Research Article

Energy Audit and Feasibility of Solar PV Energy System: Case of a Commercial Building

Sylvester William Chisale [1] **and Patrick Mangani**[2]

[1]*Department of Applied Studies, Malawi University of Science and Technology (MUST), Limbe, Malawi*
[2]*Department of Energy Resources Management Malawi, University of Science and Technology (MUST), Limbe, Malawi*

Correspondence should be addressed to Sylvester William Chisale; schisale@must.ac.mw

Energy situation in Malawi is continuing facing critical challenges to satisfy the existing demand. However, energy consumption and energy conservation studies have been neglected to help overcome this problem. In this paper, electric energy audit was conducted for a commercial building in Mchinji, Malawi, in order to identify energy-saving opportunities. The study employed a mixed method research which involved a series of surveys, observation, data collection, and analysis. The current energy consumption was determined and compared with the proposed energy consumption after replacing some equipment. The proposed system saved up to 33.46% of energy. The study also suggested behavior change towards energy saving. Additionally, an alternative energy system was also suggested. Thus, the HOMER software was employed to design, optimize, and analyze a solar-battery-grid-connected energy system. The proposed system has a simple payback period of 9.8 years. The system's cost of energy was estimated as 0.0372 $/kWh, and the capital cost was $ 150,887.

1. Introduction

Global energy consumption is constantly increasing resulting in high rates of gas emissions and global warming [1]. Alternative energy resources such as renewable sources can help to reduce the carbon content in the atmosphere thereby overcoming the global warming problem [2, 3]. Most developed countries are investing in energy-efficient technologies to reduce energy losses in order to ensure constant energy availability [4]. Industries consume about 30 to 70% of the total global energy consumption [5]. The International Energy Agency (IEA) had indicated that energy demand in the building industry would grow by about 50% in 2050 in relation to 2013 if no extra controls are applied [6]. Energy auditing is a systematic approach for energy management in order to ensure efficient use of energy with economic consideration. This approach includes aspects of the process, operation modification, conversion energy losses, load management, and investment in energy-efficient technologies [7]. Studies have shown that energy consumption in industries can be reduced by improving energy efficiency. Energy audit is the best way of evaluating energy-saving potential and develops a plan of action to achieve a clean and sustainable industrial process. Worldwide reports have indicated that 25 to 35% of energy can be saved in commercial buildings [8, 9]. This huge amount of energy can be utilized by other users including households without access to electricity.

Several countries are introducing policies to address climate challenges while trying to satisfying the demand for energy. One of the policies includes low-energy buildings. For instance, European Union came up with a "nearly-zero-energy building" (nZEB) policy, while the United States introduced "net-zero-energy buildings" (NZEB). China also introduced similar policies [10, 11].

Zero-energy building is defined as a building with zero net energy consumption. Thus, annual energy consumption by the building is approximately equal to the amount of renewable energy generated on the site [12]. This implies that the grid supplies electricity when there is no renewable power and the building export power back to the grid when there is excess generation. This mode of selling electricity can be made possible through a Feed-In Tariff program [13]. In

[14], the author emphasized that all actors need to respond and adapt to progress made on low-energy-building (LEB). This is because LEB has new characteristics in relation to technology, economy, and other related aspects.

Africa has over 600 million people without access to electricity with inefficient, old, and secondhand technologies from developed countries. This largely affects energy development, access, and utilization to the entire population [15]. Malawi compared to other Southern African Development Community (SADC) countries has the lowest electricity access rate. The country with a population of over 18 million has an electrification rate of 12.7% mostly in cities. Rural and urban electrification is estimated at 3.9% and 48.7%, respectively [16]. Malawi Government through Electricity Supply Commission of Malawi (ESCOM) conducted an energy-efficient survey across the country. The survey showed that most households use inefficient appliances. The quick response to this survey was the free distribution of energy saver bulbs to all electricity users in order to reduce energy consumption [17].

As of 2020, Malawi has no direct energy efficiency policy but rather it has action plans implemented. Malawi government is carrying out energy-efficient projects that include the use of solar water heaters in a public building, distribution of energy saver bulbs, encouraging high energy-efficient appliances on the market, and also providing civic education to people. Another action plan is that the government established national energy-efficient and renewable energy committees to ensure that industries are using high energy-efficient technologies [17]. Additionally, the government of Malawi removed other taxes on solar energy technology importation [18].

Malawi's electricity demand is rapidly increasing due to change in lifestyle due to civilization. However, the country has abundant solar energy resource which is currently being underutilized. A solar PV system connected to the grid is preferable as compared to a standalone PV system because of the limited availability of solar energy [19]. On-grid solar PV system boosts the capacity of network and improves reliability [20, 21]. Additionally, onsite energy generations increase the overall efficiency of the system [22]. On-grid system with a battery can be ideal for Malawi because of frequent power outages [23].

2. Literature Review

In [24], the author carried out a preliminary and detailed audit of the aluminum industry in Chennai, India. The survey identified energy-saving opportunities and suggested restructuring of single line diagram (SLD) of electrical wiring and replacement of lighting and fans. If these recommendations were implemented, the industry can save 29.54% of power consumption. Chakraborty et al. [25] conducted a detailed study to reduce electrical energy consumption in the complete G+6 building in NIT, Agartala campus. The results showed that the implementation of suggested recommendations can reduce 41.66% and 30.6% of energy consumption and its cost, respectively. The total investment required for implementing the recommendations would be

TABLE 1: Daily radiation and clearness index data for Mchinji.

