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Smart Building Design to Improve the Energy Consumption at an Office Room

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Abstract

Buildings are becoming smarter as a result of a variety of advanced technologies that enable energy management, optimal space utilization, and smart surveillance for safety, among other things. Energy-efficient smart building ideas and execution are of great interest and top priority due to the building's occupants' misused and high-power consumption. This paper addresses the design and execution of an energy management system that includes a solar power system for generating power for the building's needs and a PIR-based automation system for efficient power use. This project was carried out at the Military Technological College (MTC) in Muscat, in the system engineering department's offices. This project seeks to generate power for the building's energy needs using solar photovoltaic panels and reduce energy consumption within the office using a PIR-based automation system. The results demonstrate that after the breakeven point (the time it takes to recoup the initial investment), it can provide power to the building for another 17 years. The calculations and practical results presented in this study approve that the system is extremely helpful.

Keywords

Smart Building, Design, Energy Consumption, Solar Power, Passive Infra Red Sensor

1. Introduction

World is going through changes such as global warming, dramatic population growth, resource shortages and urbanization that have significant effects on our environment. Such significant changes drive us to think of different ways to minimize or eliminate the environmental damage. This concept also being applicable to buildings, engineers constantly look for innovative practices to minimize the environmentally destructive effects of construction. Nowadays, the need for maximum efficiency (Optimization) takes the topmost priority, which concerns not only with energy efficiency, but also with the need to expand the comfort levels of consumers, *i.e.*, to ensure sustainability of the building over the years, an effective synergy between comfort, energy efficiency, security and safety has to be achieved.

Due to the warning of climate change, studies on smart buildings are major goals to make our civilization sustainable in the long run and require all buildings to be more energy efficient. All houses, offices, villages, and cities must be designed to cope with diminishing resources and rising energy costs [1] [2] [3].

The author, Thomas Weng [4], focused on the reduction of power consumption within commercial buildings by improving their energy efficiency while maintaining the same level of service. The author discussed the subject with regard to how buildings should be designed and further suggested the use of suitable equipment such as sensors to achieve energy efficiency. The authors concluded that a variety of technologies must be implemented by building designers to reduce energy use, and that developing a control algorithm capable of organizing the entire building's energy should also be addressed [5].

A.H. Buckman *et al.* [6], the writers, talked about the contrasts between smart and intelligent buildings. Smart buildings were supposed to be more advanced than intelligent structures, with smart design acting as the maximum limit for future progress. Non-domestic buildings (those that are not used for residential purposes), such as colleges, offices, and other venues, were the focus of the study. It explained ways to improve building performance, operation, interaction with residents, and data collection on how the facility is used. The paper demonstrated many examples of enterprise in smart buildings, such as employing a PIR sensor to switch off lights and computers when there are no inhabitants in the room to save energy. In addition, several materials and construction strategies for smart buildings were described [7].

Francesco Asdrubali [8], the author, discussed a number of techniques to improve building efficiency, including lowering energy demand, incorporating renewable energy sources, and incorporating more efficient machinery, plants, and so on. The researcher explored specific strategies to employ particular natural resources as insulating materials for buildings. For example, materials like cellulose flocks have low embodied energy values, whereas materials like expanded polyethylene have the highest. The author proposes several methods for achieving high energy efficiency in buildings, one of which is the use of natural resources such as plants in the development of this system [8].

Individuals could modify the illuminance of light in the offices to reduce energy use according to Peter R. Boyce *et al.* [9]. The experiment was conducted in three offices, each with a color-corrected photocell to monitor illuminance levels. The photocells provide signals every ten seconds, which are saved as computer files and represent the office's illumination results. When the amount of electricity used in the office was assessed over a working day, the lighting management system revealed power savings of roughly 42 percent [9].

