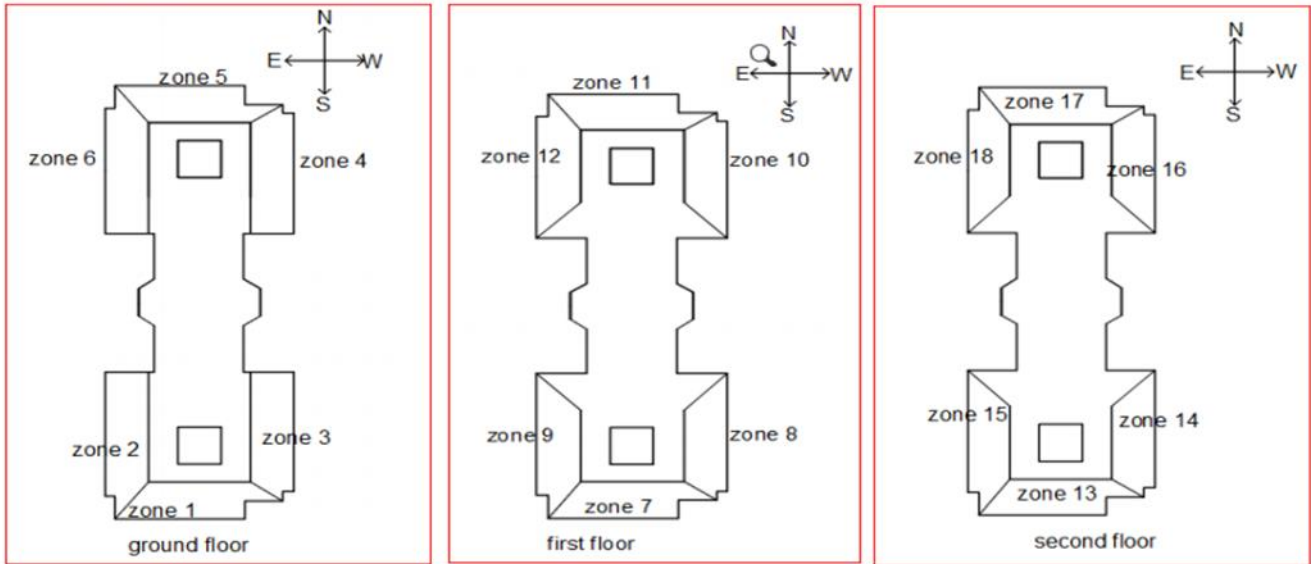
Outdoor wet bulb: 28 °C

Indoor design temperature: 24 °C

Outside relative humidity (RH): 78 %

Average wind velocity: 7.5 m/s.

The building was divided into 18 zones, to simplify the calculation process. A schematic diagram of the zones are shown in Figure 4.



**Figure 4** Schematic diagram of the building zones.

#### 4. Theoretical Concept

The following assumptions were considered, for calculation purpose: the Building is used from 8:00 AM to 5:00 PM, Light is used from 8:00 AM to 5:00 PM, all calculation made for 21st of August, as it is the highest atmospheric temperature recorded. 3536 watts of lights per zone, 2000 watts for computers per zone, for zones 8-12, and zones 14-18. The value of the overall heat transfer coefficient, was calculated. Windows type is double glazed.. Supply air tempmer is 13 °C, and return air temperature is 28 °C.

The building has three steel doors one (3.20×2.4) m and two (2×2) m. the recommended inside design conditions for summer and winter are 22-24. Referring to the comfort zones of operating temperature, it indicates that the inside condition 23.4 C db and 50% RH falls at the comfortable zone. The occupant of each classroom is 60 students. 1 person per office.

##### 4.1. Cooling load for zone number 1:

###### 4.1.1. Cooling load Temperature Difference:

$$CLTD_{corrected} = CLTD + 0.1 \quad (\text{ASHRAE})$$

###### 4.1.2. Wall loads

The heat gain through the walls, Q is

$$Q = U \times A \times CLTD_{corrected}$$

Where U is over all heat transfer coefficient = 0.576 W/ m<sup>2</sup> k, and A is exposed area = 204 m<sup>2</sup>.

Table. 1, Table.2, Table. 3, Table 4, and Table. 5, show the heat gain through walls, the heat gain through the windows by conduction, heat gained through the windows by radiation, heat gain by people, and heat gain by light, respectively.

