Potentials of an Obligatory Energy Audit of Households: Towards an Energy Resilient Ghanaian Residential Sector

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Abstract

Energy is a major resource, which gives life to every nation and hence has to be efficiently utilized. The building sector globally is responsible for the usage of about 40 percent of the energy produced, which results in about 40 percent of CO₂ emissions, as well as 30 percent of landfill waste. This situation is one of the major causes for climate change with global warming as one of the key issues of global concerns in the 21st century. Buildings are designed not to waste energy and hence, when buildings are in use, it is imperative for an energy auditing on them to minimize energy wastage. This paper aimed at exploring the potentials of energy auditing of residential homes in Ghana, towards ensuring energy resilience in the residential sector. Sixteen residential homes were purposively selected and their uses of energy were assessed to identify areas of wastage and how they could be improved. Microsoft Excel software was used to analyze the results based on the probable savings that could be achieved. Findings from this study suggest that there is significant number of homes in Ghana wasting considerable amounts of electrical power unknowingly. If such an exercise could be carried out on the 3.7 million households in Ghana, the country could make significant energy savings as well as save the environment. The research therefore proposes the development of a comprehensive policy framework with incentives like rebates in utility bills and co-funding that will ensure that most households will embark on such an exercise.

Key words: Climate change; Energy audit; Energy efficiency; Energy use profiles; Residential homes

Introduction

Reducing significantly how much ofelectric energy wasted in the residential sector of Ghana is very critical for achieving energy efficiency and resilience considering the current inadequate energy supply in the country. US DOE (2010) indicated that by 2030, about 49% of electric energy globally will be consumed by plug loads in buildings. This therefore calls extensive study into the type of appliances building occupants purchase as well as their usage patterns. Webber et al. (2006) emphasized the stochastic nature of the end-user, which requires comprehensive study to appreciate better the building occupants. According to Aderimi et al. (2009), the development of modern day’s economy is dependent on energy and hence the growth, administration and improvements in the energy sector must be consciously planned to ensure its sustainability. Modern day living is mainly dependent on
electric energy supply due to the sophistication and complexities of life with the increased acquisition of electricity dependent appliances and equipment in response to the demands of modern lifestyles. This is in the light of the fact that, there has been major growth in family wealth in recent times as well as demand for larger homes and more energy services, which have resulted in increased consumption of energy per household.

Though a lot of gains have been made through the use of energy efficient appliances, the uncontrolled growth in the numbers of residential homes with an increased floor area as well as increased usage of the number of appliances have weaken most of the successes achieved. Ghana Statistical Service (2013), indicated that the main building types in the Ghanaian residential sector are single-family detached, attached homes, apartments and mobile homes. In the residential sector electric energy consumption is mainly from air conditioners, lighting, refrigeration, television, boosting water supply, computers, printers, power backups, coffee makers, microwaves, fridges and water dispensers among others. (U.S. Department of Energy, 2010). Considering the increasing rate of electric energy usage in recent times, there is the urgent need to reduce the extent of electric energy that residential homes consume. Households can only reduce electric energy wastage when they are aware of where the wastage is in their homes.

This situation therefore calls for the use of energy audit as a strategy to identify areas of electric energy wastage and subsequently recommend improvements for the areas of leakages and wastage in the system (Akpama et al., 2009). According to Thumann (2005), energy audit involves various surveys, inspections, tasks and analysis carried out on a building with regards to energy flow. The intention of this strategy is for conserving energy by minimizing energy usage whereas the output of the facility is not negatively affected. Surresh (2009) also considers energy audit as the process of analyzing a building or equipment to identify where and how within the element that energy consumption can be reduced. According to him, it is ultimately aimed at balancing the use of energy with energy input. This is the first action in identifying how much energy the home consumes and assesses strategies to save energy and making the home efficient. Its main goal is to ascertain Energy Conservation Opportunities (ECOs) or Measures (ECMs) that are economical and most competent. Considering the significant role that energy audits play in reducing wastage in an electric energy system, it is envisaged that when it is made mandatory for every household in Ghana, the country as a whole could make significant savings in energy sector. This is in the light of the fact that, every kilowatt of energy used worsen the environment and hence every effort must be put in place in ensure that the usage merits the environment destruction.