Smart buildings are about incorporating technology which assists in times of need and saves money in the process. Smart buildings enable use better resource utilization, reduced energy consumption, reduced operational costs, automation opportunities, new workplace opportunities etc. In addition, smart buildings make sure that the different technological systems incorporated within the buildings interact with each other, ex: fire detection and alarm system, smoke detection unit etc. display emergency messages on residents' digital signage, turn off all the lights in the room, shut down the unnecessary systems and display exit routes on the touch panels, without human interaction [3].

Nowadays, buildings consume a large amount of energy, which is almost 70% of the total electricity generated. This energy consumption has been predicted to increase even more in the coming years. In MTC, the energy consumption due to lighting and HVAC is the most dominant consumption, leading to high energy costs as well as environment effects. Therefore this project aims to upgrade MTC buildings to achieve better consumption of energy by integrating the system with solar power system using automated energy control system by using various sensing techniques within the building for better control over the lighting and HVAC system.

2. Materials and Methods

2.1. Power Consumption Analysis

Smart buildings encompass a variety of technologies, including energy management, space utilization, safety and security, and so on. Energy management in smart buildings is the focus of the current research, as it not only helps to reduce energy consumption inside the building but also helps to reduce other energy-related costs. Less use of power and, as a result, lower consumption costs as well as equipment maintenance can be secured with improved control over electricity usage inside a structure. The energy consumption statistics for MTC's Systems Engineering building is presented in **Figure 1**, as can be observed, the building's power consumption in 2017 is quite significant. The system engineering department consumes around 2852 KW, which is more than usage in other parts of the facility. As a result, this problem should be addressed by implementing an effective energy management system that will help to reduce energy use. It is planned that a solar energy system be installed, as well as an automation system to control the building's load.

2.2. Solar Energy System Setup

Installing a solar energy system in a building will give a renewable energy source with increased efficiency, lowering energy expenditures and minimizing environmental emissions. **Figure 2** depicts the system that will be utilized to harness solar energy utilizing an off-grid solar energy system in the building. Hollandia

Solar Company mono-crystalline silicon cells were used in this project's PV modules (HPS0280M). Mono-crystalline cells have long been employed in solar systems and are noted for their long life, high efficiency, and durability. The solar panels and their placement are shown in Figure 3. The electrical aspects of the solar panel are shown in Table 1.

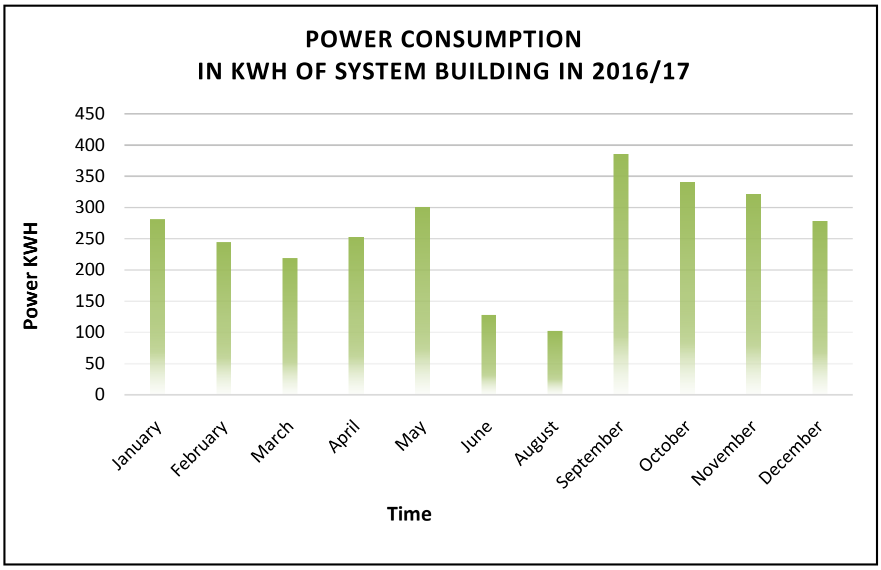

Figure 1. Power consumption in system engineering building [10].

