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Research Article

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Energy Efficiency in Buildings: A Concept of Sustainability

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Abstract The environmental impact caused by buildings accounts for 18% of global emissions today or an annual equivalent of 9 billion tonnes of carbon dioxide and the usage of energy in such buildings accounts for more than 30%, even up to 70% in some cases. Generating electricity from fossil fuels such as diesel, natural gas and petrol, negatively affects the environment. A large part of the greenhouse gases emitted into the atmosphere come from energy generation. This research aimed at identifying commercially and behaviorally low-cost ways of reducing energy consumption in the residential, public and private sectors in Nigeria, thereby reducing our carbon footprint on the environment and also sustaining it at the same time. Questionnaires, interviews, literature review and observations were used as sources of data to gather information. Findings revealed ignorance of energy efficiency measures among respondents chiefly responsible for energy wastage in Nigeria. Energy-management strategies were identified from the literature and tested against current practice. The study discovered a vast majority of households and public institutions resort to informal power supply which contributes to global warming. The alarming rate at which generators are being used in Nigeria is a cause for concern, although this is due to the intermittent nature of electricity supply in the country. The research highlighted guidelines for the development of energy efficiency policy and legislation which in turn will strengthen regulatory measures to use energy efficiently. The research proposes a good energy management framework for the residential, public and private sector, thereby eliminating the need to alternate electricity supply in Nigeria. The study concluded that energy efficiency is important both to the environment and economic development of the country.

Keywords Energy efficiency, management, environment, global warming, policies, potentials, Nigeria

1. Introduction

Energy efficiency is of paramount importance with regards to achieving a safe, clean, affordable and sustainable energy system for the future. It is the one energy resource that every country possesses in abundance and is the quickest and least costly way of addressing energy security, environmental and economic challenges [10,14]. Buildings consume a lot of energy. The efficient use of energy is the goal of efforts to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature; also, there are natural ways we can keep our homes/offices comfortable and reduce energy bill. A well placed tree, shrub or vine in our home/office environment can provide shade and act as a windbreaker. This can help to reduce the energy we spend on cooling, since the shade from these trees can keep the environment cool [5]. In Nigeria, the appliances for heating and cooling account for a large percentage of the energy we spend in our homes and offices. It has been found that heating and cooling alone account for about 44% of utility bill [14].

Generating electricity from fossil fuels such as diesel, natural gas and petrol, negatively affects the environment. The release of chlorofluorocarbons (CFCs) from Air Conditioning and refrigeration equipment destroys ozone molecules in the stratosphere through a catalytic process and harms the planet's natural shield for incoming

ultraviolet radiation [4,6,9,14]. CFCs in the stratosphere also absorb infrared radiation and create chlorine, a potent greenhouse gas. Ozone is formed in the atmosphere through chemical reactions between pollutants emitted from vehicles, factories and other industrial sources, fossil fuels combustion, consumer products, etc. Ozone has a very pungent smell. The odor can sometimes be detected after lightning strikes or during electrical discharges. Individual humans vary in their ability to smell ozone. Some can smell it at levels as low as 0.05ppm [7,8].

Energy efficiency is often defined as achieving the same services with less energy. This definition grossly understates the power of energy efficiency to provide benefits beyond energy savings for society and for the economy.