**Relevance of energy auditing in buildings**

Morgan and Krarti (2005) indicated that the International Energy Agency is of the opinion that the returns from investing in energy conservation is far higher than investing in developing new energy supply plants. This therefore calls for more efforts in the area of investments in energy conservation. According to Okoro et al. (2008), energy audit of systems and buildings lead to the development of energy improvement options, estimating cost of improvements in energy, calculating payback of investment in the improvements,
evaluate the various improvement options and ultimately reducing energy wastage. Energy audit is a significant strategy in the attempt to reducing energy consumption in buildings as it helps in identifying cost effective ways to improve the comfort and efficiency of buildings. According to Leslie et.al (2012), the importance of energy audit in ensuring energy efficiency of residential homes has resulted in developments in the technology of smart phones, which facilitates homeowners to undertake relatively sophisticated energy audits for their homes. In this same direction, according to Zenebu (2010), an interactive web-based energy consumption efficiency guide was developed in Aalto University in Finland, which apart from calculating energy consumption, also give advice on measures to save energy. Clearly, energy audits have played a major role in investigating energy consumption in various buildings and identifying areas of energy wastage with the aim of reducing energy usage without compromising on the output of the facility. According to Otegbulu (2011), a research done in 2001 on end-use efficiency of electrical energy by households in Lagos Metropolis in Nigeria identified the following as the two main elements as sources energy wastage in homes). Inefficient technologies usage and ii) Consumer behaviors. It is therefore, very necessary to have a clear checklist of the aspects that were inspected and the problems that were identified. A plan for proposed actions must be developed subsequent to that.

**Goals for Energy Auditing**

The objectives for conducting energy audit, as indicated by ASHRAE (2007) and Krarti (2000), generally may include the following concerns;

- To ascertain the energy consumption pattern of the facility.
- To make calculation of the complete energy usage of the facility.
- To ascertain the amount of energy used by different appliances.
- To group the concerns and requirements of customers/ home owners.
- To evaluate the linkage between appliances usage and monthly electric bill.
- To isolate energy wastage areas and explore the causes of such wastages.
- To select and assess procedures for conserving energy.
- To plan and execute cost-effective conservation plans that will not only lead to reducing energy usage but also lower monthly cost.
- To establish the relationship between the building, weather, occupancy and operating schedules.

**Classification of energy auditing**

The process begins from acquiring the historical data of energy consumption for review through a compilation of the electricity bills. According to Krarti (2000), in achieving energy efficiency in buildings, there are four types/ levels of energy audits classifications that can be adopted. These procedures are discussed below;
Walk-Through Audit is the first on the list and it involves a visit to the site for inspection of the facility to identify areas for direct savings on energy use as well as saving on the functional cost of the facility. This is therefore a brief energy usage autopsy targeted at diagnosing the possible reasons supporting the energy buildings consume. The process involves assessing the electrical services and systems in the building as well as the building envelop in a more qualitative manner to identify the potential areas for energy savings without extensive and expensive measures. It further throws more light on the potential energy saving areas for further detailed analysis.

Utility Cost Analysis involves the systematic assessment of the measured usage of energy in the facility as well as the operating cost. The utility data for a period of years have to be carefully analyzed to ascertain the models of usage of energy, maximum demand of energy, effects of the weather on energy use and eventually coming up with energy conservation opportunities.

There is also a Standard Energy Audit in which the researcher engages in a complete analysis of the energy usage in the facility. This involves energy usage reference for the facility being developed, with savings of energy being assessed and the having efficient selected energy actions for conservation being considered with regards to the cost effectiveness.

The last of them is a Detailed Energy Audit which is an extensively comprehensive means of energy audit. It involves the use of equipment in measuring the usage of energy in the facility as well as the major energy systems in the building like lighting, fans and air-conditioners among others. Further to this, sophisticated computer simulation programs are used and also propose the facility’s energy retrofits to ensure significant energy savings. This therefore involves extensive in-site collection of data and analysis. Additionally, the electric based systems and services and comprehensively assessed to come up with a more detailed energy-saving concepts.