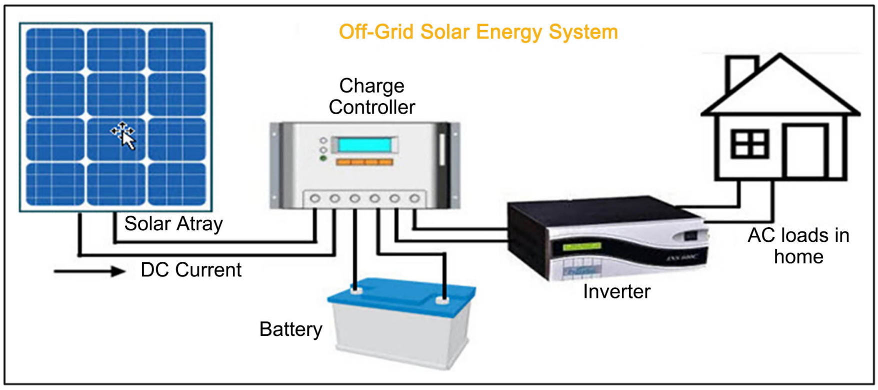

Figure 2. Off grid Solar power systems [13].

Figure 3. The installed solar panels.

Table 1. Electrical specification of the solar panel [11].

Module type: HP S0280M	
Power output (P_{max})	280 W
Power tolerance (ΔP_{max})	0/+5 W%
Module efficiency	17.24
Voltage at P max	31.3 V
Current at P max	8.95 A
Open circuit voltage	38.5 V
Short circuit current	9.37 A

The pure sine wave inverter specification is shown in **Table 2**, used in this project, which has many distinguishing features when compared to the normal inverter. The advantages of a pure sine wave inverter are increase battery life, fast charging of the battery, smart short-circuit protection, miniature circuit breaker, system protected from overload, etc.

By regulating the DC power from the panels, the solar charge controller prevents the batteries used in PV modules from overcharging. There are two types of controllers: series and shunt. They allow the battery voltage to control the solar photovoltaic system's operational voltage. Some controllers, on the other hand, can modify the operating voltage of a solar photovoltaic system without changing the battery voltage, allowing the system to operate at maximum power.

The specification of Opti-solar charge controller used in this project is shown in **Table 3**, the Opti-solar charge controller uses a three-stage charging procedure to replenish batteries more quickly than constant voltage solid-state regulators and on-off relays. The performance of the PV system is improved as the recharge time is reduced. **Figure 4** shows the battery, inverter, and charge controller present in the system.

2.3. Passive Infra Red Detectors—(Motion Sensor)

When an area is vacant, occupancy detectors turn off the lights as part of the control system. Passive infrared (PIR) detectors that detect body heat or ultrasonic detectors that detect movement are the types of detectors employed.

Motion sensors come in a variety of technologies, but in this experiment, a passive infrared sensor (PIR) was used. PIR sensors are pyroelectric, which means they can detect small amounts of heat released by objects. Because humans emit heat, the sensor can detect their movement. As a result, the way this type of sensor works is that it detects heat as it flows from one zone to another.

3. Project Methodology

The following are the key components of the solar power system: Photovoltaic (PV) semiconductors, for starters, are solid-state electronics that convert sunlight to electricity. The essential components of a photovoltaic system are these photovoltaic panels, which are coupled together to provide the required power.

Table 2. Specifications of the inverter [12].

Model name: pure sine wave	specifications
Output voltage	250 V
Output current	10 A
MCB input	6 A/240 V

Table 3. Specifications of the charge controller [14].

