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Achieving sustainable consumption of electricity through energy audit: A case study of a public sector institution in Ghana

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Abstract

This paper investigated and recommended possible solutions to the high electricity consumption of a public sector organization. The activities of the organization include managing database and information systems and host a number of training workshops in the course of the year as part of its core activities. A hybrid of a walkthrough and standard energy audits were conducted in the organization in September 2009 with the full implementation date in March 2010. This involved the visual inspection of the building, cataloguing of the electrical appliances and the installation of energy monitoring meters on selected electrical equipment of the building. The main segments of energy consumption in the organization were on its lighting systems, computers and accessories, and air conditioners. The total instantaneous power consumption in the building was 79.38 kW, with the highest consumption of energy being from lighting (48%) followed by air conditioners (24.1%) and then computer and accessories (10.1%). Measures on energy conservation were recommended based on the audit. The follow up visit in February 2011, it was realized that electricity consumption by the end of 2010 had dropped by 46% equivalent to 29% of cash savings in spite of tariff increase of 42% in June 2010.

Keywords: Electricity; Energy audit; Energy consumption; Commercial building

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1. Introduction

1.1. History and background

It is estimated that about 1.4 billion people around the world lack access to electricity, some 85% of them in rural areas. Projections are that the situation would actually get worse in the next 20 years (Kaygusuz, 2012). Increasing electricity production has global warming implications since a greater proportion of generation (67.5%) is from fossil fuel source (coal, natural gas and oil) (International Energy Agency, 2010). Spiraling oil price on the world market therefore, has direct impact on electricity cost. The approach to managing this increasingly scarce resource is by incorporating sustainable consumption so that the resources can be extended to the many people who do not have access, without necessarily increasing production, which has both economic and environmental consequences.

In Ghana, the effective capacity for electricity generation is 1725 MW with 970 MW from hydro and the remaining 755 MW from thermal. With this generation capacity, still only 60.5% (14.4 million) of the population has access to electricity.

Cost of producing electricity from hydro source is between US Cent 2-2.5 per kWh while that for thermal is between US Cent 4 and 8 per kWh. The average cost in 2002 was about US Cent 6 per kWh. End user tariff is about US Cent 8.2 per kWh. However, tariffs to end users have not always reflected these costs due to government's subsidy on electricity (Resource Center for Energy Economics and Regulation, 2005). The lifeline tariff (below 50 kWh per month) for example is USD 3.14 and the government subsidized lifeline consumers to the tune of about USD 0.72 per month in the year 2010. This means the Government of Ghana subsidized electricity to an equivalent of USD 185.79 million to absorb 10% of bills of all categories of electricity consumers to cushion them against tariff increases. Customers who use up to 150 units received USD 22 million whiles residential and lifeline consumers who use up to 50 units per month received a total of USD 48.79 million. Non residential and industrial consumers also received a total of USD 112 million (Ghana News Agency, 2010) This arrangement obviously imposes a huge burden on government expenditure as the Government of Ghana owed the distribution utility by end of 2003 a total of between USD 400000 and USD 1400000, in subsidies. Ghana had enjoyed lower tariffs than most countries in sub-Saharan Africa because of the traditional reliance on hydroelectricity as its prime source of energy. Electricity tariff in Ghana has however, risen very sharply (120%) from 2007 to 2010 since the introduction of thermal power generation systems (with natural gas, diesel and light crude oil as source of energy) to meet increasing demand for power (Power Systems Energy Consulting, 2010). Government policy is aimed at reducing subsidies on electricity to the barest minimum and with the increasing presence of thermal generation; it is obvious that the period of cheap power is facing out.

In Ghana, electricity accounts for 79% of lighting in urban households. Nationally, it accounts for 49.2% of households. The average annual household expenditure on housing, water, electricity and gas in 2008 was USD 212, which amounts to USD 71 per capita. The total annual cash expenditure on housing, water, electricity and gas was USD 814 million. 36% of this amount was on electricity, gas and other fuels.

Meanwhile 72% of rural household rely on kerosene for lighting whilst nationally 49.3% of household depend on kerosene as the main source of lighting (Ghana Statistical Services, 2008).

Electrical equipment has life span not more than 7 -15 years of usage (Environmental Protection Agency, USA, 2003) [i]. Technology has also improved steeply over the last five years. New electrical equipment perform 10 -75% better than those which existed previously. However, in developing countries including Ghana a greater proportion of the populace still use obsolete electrical appliances, which are not energy efficient. It has therefore become necessary to; review electricity usage practices in order to determine; direct financial benefits of best energy management practices, replace inefficient practices with ones that are more efficient, improve usage methods and influence policy direction on energy production and consumption.