Components of Buildings for Energy Audit

Further to the above-discussed steps, there are critical areas and aspects of buildings that are focused on and assessed when conducting full scale comprehensive auditing of any energy system in a home. Each of the aspects requires unique equipment for assessing its level in the home. They include the following;

i) electricity- which requires the use of an energy analyzer or meter or wattmeter to measure the amount of energy being used by a system;

ii) mass flow- which requires the use of anemometer to measure the velocity of wind in the space. They come in various types but with the core task of assessing how fast or slow air mass within the space moves. It helps to determine the air change rate within an indoor space;
iii) **temperature**- this requires the use of thermometers to assess the level of cooling or heat within the space to determine whether the space offers occupants a minimum standard of comfort. There are also infra-red thermometers that are used in buildings to assess the thermal radiation being emitted into the indoor spaces by walls that have its back facing sources of radiation;

iv) **humidity**- this element require a hygrometer (also referred to as humidity meters) to assess the amount of water vapor that exist within the indoor space;

v) **flue gas composition**- requires the use of O2, CO2, CO analyzer to assess the level of indoor air quality since that invariably ends up determining the energy related behavior targeted at achieving comfort within the home by occupants; and

vi) **luminance**- this aspect requires the use of lux meter to determine the illumination levels of the lighting systems within the indoor spaces. Human requires standard luminance to enable them perform required task effectively. Too much of it can lead to glare and discomfort whiles less of it makes activity execution difficult. Measuring the luminance levels and comparing with the standards will be a sure way to minimize wastage of electric energy through lighting;

vii) **air tightness test**- this procedure requires the use of a blower door which is a machine that injects air pressure into an indoor space to determine the level of air tightness. It can equally check air leakages from adjoining rooms and spaces. This is important considering heat transfer by convection as well as conduction and the impact on increasing the indoor air temperature with its associated heat loads.

viii) **earth resistance**- ground is “a conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth” (US National Electrical Code (NEC) Article 100). Poor grounding can cause buildings to use more energy whereas lack of it could also destroy appliances that have been connected to the power system. There is therefore the need to use ground testers to assess the earth resistance on an annual basis to identify any increases that may have occurred. An increase in the resistance beyond 20% should call for an investing to restore it back to normal situation. These areas are critical and can significantly determine how much electric energy a building consumes and hence gives a comprehensive picture of the total drivers of electric energy usage in buildings.

**Electric Energy Usage in the Ghanaian Residential Sector**

Buildings globally are responsible for the consumption 40% of the energy produced (United Nations Environmental Program- UNEP, 2007) and the situation in Ghana does not deviate from the global trends. About 32% of the country’s total electricity is consumed by the residential sector in Ghana. Interestingly, out of this 32%, the sector experiences 30% of end-use wastage of electric energy (Energy Commission, 2012). This could be as a result of the behavior patterns of occupants as well as inefficient appliances usage. Globally it is estimated that an energy consumption range from 20% to 50% of the entire building energy use is attributable to the occupants’ behavior (PC Energy Report, 2009). Friedrich & Afshari (2015) maintained that, this is further worsened by the current energy regime where prices of energy have been subsidized.
and hence does not motivate residential occupants to embark on energy efficiency measures in their homes to ensure that wastages in their systems are minimized. There are two fundamental issues to be considered when embarking on reducing wastage; (i) how the wastage can be defined, and (ii) how the buildings energy performance can be evaluated (Wang et al. 2012). They further argue that, energy auditing is very critical in evaluating energy performance of buildings. This is because occupants are offered the motivation to make improvements in their systems and services as well as building envelop to secure energy savings in their homes. The lack of this situation among others are probable cause of the large power deficit between generation and consumption of electric energy in Ghana. Ensuring that Ghana accomplishes an appropriate level of energy efficiency is therefore an inevitably urgent and important issue which requires comprehensive solutions.