Model name: SC 12-24-48 V/30 A	
System voltage ratings	12 V or 24 V or 48 V (adjustable)
Current rating—Battery charge control	60 A
Current rating—Load control	60 A
Max. operating voltage	68 V
Pulse power rating	4500 watts

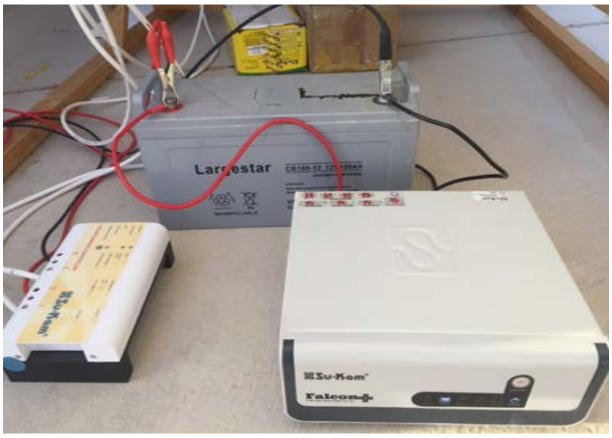

Figure 4. Inverters and the battery.

Figure 3 shows how the PV panels are mounted on a platform. The stand aids in the adjustment of the solar panels' angle and direction. The stand utilized in this project was at a 45-degree angle, which was determined to be the ideal angle for the solar panels, and the installation orientation was set to east. The solar charge controller is the second component in the solar power system. Even though solar panels are anticipated to produce 31.4 volts, the voltage generated varies depending on whether the sun's energy is too high or too low. In this scenario, a solar charge controller assists in regulating the solar panel's charge so that it is exactly 12 volts, despite variations in radiation. Furthermore, by limiting the DC current from the panels that reaches the batteries, the solar charge controller prevents the batteries used for the PV panels from overcharging. Batteries are utilized in solar power systems to store energy for later use. The inverter is the final component. The inverter converts DC electricity to AC power, which is utilized in a variety of applications such as lights, home appliances, power tools, and even air conditioning. The inverter's input is connected to the batteries' DC source, and the output is connected to the room's control box.

Specific sensors that regulate lighting and HVAC systems used to develop automated systems in buildings. The project's aim is to use motion sensors to regulate the system's operations whenever they are needed, turning it on and off based on the presence of occupants inside the building. This method has the advantage of reducing power use throughout the day, resulting in lower energy expenses.

This project's complete circuit is shown in Figure 5. The office is supplied with power from two sources, the first of which is the grid, which provides 220 V AC to the linked loads. The lights are powered by three lines from the grid, with two more lines going to the ventilation system (FCU1 and FCU2). All of the lines are then linked to the circuit breaker board, which protects the equipment while also connecting it to the new solar power source.

The second source comes from a solar power system, and solar panels are connected in parallel to give 31.4 V DC and 35 A. that is delivered to the solar charge controller, which helps to regulate the voltage to exactly 12 volts in order to charge the battery safely and efficiently to extend the battery's life. The battery is directly connected to the inverter, which converts the voltage from 12 V DC to 220 V AC so that it can be used for AC loads in the office. The measured output from the inverter is roughly 221 AC, which is comparable to the grid output. Finally, within the workplace, a control box is installed to switch the sources connected to the load from the grid to the solar power system and vice versa.

Table 4 shows the details of the loads calculation used for the lighting system and ventilation in the office room, which has three light groups and two FCU ventilation, the total power load of the room is 1120 W. Table 5 shows the estimated cost for the installed solar system and its associated components.

