Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: The case of KNUST, Ghana

Article *in* AEJ - Alexandria Engineering Journal · February 2020

DOI: 10.1016/j.aej.2020.01.011

4 authors:

Richard Opoku
Kwame Nkrumah University Of Science and Technology

Eunice Akyereko Adjei
Kwame Nkrumah University Of Science and Technology

Divine Kwaku Ahadzie
Kwame Nkrumah University Of Science and Technology

Kofi A. Agyarko
Energy Commission

ARTICLE IN PRESS
Alexandria Engineering Journal (2020) xxx, xxx–xxx

HOSTED BY
ELSEVIER

Alexandria University
Alexandria Engineering Journal
www.elsevier.com/locate/aej
www.sciencedirect.com

ORIGINAL ARTICLE

Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: The case of KNUST, Ghana

Richard Opoku [a,b,*], Eunice A. Adjei [a], Divine K. Ahadzie [c], Kofi A. Agyarko [d]

[a] *Department of Mechanical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*
[b] *The Brew-Hammond Energy Center, College of Engineering, KNUST, Ghana*
[c] *Department of Settlement Studies, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*
[d] *Energy Efficiency and Renewable Energy Directorate, Ghana Energy Commission, Ghana*

Received 28 October 2019; accepted 8 January 2020

KEYWORDS
Energy efficiency;
Energy conservation;
Solar energy;
Electricity cost savings;
Cost of conserved energy

Abstract High electricity consumption and corresponding cost in public tertiary institutions in many developing countries is a major challenge to their respective governments. Low efficiency electrical appliances are common in these institutions. In this work, studies have been conducted on sustainable energy efficiency measures and solar energy to reduce electricity cost in public tertiary institutions with a case study at the Kwame Nkrumah University of Science and Technology, Kumasi-Ghana. Energy audits as well as actual measurements of power consumptions of some selected electrical appliances using power quality analyzers were conducted. The result showed that there is total electricity savings opportunity of 163,400 kWh ± 5% per month by implementing energy efficiency retrofitting for the air-conditioners, lighting systems and ventilation fans for the faculty areas and the main administration buildings. This electricity savings translates to electricity cost reduction of about US$ 37,880 per month. Analysis also showed that the cost of conserved energy for the three electrical appliances are all lower than the utility tariff for KNUST. Considering large-scale solar PV integration in KNUST's energy mix, the financial analysis has revealed that there is opportunity for electricity cost savings of US$ 69.1 million over a 20-year period with payback of 6 years.

1. Introduction

High electricity consumption and cost in public buildings/institutions is a major challenge to many nations over the world, particularly in developing countries [1]. Low-efficient electrical appliances, poor building envelopes and poor energy

* Corresponding author at: Kwame Nkrumah University of Science and Technology (KNUST), Ghana.
E-mail address: ropoku.coe@knust.edu.gh (R. Opoku).
Peer review under responsibility of Faculty of Engineering, Alexandria University.

https://doi.org/10.1016/j.aej.2020.01.011
1110-0168

Please cite this article in press as: R. Opoku et al., Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: The case of KNUST, Ghana, Alexandria Eng. J. (2020), https://doi.org/10.1016/j.aej.2020.01.011

conservation practices are major contributing factors to the high electricity consumption [2–6].

Energy efficiency retrofit interventions and policies [7,8] to reduce electricity consumption and cost have therefore been explored in many countries [7–13] including energy efficiency for building envelopes and windows [14–18]. For example, energy efficiency retrofits in Ghana in 2007 for lighting systems alone by changing incandescent lamps to compact fluorescent lamps (CFL) resulted in peak electricity savings of 124 MW [19]. Studies have also shown that energy efficiency standards and benchmarks for buildings and electrical appliances are crucial in reducing building energy consumption and carbon footprint [20–22]. The use of appropriate energy management technologies and devices [23] can also result in significant reduction in building energy consumption, thereby contributing to climate change mitigation strategies [24].

With increasing pollution from fossil-fuel based electricity generation systems contributing to climate change and its negative impacts on the environment, many countries all over the world are developing programmes and initiatives to reduce their energy consumption and carbon footprint [25] as well as increase their sustainable energy portfolio [26]. For instance, in Europe, Green Building Programmes (GBP) have been developed to promote energy efficiency and the use of renewables in buildings [24,25].

In many developing countries and Ghana in particular, electricity consumption and cost in public buildings including the ministries, departments and agencies (MDAs) as well as public tertiary institutions is a major challenge to the Governments. For example, electricity consumption for the three main public universities in Ghana is averagely over 1000 MWh per month in each of the institutions. High power demand during peak hours (11 am–2 pm) of the day which exceeds their contracted demand usually result in a lot of power fluctuations, distracting academic work. Solar energy that could be used to supplement and provide stable electricity supply during daytime hours has not been explored.

In this work, studies have been conducted on how energy efficiency and solar energy can be used to reduce electricity consumption and cost in public tertiary institutions, with a case study at the faculty areas and main administration of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi-Ghana.

2. Materials and methods

2.1. Electricity consumption in public tertiary institutions in Ghana

There are ten main public universities in Ghana offering different degree programs in engineering, applied sciences, social sciences and humanities, medicine, natural resources, arts and built environment, and the likes. Besides the ten main public universities, there are also eight public technical universities and over twenty private universities in the major cities. Electricity consumption and cost in the public universities is very high and pose a challenge to the respective University management and the central government. Fig. 1 for example shows the monthly mean electricity consumption for the three main premier universities (University of Ghana, Kwame Nkrumah University of Science and Technology, and the University of Cape Coast), with student population of over 45,000 in each of the universities.

From Fig. 1, it is observed that the average consumption in the three institutions is over a threshold of 1500 MWh/month in the months of January – May & September – December (when academic work is in session), and within 1000 – 1500 MWh/month in the months of June – August (when the students are on vacation with reduced activities on the campuses). As already mentioned, the focus of this study is on the energy efficiency, solar energy and cost saving opportunities in the public tertiary institutions with, a case study at the KNUST.

2.2. The KNUST

The Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, is a public university with approximately about sixteen kilometer square land area (16 km^2) occupied with faculty and college buildings, students' halls of residence, lecturers' bungalows, and other service providers and commercial buildings. The University has total students' population of about 45,200 (64% males and 36% females). There are also about 3460 staffs (including teaching and non-teaching staff) [29]. KNUST operates with a collegiate system with six (6) main academic colleges with a central administration that oversees all activities within the University.