Ghanaian energy situation

Over the last twenty years, consumption of electric energy in Ghana has risen significantly and this could be the probable cause of the significant amount of wasted electric energy, increasing level of housing provision in the country, whose systems and services as well as user technologies are all electric energy dependent. The entire installed capacity in Ghana was 2,831MW, as at the close of 2014, with an output of 12,963GWh for a population of 27 million, whereas the total electricity consumed for the same period stood at 11,081.3GWh (Energy Commission of Ghana, 2015). Notwithstanding this extraordinary intake rate, the system also suffered from transmission losses of 565.1GWh as well as distribution losses of 2,124GWh, which forms 25.4% of Electricity Company of Ghana’s (ECG) supply and 239GWh which forms 24% of Northern Electricity Distribution Company’s (NEDCo) supply. They further indicated that electricity is the largest supply of energy for buildings, with hydro systems providing 55.8%, followed by thermal with 44.1% and then solar with 0.1%. Inescapably, with the increase in housing provision in the country, there will be a parallel demand for electricity. This will additionally exacerbate the current shortage in the supply of energy and left uncontrolled, it could lead to numerous load management in the country.

Household energy use profiles in Ghana

Globally, most households have the following groupings as the key energy end-uses; lighting, space cooling, refrigeration, television, computing, cooking, dishwashers, freezers, clothes washers, entertainment, microwave oven, ironing, kettle usage, and water heating among others. In a survey conducted by Energy Commission of Ghana (2015), the main end uses of electric energy in a characteristic household per month in Ghana were as follows: refrigeration (77 kWh); lighting (21.8 kWh); television (12.2 kWh); fans (11.0 kWh); irons (4.9 kWh); and other electric based appliances (4.6 kWh). This is presented in Figure 1.
From the survey conducted by Energy Commission of Ghana (2015), it is apparent that the major end-use of Ghanaian households are refrigeration, with lighting coming after, then you have that of television, followed by fans, then the use of iron with others being the last category. The definition of the others is not clear in here but may include clothes washing machines, microwave oven, water heaters, air conditioners, hair dryers, computers, multimedia gadgets. Hence, all end-uses, irrespective of how little their energy demands, provide great probable in reducing energy wastage. Though the rural areas are consuming more energy with respect to refrigeration, it could be due to the fact that, these areas use more energy inefficient second hand appliances as well as having a higher household per m² of land area which results in a higher usage of fridges.

**Methods and Analysis**

The research purposively selected sixteen (16) residential household for St. Martins Catholic hospital workers located at Agroyesum in the Manso Nkwanta District Assembly for the study. These are modern housing units completed within the last three years and comparable to housing units in peri-urban areas of Kumasi, Accra and Tamale. The rational for their selection is as a result of the fact that, they are of identical nature as well as efficiency levels which made it possible for the assessment and analysis. There was initial walk-through audit of the selected households to develop a comprehensive image of the energy usage patterns in the homes. Based the energy use profile by Energy Commission of Ghana (2015) as well as predominant appliances in the homes, the study focused on refrigeration, lighting, television, fans, irons, kettle, microwave and rice cooker, as appliance for conducting the energy audit.

**Integrated Framework for the audit**

Consolidating data from extensive review of literature on energy auditing of homes, this research identified and developed the following steps as a comprehensive electric energy audit framework which facilitated the achievement of the goals of the study. The study further recommends its adoption as well as further development for auditing residential homes in Ghana. The methodological steps for the framework are as follows;
i) Preliminary stage- This involves an initial familiarity tour of the homes to form a preliminary image about the situation on the ground as to the state of the building, the age, systems and services. At this stage, the research was able to form an opinion about behavioral patterns of occupants with regards to their level of energy usage consciousness. The window and door opening and closing habits were all studied as well.

ii) Data collection- At this level, the study must collect all existing data on the building including the floor plan (if available), electricity billing data, building envelop as well as nature of building usage. It must also be ensured that all existing electrical appliances and equipment, that are working (active), within the households are well documented. The study at this stage, therefore physically counted the number of these appliances in the various homes and categorized them into end uses. The purpose for this was to develop a comprehensive inventory of the appliances in the home as well as determine the nature of appliances, i.e. whether obsolete or modern appliances.