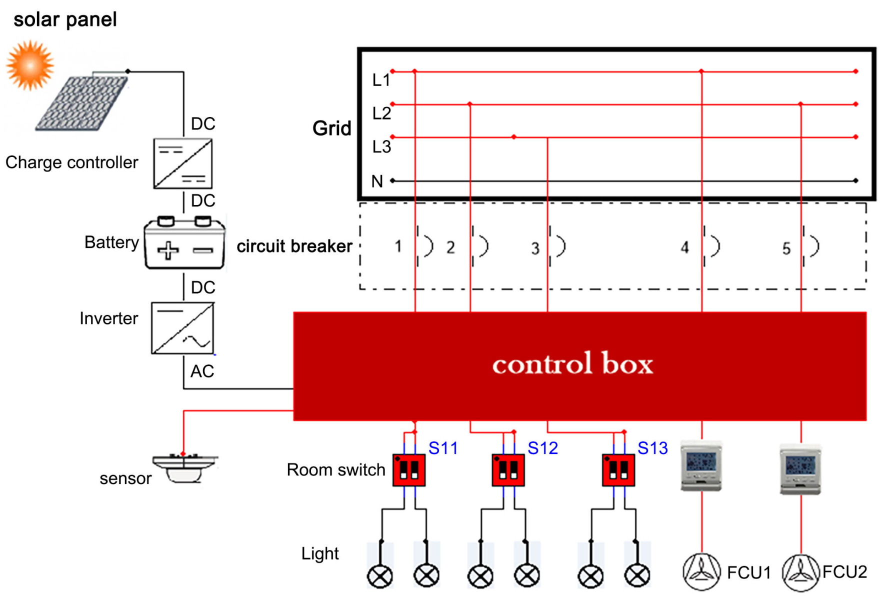

Figure 5. Complete circuit of the Solar panel system and motion sensor.

Table 4. Load calculation of the office room.

Load	Lighting systems			Ventilation		Total
	Light G1	Light G2	Light G3	FCU1	FCU2	
Voltage (V)	230	230	230	230	230	230
Current (A)	2.08	0.95	0.95	0.47	0.47	4.92
Power (W)	480	220	220	100	100	1120

Table 5. Estimated cost for the installed system.

Component	Units	Cost (OMR)
PV panels	4	496
Batteries	1	105
Inverter	1	75
Solar Charge Controller	1	45
Total		721

4. Theoritical Analysis

The analysis was done for conditions with the sensor and without the sensor. The load calculations were done for the lighting and ventilation systems for an approximate load of 1120 W [15].

Load Calculation:

Lighting system:

Light G1: $15\text{ W}\times 4\text{ lamp}\times 8\text{ unit}=480\text{ W}$

Light G2: $36\text{ W}\times 6\text{ lamp}=220\text{ W}$

Light G3: $36\text{ W}\times 6\text{ lamp}=220\text{ W}$

Total load: $480\text{ W}+220\text{ W}+220\text{ W}=920\text{ W}$

Ventilation:

FCU1: 100 W, and FCU2: 100 W

Total: $100\text{ W}+100\text{ W}=200\text{ W}$

Total load in one office: $920\text{ W}+200\text{ W}=1120\text{ W}$

PIR sensor benefit calculation

Total price in one month (without sensor):

By assuming the light work for 7 hours per one day (from 7 AM to 2 PM):

$$\text{for one day: } 1120\text{ W}\times 7\frac{\text{h}}{\text{day}}=7.84\frac{\text{kWh}}{\text{day}}$$

$$\text{for one month: } 7.84\frac{\text{kWh}}{\text{day}}\times 22\text{ day/month}=172.48\text{ kWh/month}$$

(Note: not include weekend days only 22 days in one month)

$\therefore 1\text{ kWh}=0.020\text{ OMR}$

(Note: this price according Muscat Electricity Distribution Company)

$$\text{cost in one month: } 172.48\frac{\text{kWh}}{\text{month}}\times 0.020\text{ OMR/kWh}=3.4496\frac{\text{OMR}}{\text{month}}$$

Total price in one month (using sensor):

By using the sensor, I assumed the light will work for 3 hours per one day:

for one day: $1120\text{ W}\times 3\dfrac{\text{h}}{\text{day}}=3.36\dfrac{\text{kWh}}{\text{day}}$

for one month: $3.36\dfrac{\text{kWh}}{\text{day}}\times 22\text{ day/month}=73.92\text{ kWh/month}$

cost in one month: $73.92\dfrac{\text{kWh}}{\text{month}}\times 0.020\text{ OMR/kWh}=1.4784\dfrac{\text{OMR}}{\text{month}}$

Money saved in one month is $3.445\text{ OMR}-1.478\text{ OMR}=1.967\text{ OMR}$

The number of batteries needed for the system

For a 12-Volt inverter system, each 100 Watts of the inverter load requires approximately 10 DC Amps from the battery.