The KNUST receives its bulk electricity supply from the Electricity Company of Ghana (ECG) with a contracted demand of 5396.6 kVA through 11 kV substations. The bulk electricity received is then distributed within the university to all the buildings.

2.3. Appliance energy auditing

Appliance energy auditing is the first step in assessing energy efficiency situation, and implementing a successful energy efficiency project in a facility. Energy auditing involves the process of inspection, data collection and analysis of energy flows for identification of energy savings opportunities in a building or a facility to reduce the amount of energy input into it, without negatively affecting the output(s) and with the least environmental effect.

In this study, energy audit (walk through energy audit) was conducted and technical data were collected on the electrical appliances used in the buildings at KNUST. Data on the quantity of appliance, appliance power ratings, power factor, and estimated hours of use were collected. Table 1 for instance presents information on the range of power ratings of the 3 common electrical appliances found in the buildings of which energy efficiency retrofitting can easily be implemented on them.

It is important to mention that data were also taken on other electrical appliances including printers and scanners, office computers, photocopy machines, projectors, etc, in the determination of the total building electricity consumption, however; details of their power ratings have not been presented here since the focus of this study is on the electrical appliances on which energy efficiency can easily be implemented on them.

In addition to the walkthrough energy audit, investment grade energy audit that measures the actual power consumption of the electrical appliances was conducted using energy meters (Fluke 345 power quality analyzer and energy meter

Please cite this article in press as: R. Opoku et al., Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: The case of KNUST, Ghana, Alexandria Eng. J. (2020), https://doi.org/10.1016/j.aej.2020.01.011

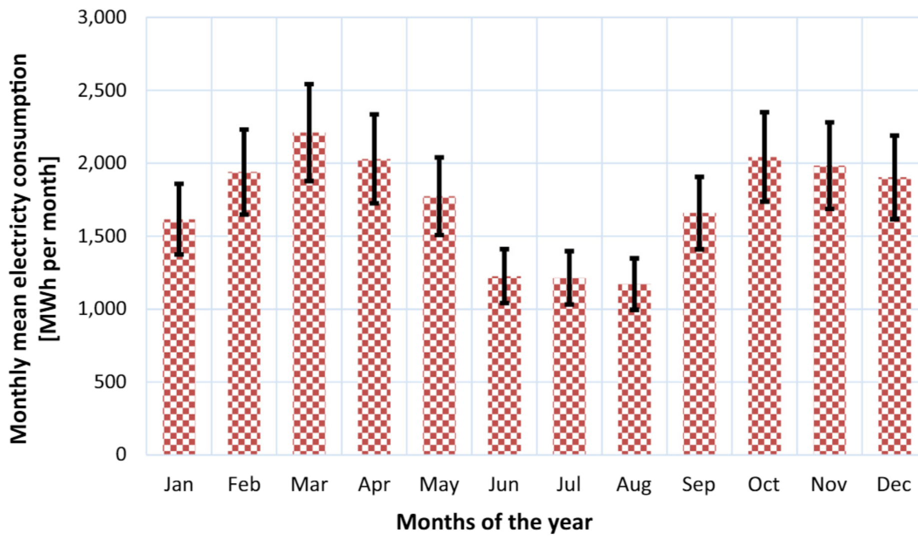


Fig. 1 Electricity consumption in the three premier public universities in Ghana.

board). Fig. 2 shows the experimental setup that was used for the actual power measurement of the electrical appliances.

With the data collected on the power consumption, the electricity consumption (E) of the electrical appliances was determined using Eq. (1).

$$E = \sum_{0}^{T} n \cdot P \cdot \Delta t \qquad (1)$$

where P is the instantaneous power consumption of the appliance, n is the quantity, Δt is the time step for each power measurement and T is the period (hours) of use of the appliance.

2.4. Observations and recommendations for efficient electricity use at KNUST

During the energy audit, identification of key operational issues relating to energy use in the buildings were ascertained. It was found out that energy management devices (motion/occupancy sensors, keycard energy savers, timer switches, etc) which can be used to minimize electricity wastage in buildings have not been explored in the offices or buildings at the faculties and the main administration. The following key recommendations are therefore made regarding installation of energy management technologies:

i. ***Installation of keycard energy savers or occupancy sensors in the offices***. From the energy audit, it was determined that many faculty members do not turn their office appliances OFF when they are outside the office. On the average, faculty members/teaching staff spend about **2.0–3.6 h per day of their time outside the office** for lectures, meetings, and other activities, of which during this time all the energy spent in the office is wasted. This translates to electricity wastage of about 125 kWh/month for offices which use air-conditioners and lighting systems. Installing energy management devices will help to drastically reduce this electricity wastage.

ii. ***Installation of motion sensors in the washrooms at the faculties and the main administration***. Lighting systems at many of the washrooms at the faculty areas are not put OFF when the place is not being used. At sometimes, they are even left ON during the weekends. It is recommended that motion-sensor lighting systems be installed in all the washrooms to minimize electricity wastage.

iii. ***Installation of occupancy sensors in the lecture theatres and the classrooms***. There is huge energy wastage in the classrooms in the daytime during hours of no lectures. The fans and the lights continue to run when there are no students/occupants in the room. It is therefore recommended that occupancy-sensors be installed in all the classrooms to minimize electricity wastage.

iv. ***Installation of timer switches and/or photo sensors to regulate the outdoor lighting systems at the faculty and main administration areas***. It was observed during the energy audit that at many times during sunshine hours, some of the outdoor lighting systems will still be ON when *the sun is so bright in the sky*. Photocells and timer-switches are recommended to be installed to control all outdoor lighting systems.

v. ***Periodic training/workshop for staff on energy conservation opportunities.*** Energy conservation opportunities exist with huge energy consumption reduction potentials. During the data collection, it was observed that many of the staffs are not energy conservative. For instance, air-conditioners could be left ON in the office for over 2–3 h when the staff is in a lecture room or in meeting outside his/her office. It is recommended that energy efficiency education be included during the annual staff workshop programs.

2.5. Analysis of sustainable energy management measures

In any facility, successful implementation of energy management measures requires analysis of the most cost-effective

Table 1 Power ratings of common electrical appliances found in the offices.