iii) Rating of appliances- This stage of the process is very critical since all the appliances have their power ratings on their labels. There is the need for checking them for all the identified appliances. This was a critical step, since the power rating of an appliance invariably determines the amount of electric energy they consume. The power ratings also inform the research to determine based on standards as to whether the identified appliances were oversized or under-sized in the context of the research households. A fair idea of this can inform the audit team as to the key areas of focus in the process. In situations where the labels do not exist, reference could be made to existing building energy data books. For instance, reliable average energy data for most appliances and equipment have been published by the U.S. Department of Energy- DOE (2012). In that same direction, energy meters could be used to measure how much energy these appliances are consuming in the homes, as discussed in the point below.

iv) Power (watts) metering- Power analyzer(meter) is an electric and electronic instrument that measures the characteristics of electrical power of devices and equipment that produce, convert and use electric energy. They are also referred to as power meter or wattmeter since they measure the true power (watts) of the appliances and equipment being used. The power analyzer was used, as a pre-testing strategy, to assess exactly how much of energy the appliances in the first household were consuming. This step was to determine whether there were significant disparities between the measured and the calculated consumptions of electric energy. Once the differences were insignificant, the study proceeded to the next stage of the audit to calculate the energy consumptions with the formula method.

v) The lux meter was also used to measure the illumination levels for the existing lighting systems to determine whether there was over illumination or not in the selected homes. This step was very significant since any excess of illumination in a space constituted electric energy wastage. There are standards of illumination level for indoor spaces and these were used as a baseline for the overall assessment. For most spaces in residential homes, the illumination levels start from 50lux in corridors and toilets to approximately 250lux for bedrooms.
vi) ENERGYSTAR rating- The energy star ratings of the appliances were also of much concern to the study since the higher the number of stars the higher the energy efficiency of the said appliances. The challenge however is the fact that, the lower star rating of the appliances, the less expensive they are. Hence, significant number of residential occupants tend to patronize them because they fall within their household budgets. Notwithstanding the initial “savings” made at the point of purchase, the households end up paying more during the operational life of the appliances since they are inefficient. As a result, they negate the initial “savings” made at the purchase point.

vii) On-hours per day- The number of on-hours of the identified appliances were also considered for the study. This is because, not all the appliances identified in the walk-through are used throughout the day. Some are used only in the evenings others mornings whereas others also run throughout the day. To accurately calculate how much energy they consume, as well as how much savings that could be made through improvements, there is the need to clearly assess the on-hours to produce the actual picture on the ground.

viii) Assess phantom loads- These are also referred to as standby loads or vampire loads and generally represents all the electric power drawn by appliances when they not put on standby and not performing their main functions. This occurs because in most appliances, whiles they are put off at the electronic interface, they still consume energy because on the electrical phase they are still on. This a major cause of power wastage in homes. This study interviewed occupants on how they switch off their laptops, televisions, irons and other appliances. Most occupants were not even aware that leaving the charger in the socket which is switched on, draws energy. It is therefore a critical aspect of the audit process. Another silent electric energy drainer is lighting switching habits of occupants. There is the need to observe this component of the occupants since that also can cause buildings to waste energy. From the research observation, occupants were switch on lights even when the sunlight was on. In other situations occupants kept on lights in the mornings at times and leave for work.

ix) The research then calculated how much energy the existing appliances in the homes were consuming. It further analyzed the potential improvements with corresponding savings and subsequently assessed the potential savings that could be made if the suggested improvements could be executed. The implications of the savings are that, “the savings constituent” are all “inherent electric energy wastage” in the selected homes. The data were then analyzed with Microsoft Excel software on their means and frequencies.

The following are some of the formula used in the study for varied calculations;

The illumination levels of the lighting systems could be mathematically calculated with the formula below;

\[ I = L_1 C_u L_{LF} / A_1 (1) \]

where
I = illumination (lux, lumen/m²), \( L_l = \) lumens per lamp (lumen), \( C_u = \) coefficient of utilization

\( L_{FF} = \) light loss factor, \( A_l = \) area per lamp (m²)

**Formula to estimate the amount of energy a specific appliance consumes:**

\[
\text{Wattage} \times \text{Hours Used per Day} \times \frac{1000}{\text{W}} = \text{Daily Kilowatt-hour (kWh) consumption}
\]

**Annual usage units** is referred to as power use for load in 1-year period (kWh/yr) as the equation illustrated below;

\[
\text{kWh} / \text{yr} = \Sigma (\text{Average power [kW]} \times \text{Hours / day}) \times \text{Days / year}
\]

**Findings**

To develop the opportunities for energy performance improvements in the residential sector of Ghana, the study adopted energy auditing of 16 selected households. The following section therefore shows the collected data, the analysis as well as the major outcomes and electric energy savings opportunities in Ghana.