1.1. Statement of the Problem

- It is common practice in Nigeria to see outdoor lighting on during the day. This practice is quite common even in public institutions such as universities, polytechnics and government ministries [14]. This is particularly so, because a lot of Nigerians are not aware of the amount of energy consumed by the commonly used incandescent bulbs. A lot of energy can be saved if Nigerians cultivate the habit of putting off their outdoor lighting in the day time. Energy saved from using the natural light instead of light bulbs during the day can be made available for use in offices and for industrial activities.
- An estimated 60 million Nigerians own power generating sets for their electricity, while the same number of people spend a staggering N1.56 trillion ($13.35m) to fuel them annually [15].
- According to a recent claim made by the Vice Chancellor of the University of Jos, an average sum of N31,000,000 (thirty-one million naira) is spent monthly as electricity bill for Students' Village Hostel (just one out of four hostels of the university) alone. This implies that a total of $1,039,104.00 (one million, thirty-nine thousand, one hundred and four dollars) is spent annually on that facility alone. Such a staggering amount of money can be put to better use by devising cleaner and cheaper ways of generating energy. The current price of electricity in the country is N31.28pKw (thirty-one naira per kilowatt of electricity). If the University spends N31,000,000 monthly on that facility alone, it means that the facility consumes a whopping 991,048.59Kw on the average every month. This does not only create economic problems, but also environmental concerns as most of the energy generated in Nigeria comes from the burning of fossil fuel (oil and gas). For every kilowatt of electricity, we consume, there is an equivalent emission of greenhouse gases (GHGs). Each kWh of energy delivered to a building incurs atmospheric emissions of the major greenhouse gas CO_2 from the extraction, processing and delivery of each fuel and its consumption on site. Energy efficiency can help to reduce the emission of GHGs and reduce the reliance on petroleum to drive our economy. The negative environmental impacts associated with the generation of energy will also be reduced if we use energy efficiently. The epileptic nature of power supply in the country partly explains the mammoth sums of money being spent on power.

1.2. Aim and Objectives of the Study

- To create awareness of the benefits of efficient use of energy resources
- To reduce waste, pollution and environmental degradation
- To identify renewable energy potentials in the different regions of Nigeria, thereby suggesting ways of generating cleaner and cheaper sources of energy
- Eliciting information for formulating energy efficiency policies by providing the highest-quality data, analysis and policy advice to the Nigerian government.
- Protecting inhabitants' health.

2. Materials and Methods

2.1. Literature Review

Energy efficiency does not mean that we should not use energy, but we should use energy in a manner that will minimize the amount of energy needed to provide services. This is possible if we improve in practices and products that we use. If we use energy efficient appliances, it will help to reduce the energy necessary to provide

services like lighting, cooling, heating, manufacturing, cooking, transport, entertainment etc [1,3]. Hence, energy efficiency products essentially help to do more work with less energy. For instance, to light a room with an incandescent light bulb of 60 W for one hour requires 60 W/h (that is 60 watts per hour). A compact fluorescent light bulb would provide the same or better light at 11 W and only use 11 W/h. This means that 49 W (82% of energy) is saved for each hour the light is turned on.

The increased volumes of carbon dioxide and other greenhouse gases released by the burning of fossil fuels, land clearing, agriculture, and other human activities, are believed to be the primary sources of the global warming that has occurred over the past 50 years [8,11].

2.1.1. Lighting

Consumption of light depends on building type, utilization of daylight, illuminance levels and hours of use. In open plan buildings, where no individual has responsibility, efficient control of lighting is more difficult [12,14], and so lights usually stay on much longer than strictly necessary. Efficient installations and good, user-friendly controls should be the norm.

Energy use in public institutions has risen in recent years because of the growth in information technology, air-conditioning, and intensity of use. However, this trend is offset by considerable improvements in insulation, plant, lighting and controls. Findings revealed that in many places where people experience low voltage, people purchase the 100W and 200W in order to get a brighter effect. Also, many people use the high rating incandescent bulbs for outdoor lighting because they appear brighter [5,14]. A major factor working against the shift from incandescent bulbs to energy saving bulbs is the cost. Energy saving bulbs are far more expensive than incandescent bulbs. The cost of energy saving bulb in the Nigerian market ranges between N800 to N1000(which is about $3) [14]. However, some substandard energy saving bulbs could be purchased for as low as N200. On the other hand, the prices of incandescent bulbs range from N30 to N100 (about $0.3).

2.1.2. Switching on Outdoor Lighting during the Day

This is another high end-use of electricity in Nigeria. Typically, most Nigerians do not switch off their outdoor lighting during the day as revealed by the findings of this study. This results in a large amount of energy being wasted. Most of the respondents in the study blamed the Power Holding Company of Nigeria (PHCN) for this ugly trend [13,14]. Intermittence in power supply during the day and nighttime makes one unconscious of when the switches are on or off especially when there is power outage during the night and it extends into the day time. A lot of energy can be saved if Nigerians cultivate the habit of putting off their outdoor lighting in the day time. Energy saved from using the natural light instead of light bulbs during the day can be made available for use in offices and for industrial activities.