	Clearness index	Daily radiation (kWh/m²/day)
January	0.481	5.41
February	0.502	5.54
March	0.552	5.72
April	0.612	5.68
May	0.664	5.43
June	0.672	5.11
July	0.675	5.29
August	0.669	5.87
September	0.672	6.65
October	0.628	6.75
November	0.573	6.38
December	0.498	5.61

to the extent of Rs. 242,062 with a payback period of 3.15 years for the investment. In [4], the author conducted a physical home energy audit in Phuentsholing, Bhutan, and recommended the replacement of lamps with a compact fluorescent lamp (CFL) resulting in 202.6 kWh saving per day for 200 households (i.e., 41.30%). It was further analyzed that if 24,358 electrified household of Bhutan saves 1.01 units per day then 8,979,576.70 kWh of energy will be saved in a year. The author also suggested that Bhutan should establish a policy framework for energy consumption.

Magdum et al. [26] conducted a brief study of supply system in cooperative Patsanstha by carrying out a detailed energy audit in cooperative Patsanstha Ltd. Premises for systematic methodology specified as per Bureau of Energy Efficiency (BEE). The study showed that the replacement of inefficient equipment is more important because it reduces the gap between generation and demand of energy. The natural daylight usage is most beneficial to reduce energy usage. The building must have windows and doors to archive more sunlight. In [27], the author conducted an energy audit survey of two commercial buildings in Dhaka. It was found out that 8 to 15% of electrical equipment are not efficient and 28 to 45% of electrical energy can be saved in the lighting section. The study also showed that energy audit can be a cost-effective and holistic approach for energy conservation in Bangladesh.

HOMER-based hybrid systems had been studied in various applications. In [28], the author conducted a study of cost analysis of on-grid and off-grid solar PV systems for the Institute of Environmental Engineering and Management, MUET Jamshoro, Pakistan. The results showed that the grid-connected system is technically and economically feasible. Nurunnabi and Roy [29] conducted a study on a PV-wind turbine-grid hybrid system using HOMER for the rural area of Lobon Chora, Khulna, Bangladesh. The simulation results indicated that the grid-connected solar PV and wind turbine hybrid system is economically viable as compared to the traditional hybrid system of solar PV-wind turbine and battery. In [30], the author presented the simulation and optimization study of a stand-alone photovoltaic power system to satisfy desired power needs of an orphanage in
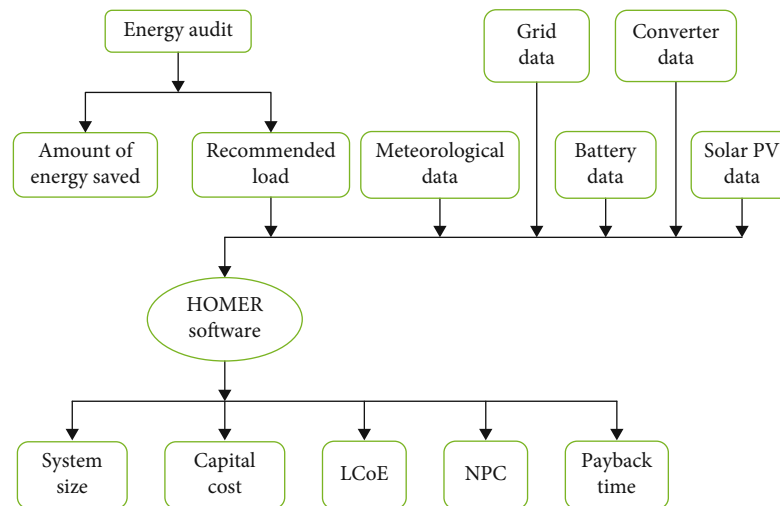
FIGURE 1: Summary of methodology for the study.

Nigeria. The patterns of load consumption within the orphanage were studied and suitably modeled for optimization using the HOMER software. The results showed that solar energy can be a choice for green power solutions in powering orphanages located in remote areas.

The purpose of this paper is to carry out an energy audit and feasibility study of solar PV installation as an action plan for a commercial building in Mchinji, Malawi. The study will also contribute to the existing literature by promoting energy audit in buildings using available auditing approaches in order to reduce energy consumptions and bills. The feasibility study will be carried out through simulation and optimization of solar PV-battery grid-connected system in order to determine the appropriate sizing required for the demand after audit results using HOMERPro.

3. Case Study

Pagwanji is a small commercial multipurpose building situated at Bua trading centre in Mchinji, Malawi. It is approximately 25 km from Mchinji Boma. The building is comprised of shops, printing services, gaming services, paying TV room, Bars, restaurants, and other small business activities. The solar GHI resource and temperature for Mchinji were obtained from NASA's surface meteorology and solar energy database for a period of 22 years from 1983 to 2005. Table 1 shows daily radiation and clearness index data for Mchinji with annual average daily radiation is 5.79 kWh/m^2/day.