Appliance	Power ratings	Picture	
Lighting	15–45 Watt Compact Fluorescent Lamps (tubular & spiral type CFLs). Usually for indoor use.		
	85–105 W CFLs (octagonal tubular type). For outdoor use in the corridors, and some used indoor for the laboratories and auditoria.		
	36 W T8 fluorescent lamp. Used in some offices and corridors		
Fan	60–120 W. Used in the classrooms, some offices and laboratories	 120 W ceiling fan in one of the offices	
Air-conditioners	1200–3400 W (Offices) 3000–8870 W (multiples of them in the conference rooms and auditoria)		

and sustainable options to achieve the desired energy efficiency targets and savings. In this study, the concept of "***cost of conserved energy (CCE)***" that annualizes the energy efficiency investment to the annual energy savings was used [27,28]. The CCE is an investment metric that is well suited for analysis of energy conservation investments [30]. The cost of conserved energy (CCE) is computed by Eq. (2) [31]:

$$CCE = q \cdot \frac{I}{E_s} \tag{2}$$

where q is the capital recovery factor, I is the annualized additional cost of purchasing the higher efficiency equipment, and Es is the annual energy savings. The capital recovery factor can be computed by Eq. (3).

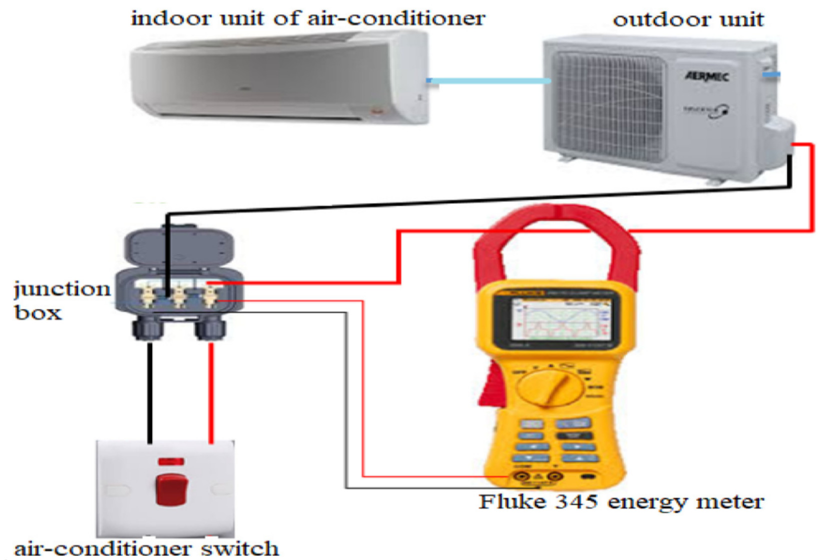
$$q \cdot = \frac{r}{1-(1+r)^{-L}} \tag{3}$$

where r is the discount rate and L is the average lifetime of the appliance.

In the present study, analysis was also conducted on the financial viability of grid-connected solar PV system for faculty and main administration buildings at KNUST. The total life cycle costs (LCC) of the solar PV system was computed using Eq. (4) [32].

$$\mathrm{LCC} = I + \sum_{n=1}^{20} (OMR_n + CE_n) \tag{4}$$

where I is the total initial investment cost for the solar PV energy system; OMR_n is the cost of operation, maintenance and repairs for the energy system in year n; and CE_n is the cost of additional grid electricity supplied which is unmet by PV power supply.



(a) Setup for reading power consumption of air-conditioner

(b) Power consumption measurement of an LED bulb reading 28.6 W

Fig. 2 Measurement of power consumptions of some appliances.

Data gathered from the energy audit, as well as that of appliance prices on the market were analysed and the results are presented in the following sections.

3. Results and discussions

3.1. Electricity consumption by appliance type

As already indicated, the scope of the present study is to analyze how energy efficiency and solar energy can be used to reduce electricity consumption and improve power supply reliability at the faculty areas and the main administration of the KNUST. From the analysis of the energy audit data collected on the electrical appliances, and the electricity bills obtained from the utility company, it is determined that the total electricity consumption of the faculty areas and the main administration buildings alone is 707.4 MWh ± 12% per month. The remaining electricity consumption of over 1000 MWh per month out of the total consumption (see Fig. 1) is consumed by the students' halls of resident and other commercial buildings on campus.

Fig. 3 shows the percentages of the total electricity consumption (707.4 MWh ± 12% per month) by appliance type for all the buildings considered at the faculties and the main administration.

From the study result presented in Fig. 3, it is observed that air-conditioners are the highest electricity consuming appliances (62% ± 3.2%) for the buildings considered, followed by lighting (16% ± 2.5%), and ventilation fans (10% ± 3%). The 12% electricity consumption by other appliances is

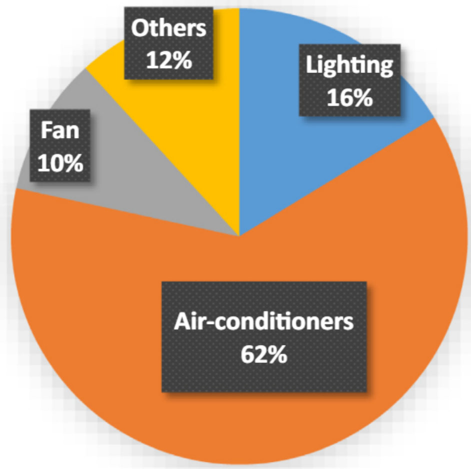


Fig. 3 Average percentage of electricity consumption by appliance type.

for the office computers; desktop printers; photocopier machines; as well as table-top refrigerators found in some of the departmental/administrative offices.

3.2. Reducing energy consumption through energy efficiency measures

3.2.1. Energy efficiency for lighting systems

During the energy audit, it was observed that many of the lighting systems were energy efficient LED lamps (18 Watt T8 fluorescent lamps, and 15–40 Watt LEDs). However, few of the offices, classrooms, washrooms and the laboratories (24%) are still using the compact fluorescent lamps (CFLs) with relatively high power ratings between 85 and 105 Watt, and the 4 feet T8 fluorescent lamps of 40 Watt power rating. For the 24% lighting systems yet to receive energy efficiency retrofit, the following replacement recommendations are made (Table 2) with their lighting efficacy.

Table 2 Recommended energy efficiency measure for lighting systems.

Old Incandescent/ CFL Bulb to Replace	Typical LED Replacement	Recommended Minimum Lighting Efficacy (Lumens/ Watt)
40 Watts	11–15 Watts	45 or more
60 Watts	15–20 Watts	60 or more
75 Watts	20–25 Watts	60 or more
85–105 Watts	30–40 Watts	60 or more

3.2.2. Energy efficiency for ventilation fans

It was also observed during the energy audit that ventilation fans installed in the offices and classrooms of the new buildings were relatively energy efficient with power rating between 60 and 70 Watt compared to the fans in the old buildings. Some of the fans in the old classrooms and the laboratories are the old type with high power consumption of 120–150 Watt. More energy efficient fans with power consumptions of 40–50 Watt with equivalent ventilation efficiency are available on the market. Fig. 4 shows samples of the high energy consuming old fans and the energy efficient new fans.