Energy audit is the energy analysis made on a facility to derive information on the building and its energy characteristics to determine the energy consumption pattern (usage and cost). It is a tool, which can be used to recommend ways of efficient energy usage without changing the main function of the building. A walk-through energy audit is the type in which the facility is examined by close visual inspection. The audit accounts for each electrical equipment, with either power consumption or energy rating. The architectural design is also inspected to find out about the extent of day light usage and the level ventilation for human comfort. Data on electricity bill from the previous years (between one and two years) are analyzed and compare to best energy practice of similar facility. The walk-through audit reveals areas of great concern which needs immediate address for potential energy savings. It involves the least time and cost in addressing the building's energy needs (Reyes et al., 2007; Hasanbeigi and Price, 2010).

A standard energy audit entails a relatively more detailed analysis of a facility and thus involves measurement of specific energy usage pattern. The electrical appliances are metered and monitored for a period and the data logged into a recorder. Data gathered is more accurate and energy efficiency recommendations are much less subjective than the walk-through method (Reyes et al., 2007). The time and cost involve are also higher than the walk-through audit. It may be necessary to do a walk-through audit from which it would be determined if there is the need for a standard audit (Hasanbeigi and Price, 2010).

Computer simulation, the third type of energy audit, is the most comprehensive and most expensive type of audit. It requires the use of detailed measurement of physical parameters such dimensions of each room, window size, building material used for wall and building insulation as well as external factors such as the local weather conditions. Mathematical calculations and computer simulation are used to determine the accurate operation conditions and performance of the building. Findings from such simulations are much accurate and recommendations for energy efficiency are more specific (Reyes *et al*., 2007). It may sometimes require reconstruction of parts of the building.

For a developing country like Ghana, a hybrid of a walk-through and standard audits can be an essential tool for prudent energy management, reduction and subsequent elimination of waste in order to achieve sustainable consumption of electricity as per the Millennium Development Goal (MDG) 7.

This paper investigates the causes and recommends possible solutions to the high level of electricity consumption in a public sector organization. It also aimed at providing research support to shaping a new paradigm in the framework of government subsidy on electricity, as well as mechanisms to develop legislation for improving the energy efficiency in the building sector.

2. Methodology

This study to demonstrate the energy and cost-saving potential of new energy efficiency measures in public buildings was conducted in September 2009 and the recommendations were implemented in March, 2010.

2.1. Site selection

During the selection of a suitable site to mirror typical electricity usage in commercial buildings, a public sector organization was considered in the study. The building has offices, an ICT laboratory, a conference room, a library, storerooms and washrooms. It houses an organization with a staff of about 60 and core activities include managing database and information systems as well as organizing training workshops on quarterly basis. This site was chosen because it typically reflected the occupancy population, office space and activities in many of the Departments and Agencies of Government. Electricity bills in such Departments and Agencies are funded from the consolidated account of Government and there is therefore a direct impact on Government budget. Also the managers of the building had expressed concern about rising electricity bills.

2.2. Audit method

A hybrid of a walkthrough and standard audit methods was adopted in this study, which involved visual inspection of the block, cataloguing of the electrical appliances in the building and installation of energy monitoring meters to measure energy of high consuming electrical appliances. The actual power consumption of the building was assessed by evaluating the monthly electricity bills of the organization at the pre-audit period (2009) and the post audit period (2010).

2.2.1. Visual Inspection of the Block

During the inspection, the team took into account the following:

i. Electrical load of the building i.e. the appliances being used. e.g. Air Conditioners (split and window), fridges, kettles, computer monitors i.e. Cathode Ray Tube (CRT) or Liquid Crystal Display (LCD)/Light Emitting Diode (LED), photocopiers, printers, televisions (TVs) and Lighting system (lamps e.g. Compact fluorescent lamps, Incandescent lamps, halogen lamps, Fluorescent lamps) in the building,

ii. Leakages around the Air Conditioner (AC) installations and windows,

iii. Hours these electrical appliances are turned on during the day,

iv. Hours the ACs have been in operation and their servicing records, and

v. Location of the AC installations (that is height above the floor).

2.2.2. Cataloguing all electrical appliances

An inventory of all the electrical appliances was made. Power ratings for low consumption equipment (below 500 W) were recorded whilst the actual power consumption of high energy consuming electrical appliances (above 1000 W) were measured to determine the total energy load of the building.