4. Materials and Methods

The study employed a mixed methods research which involved a series of surveys, observation, data collection, and analysis. Questionnaire was used to find out behavior pattern on the energy use such as switching off appliances that are not in use. The rated power of all appliances was recorded, and the estimated time of operations was also recorded for further analysis of the system. Energy consumption for each appliance was calculated and their associated costs. Similarly, after recommendations of appliance replacement and behavior change, energy consumption and their associated costs were calculated. The two scenarios were analyzed for a recommendation of possible action. Finally, the HOMER software was used to design, optimize, and analyze the energy requirements of the proposed appliances in the building.

4.1. Modeling of the System Using HOMER. The HOMER software is one of the best modeling tools of hybrid renewable energy systems. The software is used in designing, simulating, and analyzing hybrid renewable energy systems. The software is applied in grid-connected or off-grid hybrid systems [31]. HOMER software also performs powerful optimization in relation to the cost of various energy project scenarios which allows minimization of cost [28]. Additionally, the software performs sensitivity analysis of the hybrid system. The mix contained in HOMER includes combined heat and power, conventional generators, wind turbines, solar PV, batteries, fuel cells, hydropower, biomass, and other inputs. The HOMER software does optimization of the key performance indicators of the hybrid power system as net present cost (NPC), fuel cost, operation cost, and cost of energy (COE) of the hybrid [32].

4.2. Solar Photovoltaic Systems. A Monocrystalline Silicon solar PV and model number BSM500M-96 cost $0.26/Watt in China. A panel has a rated power of 500 W and an efficiency of 19.51%. Thus, 1 kW costs $ 260 and module lifetime is 25 years [33]. However, considering shipping and other logistic cost up to landlocked country, Malawi, the capital cost of 1 kW generic flat plate was pegged at $ 950 with operation and maintenance cost of $ 1 per year. The replacement cost was pegged at $ 800 per kW. A derating factor of 90% was also considered for the solar module.

4.3. Grid System. Power outages in Malawi are more frequent making a very important parameter in designing of grid-connected system. The monthly average number of outages and average duration of outage in Malawi were 7.4 and 3.6

TABLE 2: Current energy use for the building.

Appliance	Power rating (W)	Quantity	Connected load (W)	Operating time (h)	Daily energy (kWh)
Refrigerator	120	4	480	24	3.4
Fan	75	7	525	6	3.15
Air conditioners	1800	5	9000	5	45
Printers	1200	3	3600	6	21.6
32″ TV	120	4	480	7	3.36
Internet router	5	3	15	10	0.15
Computers	100	5	500	7	3.5
CCTV cameras	15	9	135	12	1.62
Kettles	1200	4	4800	1	4.8
Rice cookers	1200	2	2400	0.75	1.8
Laminator	1300	3	3900	2	7.8
Emergency bulbs	6	12	78	12	0.936
Incandescent bulbs	60	15	900	8	7.2
Total energy need in a day					104.316
Total energy need in a month (31 days)					3233.796
Total energy need in a year (365 days)					38075.34

TABLE 3: Recommended energy use for the building.

Appliance	Power rating (W)	Quantity	Connected load (W)	Operating time (h)	Daily energy (kWh)
Refrigerator	120	4	480	24	3.4
Fan	50	7	350	6	2.1
Air conditioners	1500	5	7500	5	37.5
Printers	500	3	1500	6	9
32″ TV	55	4	220	7	1.54
Internet router	3	3	9	10	0.09
Laptop	50	5	250	7	1.75
CCTV cameras	6	9	54	12	0.648
Kettles	1000	4	4000	1	4
Rice cookers	1200	2	2400	0.75	1.8
Laminator	600	3	1800	2	3.6
Emergency bulbs	6	12	72	12	0.864
Florescent tube	26	15	390	8	3.12
Total energy need in a day					69.412
Total energy need in a month (31 days)					2151.772
Total energy need in a year (365 days)					25335.38

hours, respectively [23]. Thus, in HOMER, the mean outage frequency was set at 88.8 per year, while the mean repair time was 3.6 hours for the software to determine random outages. The cost of energy on grid for household use in Malawi as of December 2020 was 0.13 $/kWh [34].

4.4. Battery. Power backup system is very important for unreliable grid since solar is an intermittent source of energy. Thus, the battery becomes useful during cloudy days and at night when the grid is down. Yichen from China manufactures batteries with model number CE,MSDS,Rohs. Lithium iron phosphate with nominal voltage and maximum capacity of 3.2 V and 206 Ah, respectively, costs $ 125 per battery [35].

Therefore, the cost of generic 1 kWh Lead Acid battery in HOMER was considered as $ 200 to reach Malawi, while the operation and maintenance coat for each battery was pegged at $ 1 per year, respectively. Battery life also depends on its depth of discharge (DoD); hence, DoD was set at 60%.