3.2.3. Energy efficiency for air-conditioners

From the energy audit, a total of 2133 working air-conditioners were counted (as at November 2018) in the buildings under study. It was observed that many of the air-conditioners used in the colleges and the main administration are not energy efficient. They are either the old-type window air-conditioners with very high electricity consumption or the low-star split-type air-conditioners (1-star) with electricity consumption more than 3000 kWh per year. Fig. 5 for example shows some samples of the energy performance ratings (from the labels) of the air-conditioners installed in the offices with their average electricity consumptions in kWh per year.

From the energy audit conducted on the electrical appliances installed in the buildings, the air-conditioners were the appliances which were least energy efficient compared to international and national minimum energy performance standards [33].

Over 80% of the air-conditioners have 1-star rating, which is the minimum rating for air-conditioner equipment in Ghana. It was also determined that modern energy efficient air-conditioners which use the inverter technology (variable speed compressors) with huge energy savings potential have not been fully explored at KNUST.

For modern split-type energy efficient air-conditioners (inverter technology), the electricity consumption is usually 1600 kWh/year or less (Fig. 6), with comparable cooling effect as the conventional single speed compressor air-conditioners with 3600–5400 kWh/year electricity consumption.

It is important to note that the annual energy consumption of air-conditioners as specified by the Ghana Standard Board

(a) 120 W old ceiling fan

(b) 40-50 W fan

Fig. 4 (a) Old ventilation fans (120 W); and (b) new energy efficient fans (40–50 W).

4,139 kWh/yr Samsung AC

3,604 kWh/yr Chigo AC

5,475 kWh/yr Samsung AC

Fig. 5 Energy consumption of common air-conditioners installed in the offices.

Fig. 6 Inverter technology air-conditioner.

(GS 362:2001) is based on 2000 h of use per year [33]. The actual energy consumption may differ from the name plate energy consumption depending on the use of the appliance and the environmental conditions.

In this study, the electricity consumption of an inverter air-conditioner (variable speed inverter technology) and a conventional air-conditioner (single speed technology- which is common at KNUST) with similar cooling capacities were measured using an energy meter (power quality analyzer). Fig. 7 shows the electricity consumption of the 2 air-conditioners for normal office working hours.

From Fig. 7, it is observed that the average power consumption of the energy efficient variable speed inverter air-conditioner was about 1 kW (1000 Watt). The power consumption of the conventional single speed air-conditioner of similar cooling capacity was about 1.5 kW (1500 Watt). That is, the inverter air-conditioner has power consumption saving potential of 0.5 kW (500 Watt) compared to the conventional ones, translating to electricity savings of 4 kWh per day (for an office working 8 h per day). This results in 88 kWh electricity savings potential per month. An average of 22 days was used to compute the monthly electricity consumption considering the air-conditioner being used on only the weekdays during office hours.

3.3. Electricity savings opportunity at KNUST

Based on the findings of the energy audit conducted, electricity savings opportunities using a 5-year energy efficiency retrofitting programme is proposed:

i. 20% penetration of energy efficient air-conditioners per annum. Inverter technology or 3–5-star air-conditioners should be considered. 1-star and 2-star air-conditioners should not be considered for the energy efficiency programme.
ii. All incandescent and CFLs with high power ratings should be replaced according to recommendations in Table 2 above.
iii. All old inefficient fans (120–150 Watt) in the classrooms and the laboratories should be replaced with 40–50 Watt energy efficient fans.

Analysis was then conducted using the RETScreen software energy efficiency modeling tool, considering the implementation of the proposed energy efficiency retrofitting measures. Fig. 8 shows the potential reductions in electricity consumption in the buildings.

From the analysis of energy efficiency retrofitting, the following energy savings potential are achievable at the end of the 5 years (Table 3).

Please cite this article in press as: R. Opoku et al., Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: The case of KNUST, Ghana, Alexandria Eng. J. (2020), https://doi.org/10.1016/j.aej.2020.01.011

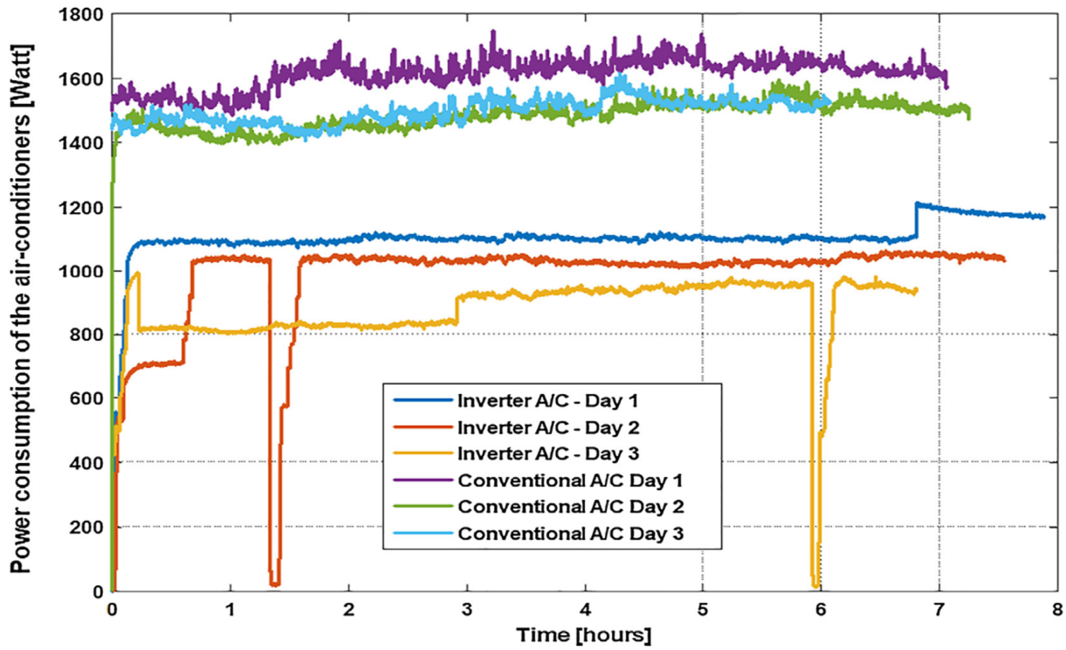


Fig. 7 Power consumption of inverter technology and conventional air-conditioners.