**Inventory of existing appliances**

The study identified the appliances that were available in the sixteen households and included refrigeration, lighting, television, fans, irons, kettle, microwave and rice cooker as indicated in Table 1. The study found that all the lighting systems available CFLs which were also of very high power rating. Interacting with the occupants, they indicated that these lights gave them brighter illumination and hence their preference for them. All the fridges in the households were 1-energy star rated. Occupants indicated that they were provided by the institution. The inference is that, they are much cheaper and hence met their budget. For them, a fridge is basically a fridge and hence they were much concerned with their budget at the time of purchasing. Below is a table showing all the identified appliances in the study area.

**Table 1. Electric-based appliances in the selected households**

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Electrical gadget</th>
<th>Bedroom</th>
<th>Bathroom</th>
<th>Lounge</th>
<th>Kitchen</th>
<th>Terrace/compound</th>
<th>Balcony</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fridge</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>2</td>
<td>Lighting (105w) CFL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Lighting (85w)</td>
<td></td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>Lighting (45w) CFL</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Lighting (25w) CFL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Lighting (15w) CFL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>7</td>
<td>Fan</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>Television</td>
<td>3</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>Iron</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>Kettle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td>11</td>
<td>Microwave</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>12</td>
<td>Rice cooker</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>
**Energy usage patterns of household appliances**

The study also analyzed the power rating of the appliances and how they correspond to the amount of energy in kWh that they consume. Table 2 shows that significant amount of the energy used in the selected homes were for lighting purposes with 42.46 kWh/24 hours, which was then followed by refrigeration with 28.8 kWh/24 hours and then fan came next with 14.4 kWh/24 hours. The appliance that recorded the lowest energy usage was microwave having 1.485 kWh/24 hours. From Table 1, the total energy used by the 16 households was 123.705 kWh/24 hours.

**Table 2. Usage of energy by the electric-based appliances in the selected households**

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Electrical gadget</th>
<th>Total (W)</th>
<th>Power rating (W)</th>
<th>Total load (W)</th>
<th>Usage (hour)</th>
<th>Usage 24hours (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fridge (1 star)</td>
<td>16</td>
<td>150</td>
<td>2,400</td>
<td>12</td>
<td>28,800</td>
</tr>
<tr>
<td>2</td>
<td>Lighting (105w)</td>
<td>12</td>
<td>105</td>
<td>1,260</td>
<td>12</td>
<td>15,120</td>
</tr>
<tr>
<td>3</td>
<td>Lighting (85w)</td>
<td>32</td>
<td>85</td>
<td>2,720</td>
<td>9</td>
<td>24,480</td>
</tr>
<tr>
<td>4</td>
<td>Lighting (45w)</td>
<td>16</td>
<td>45</td>
<td>720</td>
<td>2</td>
<td>1,440</td>
</tr>
<tr>
<td>5</td>
<td>Lighting (25w)</td>
<td>20</td>
<td>25</td>
<td>500</td>
<td>2</td>
<td>1,000</td>
</tr>
<tr>
<td>6</td>
<td>Lighting (15w)</td>
<td>28</td>
<td>15</td>
<td>420</td>
<td>1</td>
<td>.420</td>
</tr>
<tr>
<td>7</td>
<td>Fan</td>
<td>16</td>
<td>100</td>
<td>1,600</td>
<td>14</td>
<td>14,400</td>
</tr>
<tr>
<td>8</td>
<td>Television</td>
<td>19</td>
<td>80</td>
<td>1,520</td>
<td>8</td>
<td>12,160</td>
</tr>
<tr>
<td>9</td>
<td>Iron</td>
<td>16</td>
<td>1200</td>
<td>19,200</td>
<td>.45</td>
<td>8,640</td>
</tr>
<tr>
<td>10</td>
<td>Kettle</td>
<td>14</td>
<td>2200</td>
<td>30,800</td>
<td>.20</td>
<td>6,160</td>
</tr>
<tr>
<td>11</td>
<td>Microwave</td>
<td>9</td>
<td>1100</td>
<td>9,900</td>
<td>.15</td>
<td>1,485</td>
</tr>
<tr>
<td>12</td>
<td>Rice cooker</td>
<td>16</td>
<td>600</td>
<td>9,600</td>
<td>1</td>
<td>9,600</td>
</tr>
</tbody>
</table>