4.5. System Converter. Techfire inverter with model number VE1012 is manufactured in China. 800 W inverter costs $ 117 with input and output voltage of 12 V and 220 V, respectively. Inverter efficiency is 97 to 99% [36]. However, for this system to reach Malawi, a 1 kW generic system converter was considered with efficiencies of inverter and rectifier of 97%. The converter lifetime was set at 15 years. The capital cost
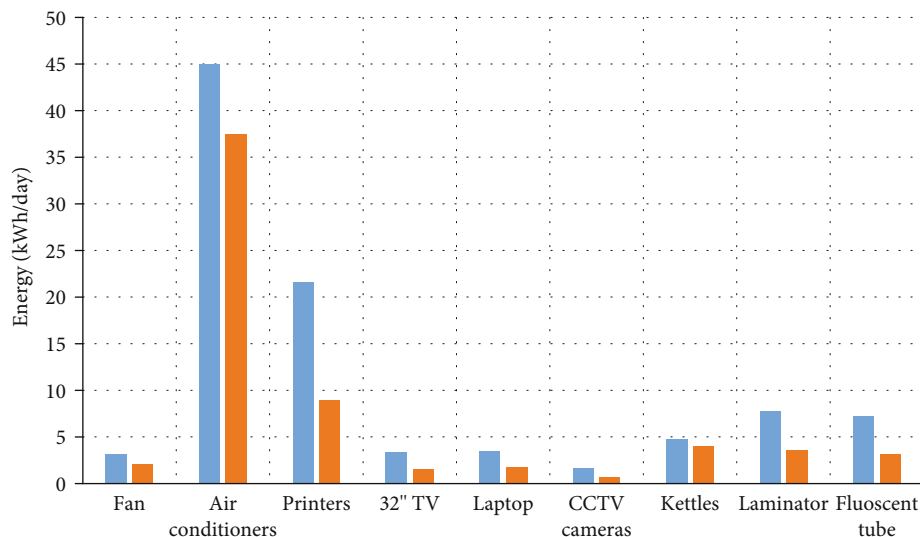
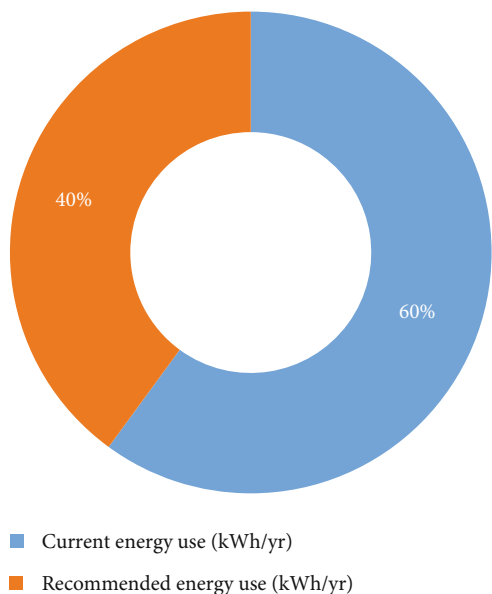FIGURE 2: Comparing energy saving of selected appliances.

- Current energy use (kWh/yr)
- Recommended energy use (kWh/yr)

FIGURE 3: Recommended versus current energy use.

TABLE 4: Cost of recommended appliances (US$1 equal to MKW 785).

Appliance	Number of equipment	Unit cost of appliance (MKW)	Total cost of appliances (MKW)
Refrigerator	4	300000	1200000
Fan	7	25000	175000
Air conditioners	5	450000	2250000
Printers	3	550000	1650000
32″ TV	4	200000	800000
Internet router	3	35000	105000
Laptop	5	250000	1250000
CCTV cameras	9	90000	810000
Kettles	4	12000	48000
Rice cookers	2	35000	70000
Laminator	3	35000	105000
Emergency bulbs	12	15000	180000
Fluorescent tube	15	2500	37500
Total expenditure			8680500

of 1 kW system converter was pegged at $ 200, while the replacement cost was $ 140. The operation and maintenance cost for a 1 kW converter was set at $ 4 per year which is 2% of capital cost. Figure 1 shows the summary of the entire methodology for the study.