From the result of Table 3, total monthly electricity reduction of about 163,400 kWh is achievable with the energy efficiency retrofitting of the air-conditioners, lighting systems and fans at the end of the proposed energy efficiency retrofitting measures. This translates to estimated electricity cost savings of about US$ 37,880 per month (with levies and demand charges included), based on utility tariffs in Ghana. The percentage reduction in electricity consumption for the three electrical appliances (17–30%), as a result of the energy efficiency measures is consistent with similar studies conducted by [34–37].

Table 3 Electricity savings opportunities with energy efficiency retrofitting.

Item	Air-conditioners	Lighting	Fan
Before energy efficiency retrofitting (kWh/month)	423,080	113,176	70,735
After energy efficiency retrofitting (kWh/month)	295,588	88,975	59,004
Percentage reduction in electricity consumption	30%	21%	17%

To determine the financial viability of the energy efficiency measures, the cost of conserved energy (CCE) was computed for the appliances and then compared with the utility electricity tariffs. Fig. 9 shows the CCE for the three electrical appliances of which energy efficiency measures are to be implemented on them.

The result of Fig. 9 shows that for all the three electrical appliances considered for energy efficiency measures, the

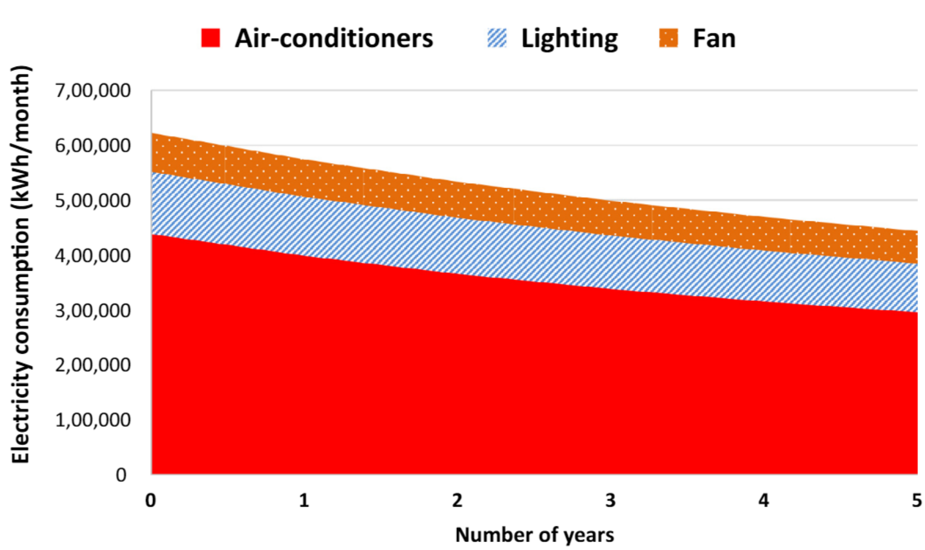


Fig. 8 Reduction in electricity consumption with energy efficiency retrofitting.

CCE is lower than the average unit cost of utility electricity for special load tariffs (SLTs) in Ghana. KNUST is charged with electricity prices for SLTs because its demand is higher than 100 kVA. The CCE analysis shows that there is higher opportunity cost savings with lighting systems followed by air-conditioners (ACs) and then ventilation fans.

3.4. Diversifying power supply and improving reliability with solar energy

3.4.1. Solar energy for the buildings

Solar energy has been determined as one of the most cost-competitive and sustainable energy options for KNUST [38]. From a previous study [39], it was determined that the total rooftop area (56,000 m^2) of KNUST buildings on campus can accommodate solar PV installation of about 7800 kWp (7.8 MWp). Using the solar resource available at the study site, the potential solar PV electricity generation of an installed 7.8 MWp was therefore assessed using RETScreen simulation package. The result of the monthly solar PV electricity generation is shown in Fig. 10. For the purpose of comparison, the monthly mean electricity consumption at the faculties and the main administration, as well as the total electricity consumption of all buildings on campus are also shown in Fig. 10.

The result of Fig. 10 shows that the monthly solar PV electricity generation potential of the 7.8 MWp solar PV system is between 500 and 820 MWh/month. Comparing the PV electricity generation to the total electricity demand of the KNUST, it is analysed that the PV generation can meet between 32% and 54% of the total demand depending on the month of the year. For the consumptions at the faculties and the main administration buildings, the PV electricity generation can meet 85–100% depending on the month of the year. It is to be noted that the total 7.8 MWp solar PV system

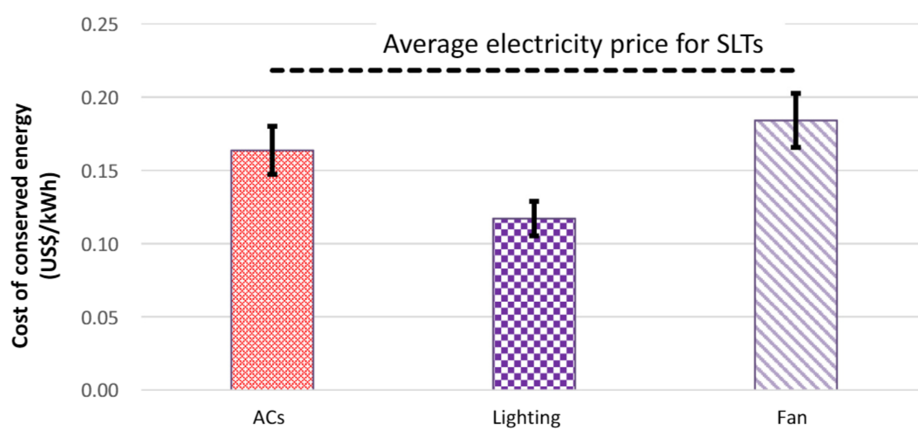


Fig. 9 Cost of conserved energy for higher efficiency measures.