**TOTAL ENERGY CONSUMPTION OVER 24HOURS**

123.705

**Energy efficiency improvements**

The study subsequently, made some proposal for improvements with regards to the major drainers of energy in the households. The study did not consider televisions, irons, kettle, microwave and rice cookers. The rational for their exclusion was based on the fact that, savings from them are mainly achieved through energy-conscious occupant behavior. From Table 3, if the improvement in lighting is executed, there will be an average consumption for lighting purposes reducing from 42.46 kWh/24 hours to 4.884 kWh/24 hours which reflects an 88% reduction only for lighting. The overall consumption of the proposed improvements may drop the consumption from 123.705 kWh/24 hours to 69.569 kWh/24 hours which will be an average of 44% reduction.

**Table 3. Usage of energy by the electric-based appliances in the selected households**

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Electrical gadget</th>
<th>Total (W)</th>
<th>Power rating (W)</th>
<th>Total load (W)</th>
<th>Usage (hour)</th>
<th>Usage 24hours (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fridge (4 star)</td>
<td>16</td>
<td>100</td>
<td>1,600</td>
<td>12</td>
<td>19,200</td>
</tr>
<tr>
<td>2</td>
<td>Lighting (14w) LED</td>
<td>12</td>
<td>14</td>
<td>168</td>
<td>12</td>
<td>2,016</td>
</tr>
<tr>
<td>3</td>
<td>Lighting (9w) LED</td>
<td>32</td>
<td>9</td>
<td>288</td>
<td>9</td>
<td>2,592</td>
</tr>
<tr>
<td>4</td>
<td>Lighting (6w) LED</td>
<td>16</td>
<td>6</td>
<td>96</td>
<td>2</td>
<td>.192</td>
</tr>
<tr>
<td>5</td>
<td>Lighting (6w) LED</td>
<td>20</td>
<td>6</td>
<td>120</td>
<td>2</td>
<td>.240</td>
</tr>
<tr>
<td>6</td>
<td>Lighting (3w) LED</td>
<td>28</td>
<td>3</td>
<td>84</td>
<td>1</td>
<td>.684</td>
</tr>
<tr>
<td>7</td>
<td>Fan</td>
<td>16</td>
<td>50</td>
<td>800</td>
<td>9</td>
<td>7,200</td>
</tr>
<tr>
<td>8</td>
<td>Television</td>
<td>19</td>
<td>80</td>
<td>1,520</td>
<td>8</td>
<td>12,160</td>
</tr>
<tr>
<td>9</td>
<td>Iron</td>
<td>16</td>
<td>1200</td>
<td>19,200</td>
<td>.45</td>
<td>8,640</td>
</tr>
<tr>
<td>10</td>
<td>Kettle</td>
<td>14</td>
<td>2200</td>
<td>30,800</td>
<td>.20</td>
<td>6,160</td>
</tr>
<tr>
<td>11</td>
<td>Microwave</td>
<td>9</td>
<td>1100</td>
<td>9,900</td>
<td>.15</td>
<td>1,485</td>
</tr>
<tr>
<td>12</td>
<td>Rice cooker</td>
<td>16</td>
<td>600</td>
<td>9,600</td>
<td>1</td>
<td>9,600</td>
</tr>
</tbody>
</table>

**TOTAL ENERGY CONSUMPTION OVER 24HOURS**

69.569
Potential energy savings

The study indicated potential energy savings if energy auditing through policy direction could be the key to providing energy resilient residential sector in Ghana. From Table 4, which is an abstraction from Table 3, the potential savings in electric energy for the year with regards to the selected 16 households will be 19758.91kWh.