2.1.3. Setting Appliances on Standby Mode

Many people do not know that if you leave your appliances on standby mode, the appliances still consume energy. Putting an electrical appliance on standby mode is not the same thing as putting it off. Electrical equipment consumes energy when on standby mode [2]. Although the energy they consume is not the same as when they are switched on, but putting them off when not in use can save some measure of energy. Consumers should be appropriately informed by the manufacturers of the energy electrical appliances at standby mode [3]. A good way to do this is to inscribe it on a label and stick them to the appliances.

2.1.4. Simultaneous Use of Multiple Appliances in Public Buildings

This is a very common practice among public officers in Nigeria, especially the senior staff. In one department or building, you find refrigerators and air conditioners at the same time in all offices. It is a familiar sight in government offices to see a refrigerator, air conditioner, television set, photocopy machine, printers, desktop computers, fans, electric kettle and incandescent bulbs, and in many cases these appliances are switched on at the same time [9,14]. You go to another office in the same department or building, you find similar things. The reason for this practice could be that public officers do not pay individually for electricity and thus they are not conscious of the way they use energy. Findings revealed that many government buildings are not metered; thus

government officers are not accountable to the energy they use during office hours. The study also found out that in university hostels, occupants use all kind of electrical materials and they do not have restriction on the kind of equipment they use. It is a common practice for students to use all kind of electrical heating equipment for cooking in student hostels. The use of particular heating equipment popularly called "hot plate" in student hostels is very energy intensive and should be discouraged. Individual rooms in student hostels are not metered; this encourages wastage as they are not held accountable for the energy they use.

2.1.5. Global Warming Contributions

Globally, stationary A/C systems account for nearly 700 million metric tons of direct and indirect CO_2-equivalent emissions (MMTCO2e) annually [1,10]. Indirect emissions from electricity generation account for approximately 74% of this total, with direct emissions of HFC and hydrochlorofluorocarbon (HCFC) refrigerants accounting for 7% and 19%, respectively [10]. While electricity consumption is the largest driver of GHG emissions from A/C (i.e., indirect impacts), emissions of HCFC and HFC refrigerants have a disproportionately large global warming impact relative to their mass [1]. Addressing direct emissions therefore offers an important path to substantially reducing A/C GHG emissions.

2.2. Methodology

2.2.1. Key sustainable features

2.2.2. Low Energy Consumption

Passive Design

1. Optimum use of site features to minimize solar heat gain with 80% roof area under covered
2. Reduce cooling demand - Optimize window to wall ratio (~20%) to reduce solar heat gain - Insulated envelope using rock wool (U-value of wall: 0.83 vs BEAM Plus Baseline 3.7, i.e. 78% reduction in thermal transmission)
3. Daylighting to reduce lighting energy consumption
4. Provision of cross-ventilated openings to utilize natural ventilation during desirable seasons

2.2.3. Active Design

1. Efficient Lighting System
    - T-5 Lamps + Task Lights w/ adjustable illuminance (30%-100%)
    - Avg. lighting power density (LPD) for office = 8.2 W/sq.m i.e. 45% less than the requirement of BEC 2012 (15 W/sq.m)
    - Daylight and occupancy sensors
2. High Efficiency HVAC System ♣ Variable Refrigerant Volume (VRV) units with higher COP (> 4.0) instead of window / split type air-conditioners (≤ 3.0) i.e. >33% increase in energy efficiency

2.2.4. Energy Simulation Results

- 33% energy reduction = 48,500kWh/year or 642 nos. 28W T5 lighting for 1 year
- 37% reduction in peak electricity demand

2.2.5. Enhance Natural Ventilation

- Openings are provided to facilitate cross ventilation in transitional seasons
- Enhance Ventilation at Courtyard. Building design to facilitate natural ventilation at courtyards and offices.