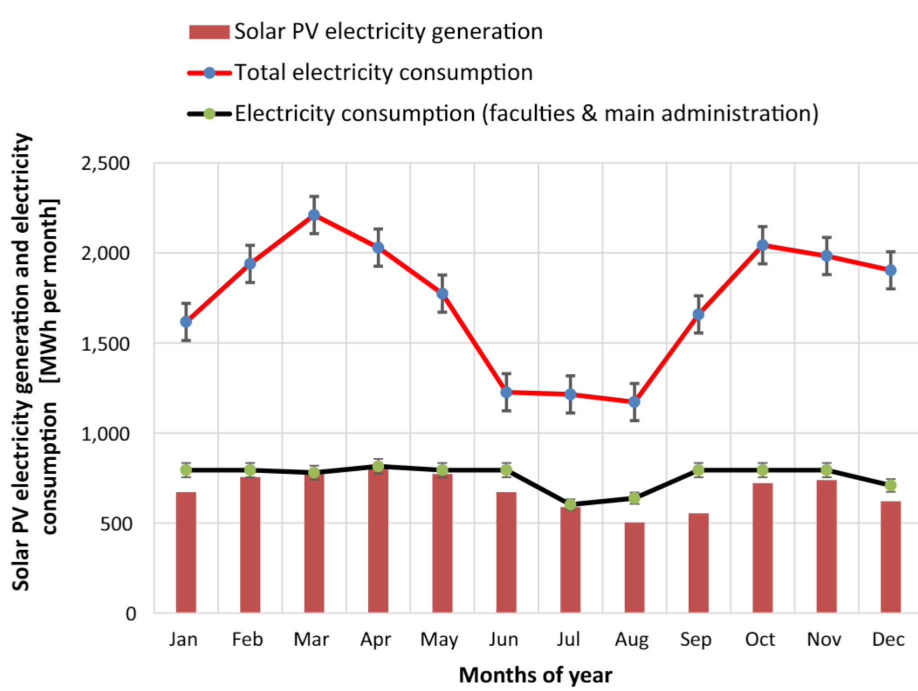


Fig. 10 Solar PV electricity generation potential with KNUST building rooftop.

that can be installed would have to be sub-divided into multiple solar systems (kWp) and installed on individual buildings based on the building energy demand.

As part of plans to advance the solar energy drive of the KNUST, an initial 20 kWp grid-tied solar PV system was installed in 2012 at the Professorial building at the College of Engineering (Fig. 11, with 5 different solar PV cell technologies [38]), and in 2016, another set of 24 kWp was installed at the Engineering auditorium, all to obtain field data in order to plan a sustainable University-wide solar rooftop programme. Fig. 12 shows the electricity generation from the combined 44 kWp grid-tied solar PV system.

The result of Fig. 12 shows that the measured monthly solar PV electricity generation from the combined 44 kWp system is in the range of 2.8–4.5 MWh per month with total annual generation of 45.1 MWh. Analysis of other performance parameters revealed average specific energy yield of 1100 kWh/kWp and performance ratio of 69.2%. The grid-tied solar system at the College, in addition to its energy generation benefits, has given the facility managers the first hand training and experience in understanding and managing such systems when fully rolled-out in the University.

3.4.2. *Solar PV for street lighting*

At KNUST, electricity for campus street lighting is significant with proportion of 5–7% of total electricity demand. The University is therefore embarking on solar energy for campus street-light. From 2016 to 2019, a total of 310 solar street-lights have been installed with total panel capacity of 37.2 kWp. Analysis conducted has revealed that about 9700–10,800 kWh per month of utility grid electricity has been displaced with the solar street-lighting systems.

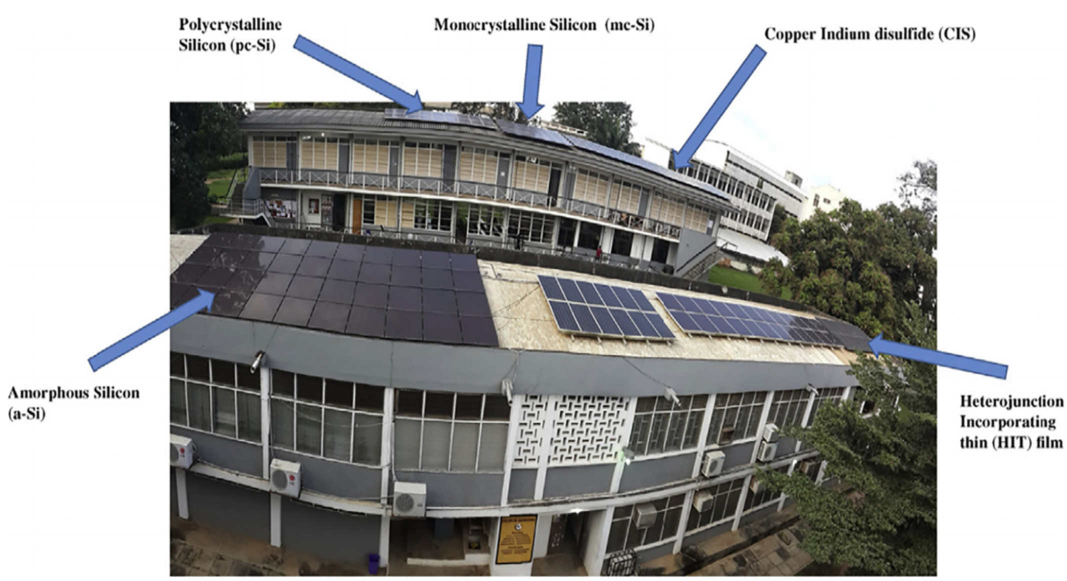


Fig. 11 A 44 kWp solar installation at College of Engineering, KNUST.

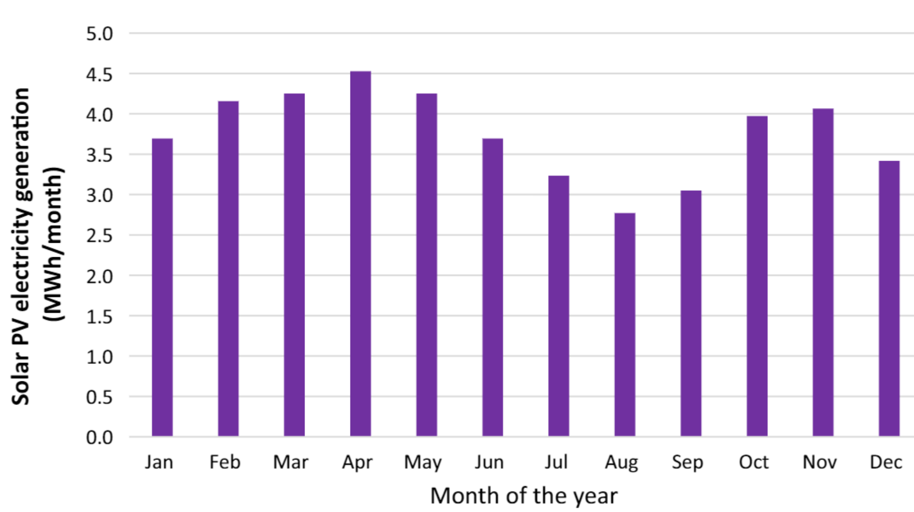


Fig. 12 Electricity generation from combined 44 kWp grid-tied solar PV system at KNUST.