<table>
<thead>
<tr>
<th>Description</th>
<th>Current usage/24hrs</th>
<th>Proposed Improvement usage/24hrs</th>
<th>Potential energy savings/24hrs</th>
<th>Potential energy savings/yr</th>
<th>Potential energy savings in MW/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usage in kWh</td>
<td>123.705 kWh</td>
<td>69.569 kWh</td>
<td>54.134 kWh</td>
<td>19758.91 kWh</td>
<td>19.75891 MW</td>
</tr>
</tbody>
</table>

Observations

Time period for study

To effectively observe and understand the occupants’ electric energy behavioral patterns in their homes, the study undertook visits to all the 16 selected households over a period of 4 weeks. Each week was divided into two components, being the weekday (Monday to Friday) and the weekend (Saturday and Sunday). The day was divided into the following two sub-sections, to make it easy to assess; (1) The day section from 6am to 12.30pm; and (2) The evening section from 1.30pm to 7.30pm.

Observation results

The observation aspect of this study was not factored in the potential wastage and savings that could be made from improvement in occupants’ energy related behavior. However, it must be emphasized that further significant savings, of about 30%, could be made from addressing the weak points that were observed.

From the study, it was realized that, most occupants usually forget to switch off their indoor lights before leaving for work. Those who did only switched off only when they are leaving the house for outside. Upon further discussions, they basically just forget that their lights are on after they switch them on in the mornings when they wake up early. According to them, the stress of working life and the need to get to work on time keeps them always mentally occupied.

Again, most of them also left their TVs and decoders on standby mode when leaving for work. This same attitude was repeated by them when they sleep at night. There were also times that verandah lights were left on till around 8.30am. An interesting observation was also when the study identified that, some of the occupants would put the TV on, with radio also on at the same time whiles standing outside of their units and chatting for over an hour. There were also some isolated cases where some would also switch their iron regulators to off position, to watch favorite TV programs but the main power would still be on. With regards to the use of kettles, it was observed that, about 85% of the occupants were not aware that filling it over the maximum level, only causes it consume more than required energy.
From the observations, it could be seen that, building occupants are not very conscious with regards to energy related behavior. They are not even aware that, such habits are major causes of electric energy wastage in residential homes. There is therefore the need for a comprehensive and extensive sensitization framework to foster behavioral change in building occupants as well as incorporation of some technologies that would fill the “electric energy occupants’ consciousness gap” of building occupants. For instance, the use of automatic lighting dimmers that will factor daylighting in lighting illumination for rooms, human sensors for lighting systems that will switch off lights when there is no occupancy, power strips (timers) that would also ensure that appliances are completely off when they are not performing their core functions.

**Conclusion and Recommendations**

The study conducted energy audit of 16 households and identified significant electric energy wastage which could be reduced if proposed improvements were made in the type of appliances being used by the occupants. The study envisaged an average of 44% savings in energy usage with the improvements. Considering that Ghana has about 3.7 million households (GSS, 2013), then it is expected that averagely, a mandatory auditing of all these households on their lighting, refrigeration and fans alone could result in about 4.569GW/year of electric energy savings. If the exercise is further carried out on all household appliances like air conditioning, washing machines, water heaters and the other appliances and equipment, the country could achieve significant energy savings. The savings could also be further improved with the incorporation of technology to execute what this research considers as “electric energy occupants’ consciousness gap”.

From the above, one could suggest that the energy problem in Ghana is more than just the increasing the installed capacity of energy. A lot more of comprehensive auditing of all electrical systems including earthing of building should be the new direction in policy formulation in ensuring resilience in the energy sector.

The following recommendations are also made based on the research findings. The research therefore proposes that, on the basis of the potentials identified, there must be a future study into the development of a comprehensive policy framework with incentives like probable rebates in utility bills as well as the discontinuation of electric energy service provision, by utility companies, to households that refuse to undertake the exercise. The policy must also factor the possibilities co-funding or sponsorship packages for improvement measures that will ensure that most households will embark on such an exercise to ensure that electric energy wastage in the residential sector of Ghana is reduced significantly.

**References**

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**Web Pages**