Taking 1120 Watts from a 12-Volt battery requires the battery to deliver approximately 112 Amps DC in one hour (1120 Watts ÷ 12 Volts = 112 Amps).

The battery used in this system deliver 100 A.H, the price for battery = 105 OMR.

Batteries needed without the sensor:

In the normal case without using sensors, the estimated time for system to be run for 8 hours

The needed A.H from batteries in one day: $112\text{ A.H}\times 8\text{ h}=896\text{ A.H}$

So the system needs about 9 batteries.

The cost for the batteries: $9\times 105\text{ OMR}=945\text{ OMR}$

Batteries needed using sensor:

By using the sensor, I estimated the time for system to be run for 3 hours

The needed A.H from batteries in one day: $112\text{ A.H}\times 3\text{ h}=336\text{ A.H}$

So the system needs about 4 batteries.

The cost for the batteries: $4\times 105\text{ OMR}=420\text{ OMR}$

Money saved using sensor: $945\text{ OMR}-420\text{ OMR}=525\text{ OMR}$

Return investment calculation:

Load of the office:

Lighting system:

Light G1: $15\text{ W}\times 4\text{ lamp}\times 8\text{ unit}=480\text{ W}$

Light G2: $36\text{ W}\times 6\text{ lamp}=220\text{ W}$

Light G3: $36\text{ W}\times 6\text{ lamp}=220\text{ W}$

Total load: $480\text{ W}+220\text{ W}+220\text{ W}=920\text{ W}$

Ventilation:

FCU1: 100 W, and FCU2: 100 W

Total: $100\text{ W}+100\text{ W}=200\text{ W}$

Total load in the office: $920\text{ W}+200\text{ W}=1120\text{ W}$

Solar energy cost:

$\text{cost of panels}=\text{No. of PV}\times\text{Cost}=4\text{ panels}\times 124\text{ OMR}=496\text{ OMR}$

$\text{cost of batteries}=\text{No. of Batteries}\times\text{cost}=1\times 105\text{ OMR}=105\text{ OMR}$

$\text{cost of inverter}=\text{No. of inverters}\times\text{cost}=1\times 75\text{ OMR}=75\text{ OMR}$

$\text{cost of one solar charge controller}=45\text{ OMR}$

Total cost = 721 OMR

Return investment:

A solar system at this price can provide energy of:

$$721\ \text{OMR}/0.020\ \text{OMR}/\text{kWh} = 36050\ \text{kWh}$$

Energy will be provided in one year from the solar system:

$$1.120\ \text{kW} \times 12\ \text{h}/\text{day} \times 365\ \text{day in year} = 4905.6\ \text{kWh}/\text{year}$$

Years needed to recoup the cost of a solar system:

$$(36050\ \text{kWh})/(4905.6\ \text{kWh}/\text{year}) = 7.3487\ \text{years}$$

About 7.4 years and 4 months

The number of benefit years in this solar system investment:

The average lifespan for solar panels is about

25 years, so 25 years − 7.4 years = 17.6 years

Figure 6 shows that the project is expected to meet its breakeven point in 7.4 years.

5. Results and Discussion

The power generated by the solar panels is measured and the load requirement inside the building is mentioned in Table 6 and Table 7 respectively. The load requirements of the lights and FCUs will be met by the power generated from the solar panels.

The allocation of the sensor shows that the sensor will minimize the working hours of the system, which will lead to minimized energy use as well as the cost of the system. Figure 7 shows the measurement of power consumption with and without the sensor. The design worked as expected, by switching the system OFF in the absence of occupants inside a room and ON when occupants entered the room.

Table 6. Power generated by the Solar panels (measured).