**Table 1** Heat gain through walls

hour	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Q (W)	834	834	717	717	717	717	834	952	588	705

4.1.3. windows load

Conduction load

$$Q_{cond.} = U \times A \times CLTD_{corrected}$$

Where  $U = 2.3 \text{ W / m}^2 \text{ k}$ ,  $A = 36 \text{ m}^2$

**Table 2** Shows the heat gain through windows.

hour	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
Q (W)	8	91	174	339	422	588	588	671	671	588

Radiation load

$$Q_{radiation} = A \times SC \times SCL$$

Where SC Shading co efficient, SCL Solar cooling load.

**Table 3** Heat gain through the windows by radiation.

hour	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
SCL	84.2	125.6	187.6	187.6	163.8	145.6	124.6	91.4	81.3	71.4
SC	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
Q (W)	1244	1855	2770	2770	2419	2150	1840	1350	1200	1054

4.1.4. People load

$$Q_{sensible} = N (QS) (CLF)$$

$$Q_{Latent} = N (QL)$$

Where N is number of occupants, QS is sensible heat (ASHRAE), CLF is cooling load factor,

QL is latent heat (ASHRAE).

**Table 4** Heat gain by people

Time	Q <sub>sensible</sub> (W/h)	Q <sub>latent</sub> (W/h)	Q <sub>total</sub> (W/h)
8:00	0	10620	10620
9:00	8015.4	10620	18635.4
10:00	9066.6	10620	19686.6
11:00	9855	10620	20475
12:00	10380.6	10620	21000.6
13:00	10906.2	10620	21526.2
14:00	11300.4	10620	21920.4
15:00	11694.6	10620	22314.6
16:00	11826	10620	22446
17:00	12088.8	10620	22708.8

4.1.5. light load

$$Q_{\text{light}} = \text{Watts} \times \text{lamp ballast factor} \times \text{CLF}$$

Where Watts is lamp nominal energy,

lamp ballast factor Fluorescent light = 1.2, Incandescent = 1

**Table 5** The heat gain by light

Time	CLF	Q (W/h)
8:00	0	0
9:00	0.72	3309
10:00	0.8	3677
11:00	0.84	3861
12:00	0.87	3999
13:00	0.88	4045
14:00	0.89	4091
15:00	0.89	4091
16:00	0.9	4137
17:00	0.91	4183

4.1.6. Ventilation load

Ventilation leak of the air from atmosphere add both sensible and latent heat to the building space.

Sensible heat gain

$$Q_{\text{sensible}} = CP \times \rho \times q \times \Delta T / 3600$$

Where, CP is specific heat of air = 1.005 KJ/Kg K,

$\rho$  is the air density (1.202 Kg/m<sup>3</sup>) at standard conditions.

Q is the air flow rate (m<sup>3</sup>/h).

$\Delta T$  Is the deference between room temperature and atmosphere temperature (°C).

$$Q_{\text{sensible}} = 26.7 \text{ kW}$$

Latent heat gain

$$Q_{\text{latent}} = (hw) (\rho) (q) (\Delta x) / 3600$$

Where hw Is the Vaporization Latent Heat (KJ/Kg).

$\rho$ : Is the Air Density (1.202 Kg/m<sup>3</sup> ) at standard conditions.

q = Is the air flow rate (m<sup>3</sup>/hr).

$\Delta x$  is humidity ratio Kg H<sub>2</sub>O /Kg dry\_air.

$$Q_{\text{latent}} = 10.02 \text{ kW.}$$

The total heat gain from the sources which were studied is 337 kW as shown in Table. 6. To ensure enough coolant to compensate heat input, the gained heat was multiplied by factor of 1.6 in order to compensate the expected heat gains from other factors, and the cooling loss due to the frequent opening of the classrooms, and offices doors so, the total cooling load required to provide air conditioning for the building is 560 kW. For each zone the heat gain used as calculated, but the supplied cold air flow rate, was multiplied by factor of 1.66.

Table 6 show heat gain per zone. The heat gain through the zones (1-6) are the maximum, and almost equal values, because all of these zones exists on the same floor, and having similar conditions. The minimum heat gain is in zones (8-10), in the first floor, where these zones have only offices, with low occupancy (1 person per office).