2.2.3. Installation of energy monitoring meters

Some high energy consuming electrical appliances (mostly ACs and kettles) were selected at random and their power consumption measured. Typically, the power supply to the electrical appliance was disconnected and reconnected through the electromechanical induction meter, which had been calibrated to measure the power consumption. Readings were taken on a daily bases to record the power consumption for a normal working day in the building for a period of two weeks.

Figure 1. Metering of Aircondioner

2.2.4. Strategy for implementation of energy saving measures

After the energy audit in September 2009 a report containing findings and recommendations were submitted to initiate an energy management program in the organization. The strategy for the implementation of the energy saving measures in the building was categorized into behavioral and technical measures.

The behavioral strategy targeted occupants and managers of the building as major stakeholders by organizing a participatory forum in the form of a seminar where presentations were made to educate them on the audit findings and the collective responsibilities needed at achieving efficiency. The technical strategy targeted managers of the building and estate officers who are in charge of routine maintenance. A roadmap to develop and execute an implementation plan (making the necessary structural and technical changes) was collectively fashioned out.

2.3. Evaluation of energy savings implementation strategy

There were follow-up visits to evaluate implementation strategy and measure the energy savings made from the execution of the implementation plan. The expenditures on electricity, pre-audit and post-implementation plan, were assessed.

3. Results and discussions

3.1. Observations

Upon closer visual inspection of the building, the following observations that does not inure to effective energy management were made:

i. Obsolete air conditioning systems: Obsolete AC systems which had been used for over 10 years were still operational in most offices without regular maintenance. Split and window type ACs usually have a life span of 10 and 8 years respectively [i] and as they grow older their energy efficiency becomes low particularly without regular servicing.

ii. Air leakages: Some of the air conditioned offices had single pane louvre windows which by design are not air tight because of the gaps between the blades when closed. The overall area of air infiltration is larger than that of a sliding glass window. Air leakages in windows, from broken single pane louvre blades, as well as around some window type ACs were a common scene. Some of the louvre systems in offices could not close well because of retrofitting in the building which had electrical cables passing in-between louvre blades. Infiltration and exfiltration of outdoor and indoor air resulted in the overworking of the ACs leading to high consumption of electricity.

iii. Powered faulty fluorescent tubes: The lighting systems in the building were mostly 2ft T12 fluorescent tubes and the 4ft T12 fluorescent tubes. Faulty tubes were still being powered. Some of the lamps were glowing red, flickering or completely burnt. The starter in the fluorescent lamp powers the choke even when the tubes are faulty which leads to energy waste.

iv. Over lamping in corridors: The building does not make full utilization of daylight to complement luminance in order to enhance visibility (daylighting) leading to over-lamping in certain areas. For example the main entrance to the building had 8 (4ft T12 fluorescent) lamps serving as utility lights which were kept on for 24 hours. The corridors were over-lamped even though per the architectural design, of the building daylighting could have been a useful option for accent lighting (O'Connor, et al., 1997).

v. CRT monitors being used: Few of the computers (9 of 48) being used in the building had CRT monitors which by design consume more power than their LCD counterparts.

vi. Wrong positioning of some air conditioners: The positioning of the ACs were not at the recommended distance off the floor. In a particular case an AC was installed on the floor and therefore could not trap hot air in the room efficiently at the rated consumption of energy. For best practices, ACs should not be installed less than 1.5 m from the floor (Sanyo, 2005); this allows the cool air flow out of the AC vent, descend through the risen warm air towards the floor thereby displacing the warm air upwards to be captured and sent into the condenser in the outer unit. Lower installations can be done but best performance will be obtained with a higher installation.

vii. Over-due servicing of most air conditioners: Without regular maintenance an AC loses about 5% of its original efficiency for each year of operation. The service check should comprise cleaning the condensing unit coils, oiling the fan motors and checking the system operating pressures and temperatures against the manufacturers operations. A system that is only 10% low on coolant can cost about 20% more to operate. However, most of the air-conditioners had run past their due maintenance schedule per the maintenance and service labels on them.

3.2. Accounting of power consumption in the building

4. From the investigations carried out to determine the power consumption in the building, the results obtained are as shown in Table 1. The table shows the individual electrical appliance, quantities and total power consumption for a year. Energy consumption in the organization was mainly due to the use of the 17 air conditioners (24.1%), computers and accessories (10.1%). and the 974 T12 fluorescent lights (48.1%).

5. Although a 2 ft.T12 fluorescent light consume 40 W which is very small compared to that of an AC, the large numbers deployed in the building makes it the major contributor to energy usage (48.1%) as compared to ACs (24.1%). Computers and accessories (monitors, UPS, system units, photocopiers, printers and scanners) account for 10.1% of power consumption. Fans also accounted for 10% of power consumption. The contribution of a high energy consumption appliance like kettles was not significant in the cumulative accounting of energy usage because of the quantities involved and also the duration of use.