Please cite this article in press as: R. Opoku et al., Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: The case of KNUST, Ghana, Alexandria Eng. J. (2020), https://doi.org/10.1016/j.aej.2020.01.011

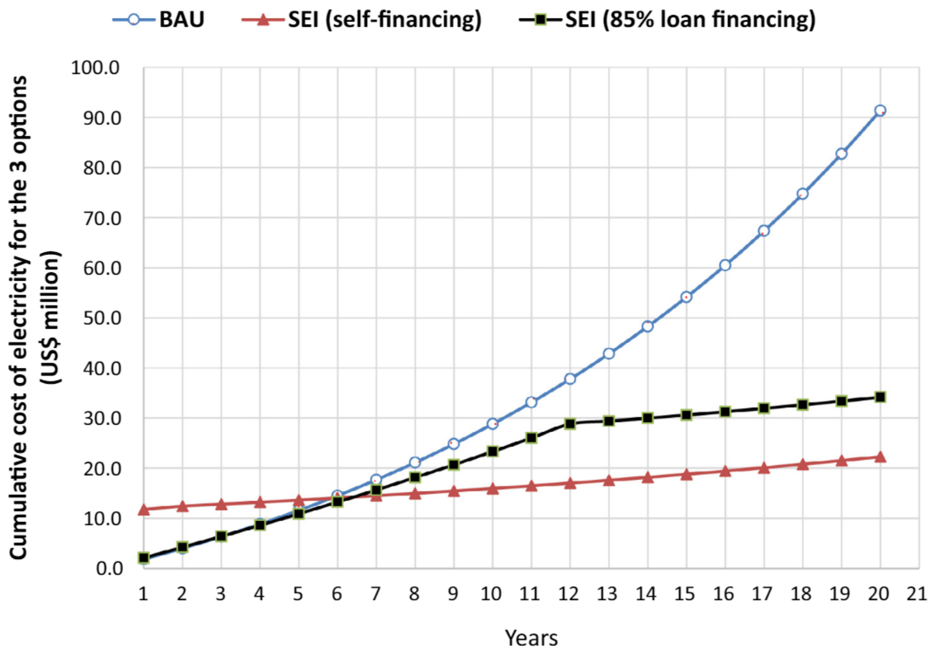


Fig. 13 Comparative cost analysis of solar energy integration and utility grid electricity.

3.5. Financial analysis of large-scale solar energy integration at KNUST

In order to ascertain the financial viability of the proposed integration of the 7.8 MWp solar PV energy system into KNUSTs energy mix, life-cycle cost analysis was conducted using prevailing prices on the local market. Average costs of materials and installation obtained from registered vendors with Ghana Energy Commission, who have installed similar roof-top grid-tied solar PV systems in other facilities in Ghana were used. In addition, a financing package presented by Nordic Energy Developers, Norway, with 85% loan financing was analyzed.

Fig. 13 shows the comparative cost analysis over a-20 year period for the solar energy integration (SEI), against if things operate as usual with utility grid electricity (business as usual - BAU). For the BAU case with 100% utility grid electricity, the total consumption at the faculties and the main administration of 707.4 MWh ± 12% per month (as presented in Section 3.1) was used for the analysis. The other facilities on campus (mainly students' halls of residence) were not considered for the solar PV integration because of the absence of net-metering systems and feed-in-tariffs, and the fact that significant of their loads are in the evenings which do not make solar energy option for such facilities cost competitive.

From the result of Fig. 13, it is observed that solar energy integration has huge opportunity to reduce electricity cost at KNUST faculty and main administration areas compared to if the University continues to run business as usual. The result is comparable to a study by Geber et al., [40], where grid-tied PV was used to reduce electricity costs in South African schools

The analysis has revealed that the payback period is about 6 years, and with total potential electricity cost savings of US$ 69.1 million at the end of a 20 year period analyzed in this study, under self-financing mechanism. The analysis has also revealed that financing the solar project with 85% loan from Nordic Energy Developers at interest rate of 4.5% per annum for 12 years has the potential electricity cost savings of US$ 57.2 million at the end of the 20 years life cycle.

4. Conclusions

In this work, studies have been conducted on energy efficiency, solar energy and electricity cost savings opportunities at the KNUST. From the results, the following conclusions are made:

i. Many of the air-conditioners installed in the offices at the faculties and the main administration are not energy efficient and are dominated with low star ratings (1-star ratings). Replacing these air-conditioners in the short-to-medium term (upto 5 years) with modern energy efficient inverter air-conditioners has the total potential electricity savings of about 127,490 kWh per month.
ii. There is total potential electricity savings of about 163,400 kWh ± 5% per month by implementing energy efficiency retrofitting for the air-conditioners, lighting systems and fans installed at the faculty and the main administration buildings of the KNUST. This electricity savings translates to electricity cost savings of about US $ 37,880 per month.
iii. Financial analysis has revealed that there are electricity cost saving opportunities of US$ 69.1 million and US$ 57.2 million for the integration of solar energy under self-financing and 85% loan financing schemes respectively.

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

Acknowledgement

The authors would want to thank the Office of Grants and Research at the Kwame Nkrumah University of Science and Technology for providing funds to undertake this study.