5. Results and Discussion

Energy auditing as a key of improving energy efficiency can be divided into two main groups: improving energy saving of energy sources and improving energy saving at the production or usage level [37]. The study showed that some of the behaviors can lead to energy wastage in a commercial building. For instance, lights were observed to be in use during the day and sometimes the building manager forgot to switch off security lights. It was also observed that the building was poorly designed to ensure maximum utilization of light during the day. Additionally, the building's windows are not well positioned to ensure the natural flow of air in order to reduce energy consumption due to fans. These observations can be solved through the use of automated control systems such as daylight and motion sensors. Furthermore, it is important to civic educate building users to change behavior towards saving energy such as switch off appliances not in use and ensuring that all electric appliances or equipment are switched off when leaving the building premises after work or business. The building design can also be modified to fit low-energy building characteristics.
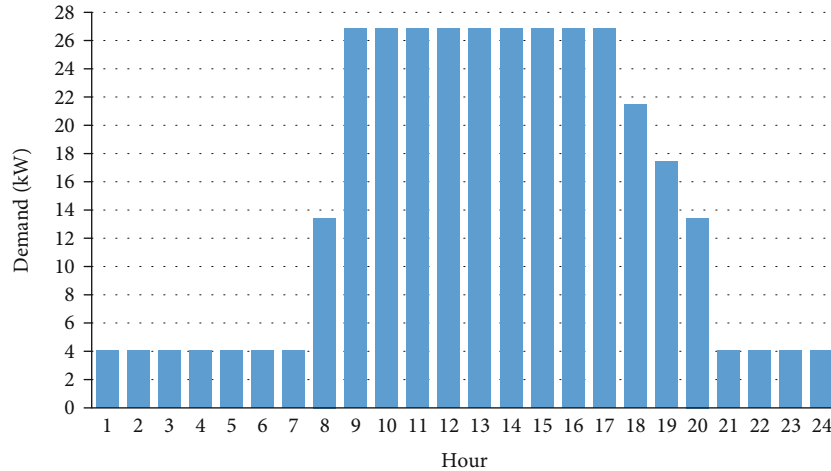
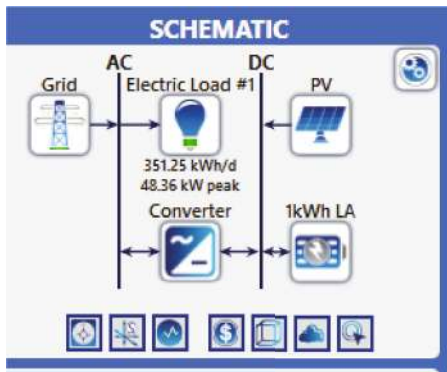FIGURE 4: Daily energy demand for the proposed appliances.

FIGURE 5: Schematic diagram of the energy system.

The building's energy use patterns were studied by estimating the time of operation of each appliance to find daily energy use with respect to rated power. However, a refrigerator labelled 120 W cannot continuously draw 120 W. For instance, a 228-liter fridge consumes 312 kWh per year. Thus, the approximate daily energy consumption for 4 refrigerators is 3.4 kWh. Table 2 shows all appliances used in the building with their corresponding energy consumption.

Energy auditing exercise proposed replacement of some appliances with more efficient ones. Some of the equipment recommended for replacement include fans, air conditioners, printers, TV, computers, laminators, and lighting. Table 3 gives a summary of equipment in the building if recommendations are followed. It also shows their approximate daily energy consumption for the building.

Selected appliances were chosen to compare daily energy saving. It was noted that the air conditioner consumes more energy for the entire building. Significant energy savings were observed in the air conditioner, printer, laminator, and lighting. Figure 2 shows a comparison between current and proposed energy consumption for selected appliances and their significant contribution towards energy saving for the building.

Energy saving for the entire building was also analyzed, and it was noted that the entire building can save about

33.46% of energy. Figure 3 depicts the proportional use of energy for the current energy system with respect to proposed energy use. Table 4 shows the list of recommended appliances with their corresponding prices at market in Malawi Figure 3.

In relation to current appliances in the building, the annual energy consumption was estimated as 38075.34 kWh. However, the cost of energy in Malawi was 0.13 $/kWh resulting in the total annual cost of energy of $ 4949.79. If the building is fully replaced as advised in Table 3, the building's annual energy consumption would be estimated as 25335.38 kWh. This implies that the annual cost of energy was estimated as $ 3293.6. Comparing these two scenarios, the annual energy bill savings is $ 1656.19. Considering the current exchange rate of $ 1 equal to MKW 785, simple payback time in years for the new appliances can be computed as follows:

$$\text{Payback time} = \frac{\text{Total expenditure (MKW)}}{\text{Total savings (\$)} \times 785}$$
$$= \frac{8,680,500}{1656.19 \times 785} = 6.68 \text{ years}$$

(1)

5.1. Energy System Simulation. From the audit results which recommended replacement of some equipment, an alternative energy source was also proposed. Energy demand for the proposed system has a scaled peak load and annual average of 48.3638 kW and 351.250 kWh/d, respectively. Load factor is 0.3026. Figure 4 shows the daily energy demand for the proposed appliances.

The proposed hybrid system is comprised of solar, battery, converter, and grid. This system was designed and simulated using the HOMER software. Figure 5 shows the schematic system design for the proposed energy system in the HOMER software.

From the simulated results as shown in Figure 6, the system requires 107 batteries of 12 V with an autonomy of 2.93 hours. The simulated solar PV capacity was 159 kW with a system converter of 128 kW. Solar PV

FIGURE 6: Optimization results for the proposed system.