Table 1. List of electrical appliances and their cumulative power consumption

POWER CONSUMPTION RESULTS Based on 8 hours use per day, 5 days in a week and 260 days in a year					
Item	**Qty.**	**Power Consumption /Unit equipment (Watts)**	**Total Power Consumption (kW)**	**Energy Consumed (KWh/year)**	**% Consumption**
2 ft T12 lights	398	40	15.9	33,113.6	19.6
4 ft T12 lights	576	40	23.0	47,923.2	28.4
Fans	54	150	8.1	16,848.0	10.0
Fridge [a]	7	200	1.4	12,264.0	7.3
Kettle [b]	2	1500	3.0	416.0	0.2
Photocopier	2	350	0.7	1,456.0	0.9
Printer	10	25	0.3	520.0	0.3
Scanner	2	17	0.03	70.7	0
Split AC	10	1000	10.0	20,800.0	12.3
Window AC	7	1361	9.5	19,816.2	11.8
System Unit	48	102	4.9	10,183.7	6.0
Television	2	60	0.12	249.6	0.1
UPS	8	120	1.0	1,996.8	1.2
VCR	1	40	0.04	83.2	0
CRT Monitor	9	46	0.4	861.1	0.5
Flat Screen	39	25	1.0	2,028.0	1.2
Total			**79.38**	**168,630.08**	**100**

[a] Calculation based on 24 hours/day operation for 365 days/year

[b] Calculation based on 0.54 hours/day operation for 260 days/year

5.1. Energy saving measures

Based on these observations made, ten (10) basic but cost effective recommendations which included both behavioral change and technical measures (equipment handling) were implemented in order to reduce significantly the energy consumption of the building.

5.1.1. Behavioral measures

The behavioral changes were achieved by organizing stakeholder participatory seminar to educate the occupants of the building and its managers on energy management practices and benefits of sustaining best practices. This was to create energy efficiency awareness for managers and users in public buildings. These practices included:

i. Shutting all windows and doors properly when ACs were on.

ii. Switching off lights when not needed and making use of daylight.

iii. Removing the starter in faulty fluorescent lamps which were not replaced immediately, to prevent the choke (with a power consumption of 12 watts/h) from consuming electricity.

iv. Servicing ACs which were due for periodic maintenance

v. Rooms should not be over cooled. In the tropics temperatures within 4-5 ^{o}C below the outside air temperature (i.e. at room temperature of 24-26 ^{o}C) are comfortable enough for normal work [ii]. ACs should be turned off if rooms would not be occupied for an hour. The energy load of the building should also be reduced by removing spoilt computers and accessories which partly filled the Information Communication Technology (ICT) room.

vi. Fans should be used in well ventilated rooms and must be turned off when rooms are unoccupied also kettles in the offices should be used to heat just enough water to the desired temperature to avoid waste.

vii. Turning off the plugs of all electrical appliances when not in use. Most modern electric appliances consume electricity even when on standby mode. For TVs, VCRs, fax machines, Hi-Fis, computer screens, cable boxes, and broadband modems they consume on average some 40 – 120 kWh/y (Ajay-D-Vimal et al., 2009). Mobile phone chargers consume power at the rate of 10 watts even when the phone has been removed. In total, losses can reach several hundred kWh/y, all for doing no work. New appliances should either have an 'off' switch that cuts power off completely or consume not more than 1 watt in standby mode.

5.1.2. Technical measures

The equipment handling remedies were also implemented with the estate managers of the building. The measures included:

i. Air leakages around the ACs being permanently sealed.

ii. Faulty fluorescent tubes being replaced or disconnected in areas over-lamped. All glowing red, flickering or completely burnt fluorescent tubes were disconnected where not essential or replaced if it is essential.

iii. To get the best energy saving lightning system in the building, T12 fluorescent tubes were replaced with CFL's. For security purposes outside the building, utility lights which comprised numerous T12 fluorescent lights were replaced with few high wattage CFL's which are more economical than halogen flood lights. For accent and ambient lighting, lower wattage CFL's were used.

With these energy management recommendations, it was expected that ACs which were consuming around 19.53 kW will now consume at a total of 17 kW. The contribution of computers and accessories would stay around 8.04 kW because the input of CRT monitors (9) to the total power consumption by computers and their accessories is relatively insignificant as most of the computers already used LCDs (39) monitors. The major savings were expected to be made from the lighting systems because of the quantities involved (974). This could lead to a drop from 38.96 kW to 10.7 kW. All these energy efficient measures were carried out to reduce the energy consumption without compromising output.