**Table 6** Heat gain per zone.

zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Q (kW)	32	33	31	31	31	32	31	7	8	6	8	10	31	8	8	8	9	11

## 5. System Design

Using PV panels. One of the available options to supply energy generated using PV system, The required electrical power needed to drive the compressor cycle is 224 kWh. Assuming that the conversion efficiency of the panels is 18% (solarfox,2020). The total power output of the solar system can be calculated using:  $P=A \times I \times CE$ , Where P is Total Power Output A total Area I is Solar Irradiance CE Conversion Efficiency. The estimated solar radiation was presented in figure 4. The lowest value was 4.6 kW h/m<sup>2</sup> /day listed in October 2015. The selected panel dimension is 1mx2 m, with efficiency considered 18%. Each panel can produce 0.275 kW/h based on the lowest solar radiation value and considering 6 lighting hour / day. The required total power needed to be produced by the solar system is 224 kWh electrical power. The required number of panels can be , by dividing the required power on the panel capacity. The required number of panels is 814. One of the possible scenarios to organize the solar panels is, to install them in an array of 16x61, this scenario needs an area of 2772 m<sup>2</sup>, considering one-meter free space between arrays.

In air conditioning systems, there are two water cooling cycle the first one between the chillier and a heat exchanger,(evaporator) and the second cycle from the evaporator heat exchanger to the coil fan unit inside the building. The coil fan unit work as heat exchanger absorb heat from the room space the chilled water. The temperature of the chilled water in the fan coil entrance may range around (2 °C), depending upon application requirements, and maintain the coil at 20 °C. Heat transfers from the building space, to the chilled water in the coil fan unit, by circulate the air throw the coil fan , this will reduce the temperature of the supply air from 24 °C to 13 °C and the relative humidity from 60% to 50%

Three chillers were used, to supply coolant to ground floor, through eighteen fan coil units, with 800 m<sup>3</sup>/h capacity, distributed in the classrooms. The first-floor space were supplied with coolant, which is connected to five 800 m<sup>3</sup>/h fan coil located, in the first floor, and another chiller is connected to six 800 m<sup>3</sup>/h fan coil units, three units located in the first floor, and another three located in the second floor. Additional to these three units the second floor also were equipped with seven fan coil units similar capacity connected the chiller.

## 6. Economic Assessments

The required power to the system will be provided by, either supply from local grid, or using photovoltaic panels. Breakdown analyses for the components of both system was carried out. The required electrical power to run the cooling system is 224 kWh. Use local grid. To run the system from the local power networks. The following items cost will be considered for the cost calculation purposes. The cost of 1 kWh power is 0.20 J.D. The C.O.P. of the compressor refrigeration cycle is 2.5. The cooling system will run from 8:00 AM to 5:00 PM. The Power consumed during the period (April to October) will be considered. The required electricity power to run the compressor refrigeration cycle was calculated as:

power consumption = ( *COOLING LOAD* *cop* ) x number of operating hours x cost of 1 kW h. The total cost of the consumed power during the comparison period is 403.2 JD/day.

Life cycle cost Life cycle cost (LLC) for PV system was calculated, considering lifespan of 10 years, and the main factors are capital cost, maintenance cost, power cost fuel cost and salvage cost. The most economical option, is using



absorption cycle, with double generator for cooling purposes.  $LLC = \text{Capital} + FV \text{ maintenance} - FV \text{ salvage} + FV \text{ power} + FV \text{ fuel}$ . The present value  $Pv$  is:  $Pv = Fv (1+r)^n$ .  $Pv$  is present value,  $Fv$  Further value,  $R$  is ratio of return,  $n$ : number of periods. Cost of power from grid for 10 years is 398436 JD Life cycle cost = 123930 J.D. Then the Payback Period = 5 years.

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## 7. Results and discussion