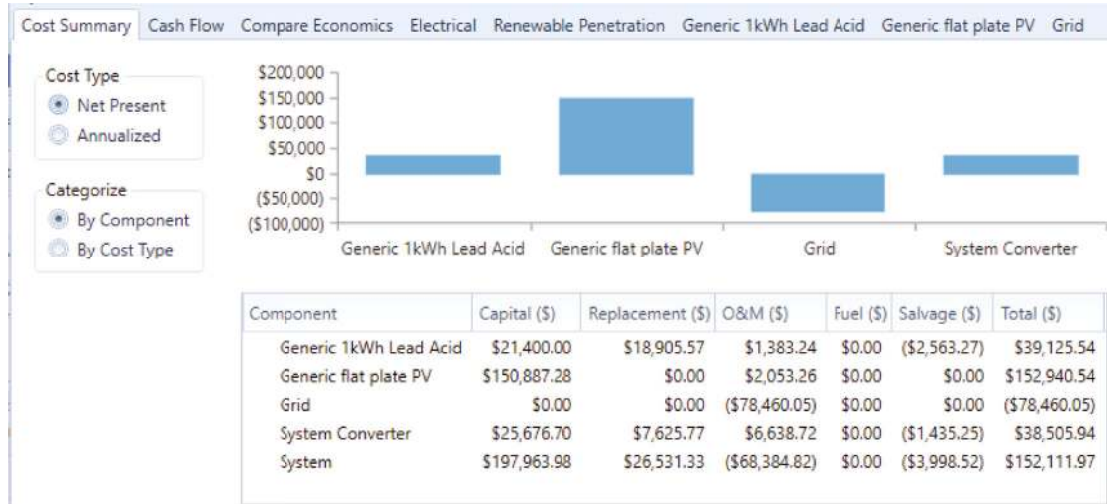| Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 1kWh Lead Acid	$21,400.00	$18,905.57	$1,383.24	$0.00	($2,563.27)	$39,125.54
Generic flat plate PV	$150,887.28	$0.00	$2,053.26	$0.00	$0.00	$152,940.54
Grid	$0.00	$0.00	($78,460.05)	$0.00	$0.00	($78,460.05)
System Converter	$25,676.70	$7,625.77	$6,638.72	$0.00	($1,435.25)	$38,505.94
System	$197,963.98	$26,531.33	($68,384.82)	$0.00	($3,998.52)	$152,111.97

FIGURE 7: Economic summary of energy proposed system.
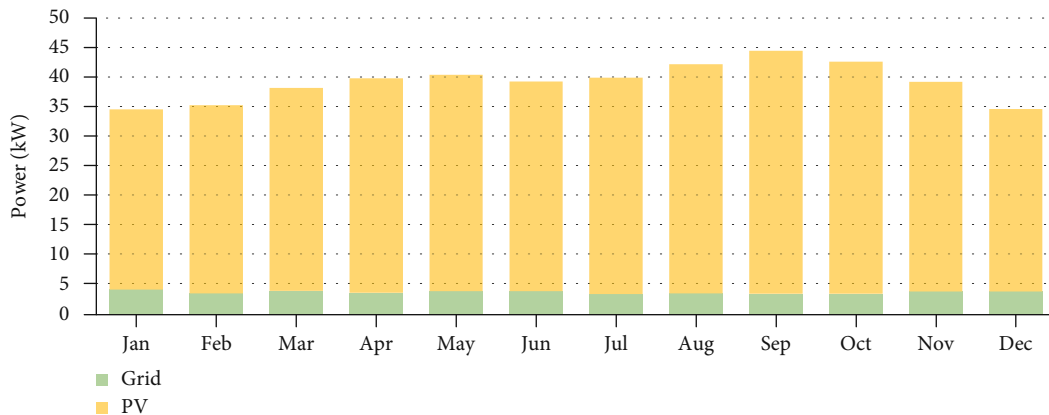

FIGURE 8: Monthly average electricity production.

system installation will result in reduced energy purchase from the grid. The building will require 33,324 kWh per year which is representing 9.66% of the annual required energy. The proposed system has a simple payback period of 9.8 years. The system's cost of energy was estimated as 0.0372 $/kWh, and the capital cost was $ 150,887. Figure 7 shows an economic summary of the energy proposed system, while Figure 8 shows the monthly average electricity production for the system.

6. Recommendations and Conclusion

Energy auditing has proven to be an effective way of determining energy losses and come up with action plan to conserve energy. This paper has shown that Pagwanji commercial building can save energy up to 33.46% if the building replaces some of the appliances with more efficient ones. Replacement of appliances in the building has a payback time of 6.68 years. This means that saved energy can

be available to other electricity users. Additionally, if more companies and buildings can follow this energy conservation technique, then saved energy will also enormously be available for other users. The study also recommended the use of renewable energy. Therefore, a feasibility study was conducted on the possibility of incorporating solar and battery to the existing grid system. The HOMER software was employed to design, optimize, and analyze a solar-battery-grid-connected energy system. The proposed system had a simple payback period of 9.8 years. The system's cost of energy was estimated as 0.0372 $/kWh, and the capital cost was $ 150,887.

The National Energy Policy (2018) recognized the numerous challenges in the energy sector. Therefore, its overall goal is to provide a guiding framework for increased access to affordable, reliable, sustainable, efficient, and modern energy for all sectors and every person in the country. One of the priority areas for action includes demand-side management issues with the aim of enhancing the efficient and sustainable utilization of energy resources. Therefore, this study is in agreement with the national energy policy for Malawi to reduce energy challenges [38].

Other recommendations include the following:

(i) Civic educating the users on the importance of saving energy and how best they can behave to save it

(ii) Employ the use of automated systems such as light and motion sensors to save energy

(iii) Refrigerator: avoid running the refrigerators when its empty. Avoid frequent opening of refrigerator doors

(iv) Fans and air conditioners: use fans and air coditioners during the time of need only. Switch them off during the night when occupants are in their homes

(v) Printers: switch off the printers when printing is done

(vi) TV: switch off TVs when not in use for example during the night

(vii) Laptops and computers: use the most recent computers which are more energy saving. Use portable Laptops when doing simple tasks

The analysis can be further improved, and the system economy can be determined more precisely if more related data like real-time energy consumption are monitored. It is also necessary to conduct a comparative study to know if the use of solar PV with battery is technically and economically profitable.