5.2. Returns on energy saving measures

The benefits of the energy saving measures and the returns on implementing the recommendations were assessed by evaluating the electricity bills over a period of two years (audit year and post implementation year).

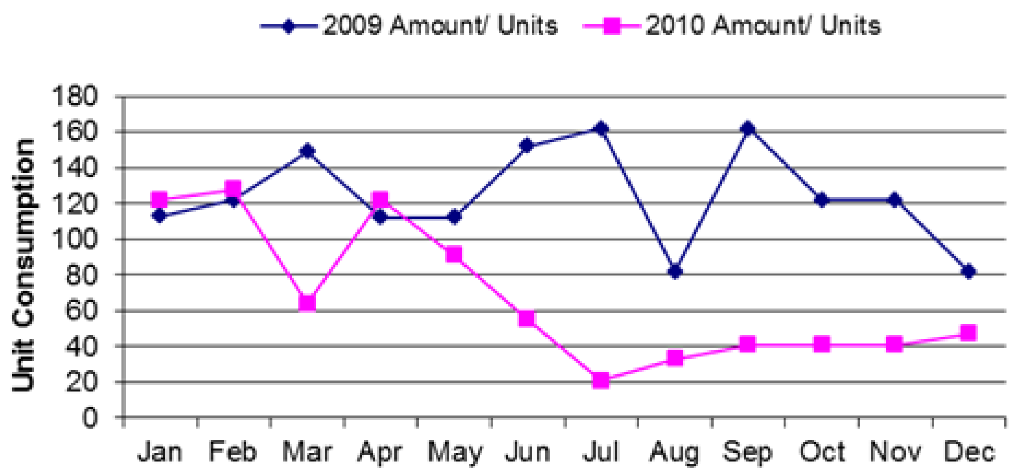

Figure 2. Trend of power consumption in 2009 and 2010

Figure 2 shows the trends of consumption of electricity before the audit (2009) and after the recommendations have been assimilated (2010). A total of 1492 units of electricity (a unit of electricity is equivalent to 1.0 kWh) were purchased within 2009 with the highest in July and lowest in December. In December, the organization closes on a two week vacation and this could account for the low usage. The average electricity consumption in 2009 was 124.33 units per month. The peaking in consumption characterized by the months of March, June and September reflected the period of organization of training workshops where activities and occupancy in the building increased. The actual drop in units of electricity consumed in 2010 was 46% of the 2009 value. For 2010, the year after the audit, the total electricity consumption was 806 units with an average of 67.2 units per month. The first four months recorded high electricity consumption in the building because the recommendations had not been fully assimilated and implemented by the staff. The realization of the benefits of the audit is observed after the month of April as shown in Figure 2, where there is sharp and consistent drop in electricity consumption in the building for three continuous months. The steady rise again from the month of August to December of 2010 can be attributed to complacency and laxation in the energy management program that had been set up as a result of the windfall savings from the audit recommendations coupled with an incremental jump on electricity tariffs in Ghana by 42%.

6. Conclusion

It is established that following through simple remedies from the assessment of energy usage in a commercial building through a hybrid walkthrough and standard energy audit method, energy consumption could reduce to about 46%. Taking into effect increased electricity tariffs (42%) even resulted in an equivalent cash savings of 29%. It is clear that the cash savings could have been higher. It was confirmed that the general activities of the institute had not changed. Virtually the same programmes have been running over the past years. This proves that the energy savings was due to the new energy management program which was being followed. However, the steady rise in consumption indicated that sustainable consumption habits should be inculcated in lifestyles to maximize benefits of energy saving measures as there is always the tendency to relapse into old habits.

7. Recommendation

1. The conclusions derived from the hybrid walkthrough and standard energy audit showed that there are questions with the architectural design of some portions of the building that does not contribute to energy efficiency. To become truly energy efficient the concept must be factored into the architectural design. A comprehensive audit would provide detailed and precise energy balance of the building for its onward upgrade or retrofit. This would further improve the efficiency of the building leading to added cost savings.
2. Governments can channel savings gained through regular energy audits of buildings which resources are currently used in subsidizing wasteful usage of energy into productive investment in energy generation. This would ensure that those who currently do not have electricity are connected to enhance their productivity.
3. Organizations may need to adopt and adapt to new technologies. There should be a conscious effort to remind occupants of buildings of their energy saving obligations through the raising of "champions" in energy efficiency. It also requires the setting up of internal policies and procedures on energy efficiency within the organization.

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