Parameters	Panel 1	Panel 2	Panel 3	Panel 4	Total
Voltage (V)	31.698	31.589	31.585	31.567	126.439
Current (I)	8.89	8.942	8.9458	8.9619	35.7397
Power (W)	281.8	282.47	282.26	282.9	1129.43

Table 7. Load measurements of the office room.

Load	Lighting systems			Ventilation		Total
	Light G1	Light G2	Light G3	FCU1	FCU2	
Voltage (V)	222	222	222	222	222	222
Current (A)	2.16	0.99	0.99	0.51	0.51	4.16
Power (W)	439.5	220	220	113.2	111	1102

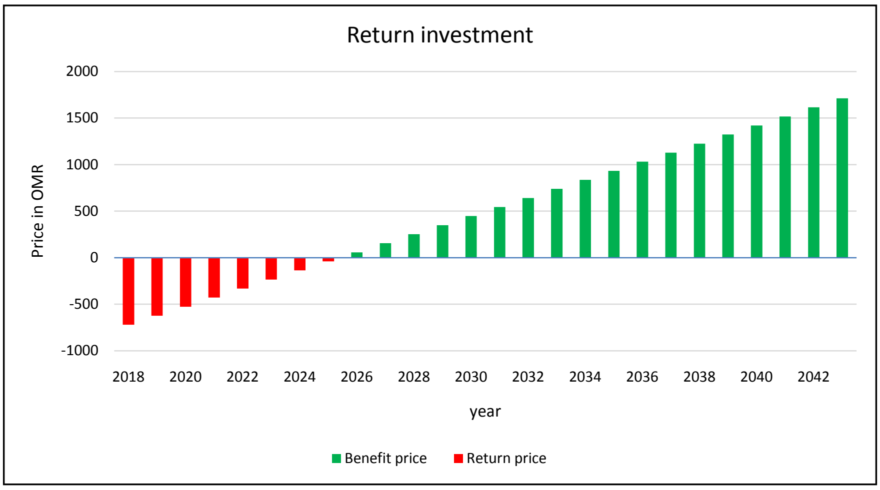

Figure 6. Return investment cost.

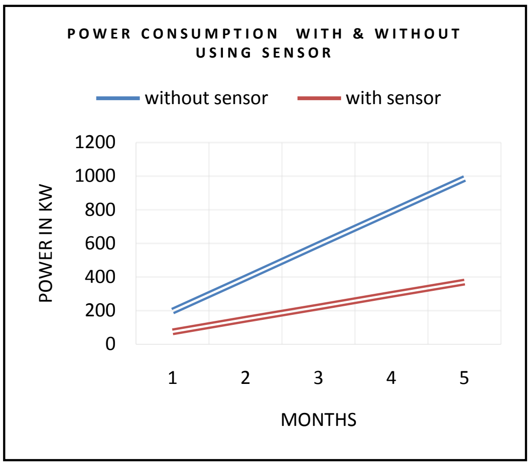

Figure 7. measurement of power consumption with and without a sensor.

The calculations not only show a minimization in energy consumption costs but also show that the cost of batteries for the solar energy system can be minimized. The measured values have shown that the power, voltage, and current when changed, the specifications of the system used change for various reasons, such as the level of radiation from the sun and other factors.

6. Conclusions

The project succeeded in proposing an efficient system that reduced the consumption of electricity inside the offices. The result showed that the proposed project will deliver free energy for 17 years after the payback period is achieved. The PIR sensor will not only reduce the cost related to the load but also the cost associated with the solar energy system by reducing the number of batteries needed, an idea never implemented so far by researchers.

The control box circuit was also a new idea that was implanted for the first time in the MTC building. This control box is very useful for small projects that require two different sources as it will eliminate the use of Supervisory control and data acquisition (SCADA) system and thereby reduce the cost of the system. *I.e.*, a SCADA system is often used for very large solar energy systems and is very expensive, making this control box an efficient option for small projects. This project has been conducted in only one office room, and if extended to the whole building, the power savings would be tremendous.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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