The collected weather data show that the average temperature was 33.2 °C, 32.0°C and 33.3 °C in 2015, 2016 and 2017 respectively. The maximum temperature was 38°C registered in 2015. The results show that the heat gain by zones (1, 2, 3, 4, 5 and 6) are almost equal because all these zones existing in the same floor and having similar condition, anyhow zone 2 and zone 6 gains more heat than the other zones in the same floor because these two zones orientation toward west so it will be effected by radiation load more than the other sides. Regarding to zones ,8,9,10,11 and 12 show less heat gain than the ground floor zones because the occupancy level in the first floor is significantly less than the occupancy level in the ground floor where the first floor consists of offices and two class rooms while the ground floor encompass 16 class rooms the occupancy of one office is one person but the occupancy of one class room is 60 person The cooling load for zones 2 and 6 are higher than the other zones in the ground floor because these two zones oriented toward east. The cooling load for zones 9 and 12 are higher than the other zones with the same occupancy level in the first floor because these two zones oriented toward east. The cooling load for zones 1 and 18 are higher than the other zones, with the same occupancy level, in the first floor, because these two zones oriented toward east. The zones in the second floors show more heat gain, compare to the same zones in orientation and occupancy level in the first floor, because the second-floor roof is exposed to the sun ray which lead to transfer more heat to those zones. The maximum heat gain, is in zone number 13, was 33 KW, in the second floor. This zone has two classrooms with high occupancy level, and the floor roof is exposed to the sun ray. Minimum heat gain in zone number 8,9 and 10 in the first floor where those zones encompass only offices with low occupancy, and it is surrounded by partitions adjacent by conditioned zones from four sides. The supply air from the handling units is used to compensate the heat lose which defined by cooling load calculation considering the same supply air inlet temperature, the more cooling load the more supply rate needed. The ground floor has the highest cooling load value which represent 54% of the total cooling load, for the building due to, high occupancy, where the ground floor consists of classrooms only with high occupancy level. The first floor has the lowest cooling load, which represent 21% of the total cooling load for the building, due to low occupancy, and the ceiling are not exposed to the sun also the adjacent space from the top and bottom, are conditioned space. The second-floor cooling load, share is 25% of the total cooling load, the first and second floor are similar in design, but the second-floor roof is exposed to the sunray. Six chillers, with a capacity of 70 KW where used, for the cooling system feeding cooled water to coil fan units, with a capacity of 800 m<sup>3</sup> / h, and 1200 m<sup>3</sup>/h. On chiller will be used to feed zones 1 and 2, one chiller will be used to feed 3 and 4, one chiller will be used to feed 5 and 6, one chiller will be used to feed 7,8 and 9. One chiller will be used to feed zones 10,11,12 and 13, and the last one will use to feed zones 14,15,16,17 and 18. The total cooling load, needed to make air conditioning for the building is 560 kW. Six chillers were used, to supply coolant to the building, three for the ground floor connected to, eighteen fan coil units with 800 m<sup>3</sup> / h capacity, distributed in the classrooms. The fourth chiller were connected to five 800 m<sup>3</sup> / h fan coil located, in the first floor. Chiller number 5, was connected to six 800 m<sup>3</sup> / h fan coil units, three units located in the first floor, and another three located in the second floor. Additional to these three units, the second floor also were equipped with seven fan coil units, similar capacity connected to chiller number 6. To energize the cooling system two options are possible, the first one use the power from Grid, which will cost for 10 years around 398436 J.D., and the other , by using photovoltaic power plant, which can cater the required power, with life cycle cost of 123930 J.D. for 10 years. In addition, the payback period for the designed system is 5 years.

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## 8. Conclusion

The engineering building, at Mutah University, located in Al karak, south of Jordan, was considered, as a case study, for calculating cooling loads. The method used, to find the cooling load was the (CLTD) Cooling Load Temperature Difference method. The study cover the spring and summer seasons (from April to October). The Cooling load analyses calculated, cover the heat gain, from radiation and conduction of solar energy, people, light and ventilation. The results show that the total cooling load for the building is 560 kW based on calculations made for the 21<sup>st</sup> of August The occupancy level has significant effect on the cooling load value. The insulation of the building walls and roof would reduce significantly the cooling load. The cooling load building zones, oriented toward south and west, is higher than the cooling load, for the zones oriented toward east and north • The results show that the using of PV panels is more economic, than power from grid for the first 10 years. In addition, the payback period for the designed system is 5 years.

## Compliance with ethical standards

### *Acknowledgments*

The authors wish to express their profound gratitude to the entire staff of Prince Faisal Center for Dead Sea Environmental and Energy Research, at Mutah University, for providing us with the data of ; maximum temperature, maximum wind speed, and monthly average solar irradiation during the years 2015, 2016, and 2017. In addition to the entire staff of the Engineering Office at Mutah University, for providing the drawings and the construction materials for the engineering building.

### *Disclosure of conflict of interest*

We ( Shahed M. Farajat and M. Abu-Zaid) the authors of the article “Design a Solar Power Air Conditioning System for the Engineering Building at Mutah University” wish to state that there are no conflicts of interest in this our research article.

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