Data Availability

Meteorological data for the site was obtained from NASA database using the HOMER software at the following coordinates: Latitude of 13 degrees 48.00 minutes South and Longitude of 32 degrees 53.58 minutes East.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] M. Kaddari, M. El Mouden, and A. Hajjaji, "Reducing energy consumption by energy management and energy audits in the pumping stations," in *2018 Renewable Energies, Power Systems & Green Inclusive Economy (REPS-GIE)*, pp. 1–6, Casablanca, Morocco, 2018.

[2] B. Pakkiraiah and G. D. Sukumar, "Research survey on various MPPT performance issues to improve the solar PV system efficiency," *Journal of Solar Energy*, vol. 2016, 20 pages, 2016.

[3] M. Karabulut, H. Kusetogullari, and S. Kivrak, "Outdoor performance assessment of new and old photovoltaic panel technologies using a designed multi-photovoltaic panel power measurement system," *International Journal of Photoenergy*, vol. 2020, 18 pages, 2020.

[4] R. Chhetri, K. Wangchuk, and M. K. S. Sastry, "Home energy audit: a case study of Phuentsholing, Bhutan," in *2014 Fourth International Conference on Communication Systems and Network Technologies Home*, pp. 1022–1025, Bhopal, India, 2014.

[5] A. Boharb, A. Allouhi, R. Saidur et al., "Auditing and analysis of energy consumption of an industrial site in Morocco," *Energy*, vol. 101, pp. 332–342, 2016.

[6] Y. Dong, X. Cui, X. Yin, Y. Chen, and H. Guo, "Assessment of energy saving potential by replacing conventional materials by cross laminated timber (CLT)—a case study of office buildings in China," *Applied Sciences*, vol. 9, no. 5, p. 858, 2019.

[7] G. N. Lalith Pankaj Raj and V. Kirubakaran, "Energy efficiency enhancement and climate change mitigations of SMEs through grid-interactive solar photovoltaic system," *Applied Sciences*, vol. 2021, pp. 1–19, 2021.

[8] A. Boharb, A. Allouhi, A. Jamil, and A. Benbassou, "Analysis of the Electrical Energy Consumption and Energy Audit of Interior Lighting for an Industrial Site in Morocco," in *2015 3rd International Renewable and Sustainable Energy Conference (IRSEC)*, Marrakech, Morocco, 2015.

[9] R. Tilwani and C. Sethuraman, "Energy savings potentials in buildings through energy audit A case study in an Indian building," in *2015 IEEE International Conference on Technological Advancements in Power & Energy Energy*, pp. 289–293, Kollam, India, 2015.

[10] J. Zhang, N. Zhou, A. Hinge, and W. Feng, "Zero-energy buildings – an overview of terminology and policies in leading world regions," in *ECEEE Summer study proceedings*, pp. 1299–1312, Hyères, France, 2015.

[11] APEC, *APEC 100 Best Practice Analysis of Nearly/Net Zero Energy Building*, China, 2017.

[12] R. Banerjee, "Importance of net zero energy building," *International Journal of Innovative Research in Advanced Engineering*, vol. 2, no. 5, pp. 141–145, 2015.

[13] G. Habash, D. Chapotchkine, P. Fisher, A. Rancourt, R. Habash, and W. Norris, "Sustainable design of a nearly zero energy building facilitated by a smart microgrid," *Journal of Renewable Energy*, vol. 2014, 11 pages, 2014.

[14] J. Persson, *Low-Energy Buildings: Energy Use, Indoor Climate and Energy Use, Indoor Climate and Market Diffusion*, KTH–Royal Institute of Technology, School of Chemical Science and Engineering Department, 2014.

[15] S. W. Chisale and Z. Sari, "Design of stand-alone solar-wind-hydro based hybrid power system: case of rural village in Malawi," *Journal of Energy Research and Reviews*, vol. 3, no. 3, pp. 1–16, 2019.

[16] S. William Chisale, J. Stanley Mlatho, E. Manirambona, and S. Richard Chikabvumbwa, "Design of a pelton turbine for a specific site in Malawi," *International Journal of Sustainable and Green Energy*, vol. 9, no. 3, pp. 65–72, 2020.

[17] Malawi Government, *Support to SE4ALL Country Actions Processes in Malawi Action Agenda*, Deloitte & ECONOLER, Lilongwe, 2017.

[18] MRA, Malawi Revenue Authority, *Amendments to the customs and excise (TARIFFS) order*, 2020, https://www.mra.mw/press-releases/amendments-to-the-customs-and-excise-tariffs-order. Dec. 20, 2020.

[19] H. A. Kefale, E. M. Getie, and K. G. Eshetie, "Optimal design of grid-connected solar photovoltaic system using selective particle swarm optimization," *International Journal of Photoenergy*, vol. 2021, 9 pages, 2021.