References

[1] K. Bos, D. Chaplin, A. Mamun, Benefits and challenges of expanding grid electricity in Africa: a review of rigorous evidence on household impacts in developing countries, Energy Sustain. Dev. 44 (2018) 64–77.
[2] S.S. Nunayon, Dataset on the patterns of electricity consumption in public universities in southwestern Nigeria, Data Br. 21 (2018) 1–7.
[3] S. Gyam, F.A. Diawuo, E.N. Kumi, F. Sika, The energy efficiency situation in Ghana, Renew. Sustain. Energy Rev. 82 (2018) 1415–1423.
[4] Y. Ding, Z. Zhang, Q. Zhang, W. Lv, Z. Yang, N. Zhu, Benchmark analysis of electricity consumption for complex campus buildings in China, Appl. Therm. Eng. 131 (2018) 428–436.
[5] D.A. Chwieduk, Towards modern options of energy conservation in buildings, Renew. Energy 101 (2017) 1194–1202.
[6] Y. Wang, J.M. Kuckelkorn, F. Zhao, M. Mu, D. Li, Evaluation on energy performance in a low-energy building using new energy conservation index based on monitoring measurement system with sensor network, Energy Build. 123 (2016) 79–91.
[7] N. Kerr, A. Gouldson, J. Barrett, The rationale for energy efficiency policy: Assessing the recognition of the multiple benefits of energy efficiency retrofit policy, Energy Policy 106 (2017) 212–221.
[8] K. Carlson, K.D. Pressnail, Value impacts of energy efficiency retrofits on commercial office buildings in Toronto, Canada, Energy Build. 162 (2018) 154–162.
[9] G. Ding, X. Ying, Embodied and operating energy assessment of existing buildings- demolish or rebuild?, Energy 182 (2019) 623–631.
[10] T. Örn, A. Luciani, A. Rizzo, Energy-efficiency measures for heritage buildings: a literature review, Sustain. Cities Soc. 45 (2019) 231–242.
[11] A. Galatioto, R. Ricciu, T. Salem, E. Kinab, Energy and economic analysis on retrofit actions for Italian public historic buildings, Energy 176 (2019) 58–66.
[12] N. Ginks, B. Painter, Energy retrofit interventions in historic buildings: Exploring guidance and attitudes of conservation professionals to slim double glazing in the UK, Energy Build. 149 (2017) 391–399.
[13] Y. Ding, Q. Wang, Z. Wang, S. Han, N. Zhu, An occupancy-based model for building electricity consumption prediction: a case study of three campus buildings in Tianjin, Energy Build. 202 (2019) 109412.
[14] E. Alkhateeb, B. Abu-hijleh, Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB), Heliyon 5 (2020) e01971.
[15] M. Abdul, O.S. Alshamrani, Prospects of energy conservation and management in buildings – the Saudi Arabian scenario versus global trends, Renew. Sustain. Energy Rev. 58 (2016) 1647–1663.
[16] A. Khalil, M. Fikry, W. Abdeaal, High technology or low technology for buildings envelopes in residential buildings in Egypt, Alexandria Eng. J. 57 (4) (2018) 3779–3792.
[17] K. Alhagla, A. Mansour, R. Elbassuoni, Optimizing windows for enhancing daylighting performance and energy saving, Alexandria Eng. J. 58 (1) (2019) 283–290.
[18] I. El-darwish, M. Gomaa, Retrofitting strategy for building envelopes to achieve energy efficiency, Alexandria Eng. J. 56 (4) (2017) 579–589.
[19] Ghana Energy Commission, Impact assessment of CFL exchange programme in Ghana, Energy Comm. Assess. Rep (2009) 1–37.
[20] IEA, Market Report Series: Energy Efficiency 2017, 2017, pp. 1–135.
[21] C.I.B.S.E. Guide, Energy Efficiency in Buildings, CIBSE Publications Department – The Chartered Institution of Building Services Engineers, London, 2004.
[22] Energy Efficient Strategies and Maia Consulting. Energy Standards and Labelling Programs Throughout the World in 2013," no. October, pp. 1–241, 2014.
[23] M. Kyprianou, M. Santamouris, C.N. Papanicolas, Achieving nearly zero energy buildings in Cyprus, through building performance simulations, based on the use of innovative energy technologies, Energy Procedia 134 (2017) 636–644.
[24] F. Ascione, Energy conservation and renewable technologies for buildings to face the impact of the climate change and minimize the use of cooling, Sol. Energy 154 (2017) 34–100.
[25] Y. Cai, C.Y. Sam, T. Chang, Nexus between clean energy consumption, economic growth and CO2 emissions, J. Clean. Prod. (2018).
[26] M. Sakah, F. Amankwah, R. Katzenbach, S. Gyam, Towards a sustainable electrification in Ghana: A review of renewable energy deployment policies, Renew. Sustain. Energy Rev. 79 (February 2016) (2017) 544–557.
[27] M. Valentová, P. Bertoldi, Evaluation of the Green building programme, Energy Build. 43 (2011) 1875–1883.
[28] European Commission Joint Research Centre, The European Green Building Programme Catalogue, 2012.
[29] K. Obiri-danso, Current state of the Kwame Nkrumah University of Science and Technology, Kumasi, State Univ. Address (2018) 1–153.
[30] A.K. Meier, What is the cost to you of conserving energy?, Harv. Bus. Rev. 61 (1) (1983) 36–38.
[31] T. Zhou, Cost of conserved energy for residential energy appliances in Australia, Japan and Korea, Int. Appl. Stud. (2012) 1–23.
[32] S. Fuller, Life-cycle cost analysis (LCCA), Natl. Inst. Stand. Technol. (NIST) 10 (2012) 1–10.
[33] L.I 1815, Ghana energy efficiency standards and labelling regulations (LI 1815), Minist. Energy, Ghana Energy Comm. Ghana Stand. Board, no. 1, 2005, pp. 1–14.
[34] D. Chitnis, N. Thejo, H.C. Swart, S.J. Dhoble, Escalating opportunities in the field of lighting, Renew. Sustain. Energy Rev. 64 (2016) 727–748.
[35] D. Siap, C. Payne, A. Lekov, The united states federal energy management program lighting energy efficiency 2017 update and impacts, Appl. Energy 233–234 (September 2018) (2019) 99–104.
[36] E. Deambrogio, S. Allegretti, P. Turi, F. Zuccarello, C. Aghemo, A. Pellegrino, Increase sustainability in buildings through Public Procurements: the PROLITE project for lighting retrofit in schools, Energy Procedia 111 (September 2016) (2017) 328–337.
[37] R. Opoku, I. Adjei, A. Agyarko, Energy efficiency and cost saving opportunities in public and commercial buildings in developing countries – the case of air-conditioners in Ghana, J. Clean. Prod. 230 (2019) 937–944.
[38] D.A. Quansah, M.S. Adaramola, G.K. Appiah, I.A. Edwin, Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate, Int. J. Hydrogen Energy (2016) 1–10.
[39] K.E. Nyarko, A. Brew-Hammond, Technical and economic analysis of A 1 MW grid-connected solar photovoltaic power system at Knust-Kumasi, KNUST Thesis Arch. (2012) 1–130.
[40] S. Gerber, A.J. Rix, M.J. Booysen, Combining grid-tied PV and intelligent water heater control to reduce the energy costs at schools in South Africa, Energy Sustain. Dev. 50 (2019) 117–125.