[20] N. M. Kumar, M. S. P. Subathra, and J. E. Moses, "On-grid solar photovoltaic system: components, design considerations, and case study," in *2018 4th International Conference on Electrical Energy Systems (ICEES)*, pp. 616–619, Chennai, India, 2018.

[21] A. Kumar, N. Gupta, and V. Gupta, "A comprehensive review on Grid-TiedSolar photovoltaic system," *Journal of Green Engineering*, vol. 7, no. 1, pp. 213–254, 2017.

[22] R. J. C. Pinto, S. J. Pinto Simões Mariano, and M. d. R. A. Calado, "Power quality experimental analysis on rural home grid-connected PV systems," *International Journal of Photoenergy*, vol. 2015, 8 pages, 2015.

[23] V. Ramachandran, M. K. Shah, and T. Moss, *How Do African Firms Respond to Unreliable Power? Exploring Firm Heterogeneity Using K-Means Clustering*, Center for Global Development Working Paper, Washington, DC, 2018, https://www.cgdev.org/publication/how-do-african-firms-respond-unreliable-power-exploring-firm-heterogeneity-using-k-means.

[24] A. Arya, P. Arunachalam, and M. G. R. Educational, "Review on industrial audit and energy saving recommendation in aluminium industry," in *2016 International Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT)*, pp. 758–764, Kumaracoil, India, 2016.

[25] A. Chakraborty, D. Dey, and P. Das, "Investigation of energy consumption and reservation scheme using energy auditing techniques," in *2018 International Conference on Smart Systems and Inventive Technology (ICSSIT)*, pp. 34–38, Tirunelveli, India, 2018.

[26] P. S. Magdum, S. R. Lokhande, P. M. Maskar, and I. D. Pharne, "A case study: energy audit at commercial and educational building," in *2017 IEEE international conference on power, control, Signals and Instrumentation Engineering (ICPCSI)*, pp. 1360–1364, Chennai, India, 2017.

[27] R. Rayhana, A. U. Khan, T. Hassan, R. Datta, and A. H. Chowdhury, "Electric and Lighting Energy Audit : A Case Study of Selective Commercial Buildings in Dhaka," in *2015 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE)*, Dhaka, Bangladesh, 2019.

[28] I. Panhwar, A. R. Sahito, and S. Dursun, "Designing off-grid and on-grid renewable energy systems using HOMER Pro Software," *Journal of International Environmental Application and Science*, vol. 12, no. 4, pp. 270–276, 2017.

[29] M. Nurunnabi and N. K. Roy, "Grid connected hybrid power system design using HOMER," in *Proceedings of 2015 3rd International Conference on Advances in Electrical Engineering*, pp. 19–22, Dhaka, Bangladesh, 2015.

[30] V. A. Ani, "Feasibility and optimal design of a stand-alone photovoltaic energy system for the orphanage," *Journal of Renewable Energy*, vol. 2014, 8 pages, 2014.

[31] M. Akbari Vakilabadi, A. Afzalabadi, A. Khoeini Poorfar et al., "Technical and economical evaluation of grid-connected renewable power generation system for a residential urban area," *International Journal of Low-Carbon Technologies*, vol. 14, no. 1, pp. 10–22, 2019.

[32] A. A. M. Nureddin, J. Rahebi, and A. Ab-BelKhair, "Power management controller for microgrid integration of hybrid PV/fuel cell system based on artificial deep neural network," *International Journal of Photoenergy*, vol. 2020, 21 pages, 2020.

[33] Alibaba, *BLUESUN solar panel 500 watt system monocrystalline 48 Volts shingled solar panel 500w price eu warehouse stock*, 2021, https://www.alibaba.com/product-detail/Solar-Panel-500-Watt-500w-500w_60772883981.html?spm=a2700.7724857.topad_classic.d_image.40aa4b6dZevmmd. Feb. 28, 2021.

[34] MERA, *Malawi Energy Regulatory Authority*, 2021, https://www.meramalawi.mw/. Apr. 01, 2021.

[35] Alibaba, *lithium iron phosphate 3.2v 206ah battery cell for Solar ESS,EV,Electric forklift*, 2021, https://www.alibaba.com/product-detail/Battery-Solar-Battery-For-Solar-Lithium_1600082255957.html?spm=a2700.7724857.normal_offer.d_title.4c31624d3dlN6d&s=p. Mar. 30, 2021.

[36] Alibaba, *12v 24v 48v solar panel inverter 1kw hybrid solar inverter factory price*, 2021, https://www.alibaba.com/product-detail/Inverter-1kw-Price-5kw-Hybrid-Inverter_1600112163394.html?spm=a2700.7724857.normal_offer.d_title.2d625453m7AxkX&s=p. Mar. 30, 2021.

[37] M. Stamenic, G. Jankes, N. Tanasic, M. Trninic, and T. Simonovic, "Energy audit as a tool for improving overal energy efficiency in Serbian industrial sector," in *2012 2nd International Symposium on Environment-Friendly Energies and Applications (EFEA)*, pp. 118–122, Newcastle Upon Tyne, UK, 2012.

[38] Malawi Government, *National Energy Policy of 2018*, Malawi Government, Lilongwe, 2018.