2.2.6. Enhance Daylighting

- Optimum window area - balance daylighting and solar heat gain

2.2.7. Sustainability Policy

- Sub-metering installed to separately monitor electricity consumption by HVAC and Electrical systems

- Green Operation (Behavioral) – operation guidelines distributed to staff

2.2.8. Raise Public Awareness of Sustainability

Promote public awareness on sustainable development and demonstrate the government's effort in promoting a low carbon environment.

2.3. The Principles of Green Building Design

The green building design process begins with an intimate understanding of the site in all its beauties and complexities. An ecological approach to design aims to integrate the systems being introduced with the existing on-site ecological functions performed by Mother Nature [6,16]. These ecological functions provide habitat, respond to the movements of the sun, purify the air as well as catch, filter and store water. Designers can create features in their buildings that mimic the functions of particular eco-systems. Species that thrive in natural ecosystems may also utilize habitats created in man-made structures. Creating new habitat on structures in urbanized areas is especially important to support bio-diversity and a healthy ecosystem [12]. The following points summarize key principles, strategies and technologies which are associated with the five major elements of green building design which are: Sustainable Site Design; Water Conservation and Quality; Energy and Environment; Indoor Environmental Quality; and Conservation of Materials and Resources.

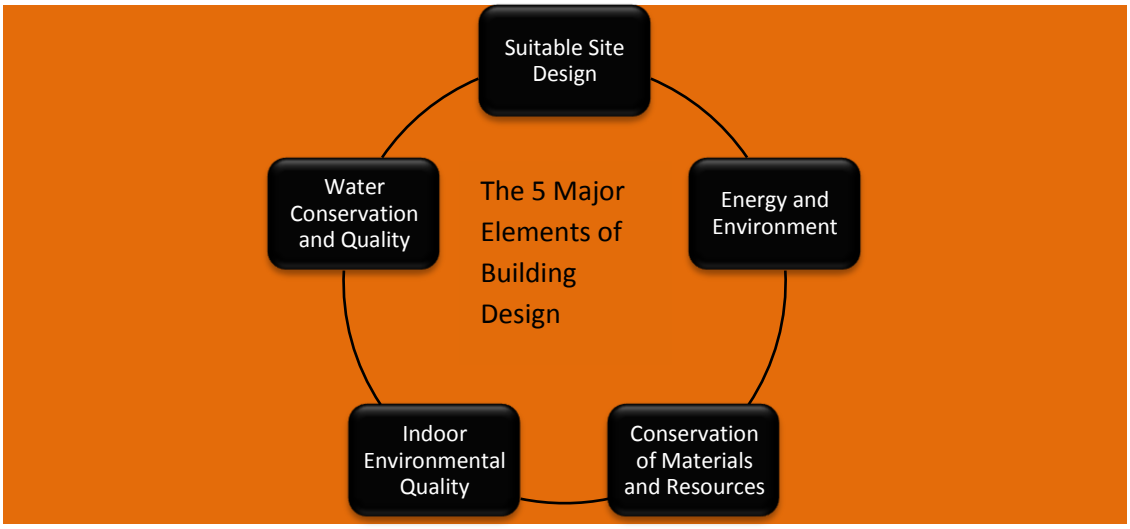

Figure 1: Elements of Green Building Design

2.4. Passive Solar Design

Passive solar design refers to the use of the sun's energy for the heating and cooling of living spaces. The building itself or some element of it takes advantage of natural energy characteristics in its materials to absorb and radiate the heat created by exposure to the sun. Passive systems are simple, have few moving parts and no mechanical systems, require minimal maintenance and can decrease, or even eliminate, heating and cooling costs[2]. Passive solar design uses that to capture the sun's energy:

- Solar passive features
- Shape and form of buildings
- Orientation of the facades
- Design of Building plan and section
- Thermal insulation and thermal storage of roof
- Thermal Insulation and thermal storage of the exterior walls.

Major Components: Orientation, double glazed windows, window overhangs, thermal storage walls roof, roof painting, ventilation, evaporation, day lighting, construction material etc. Designs depend on direction & intensity of sun and wind, ambient temperature, humidity, etc. Different designs for different climatic zones[2].

3. Results

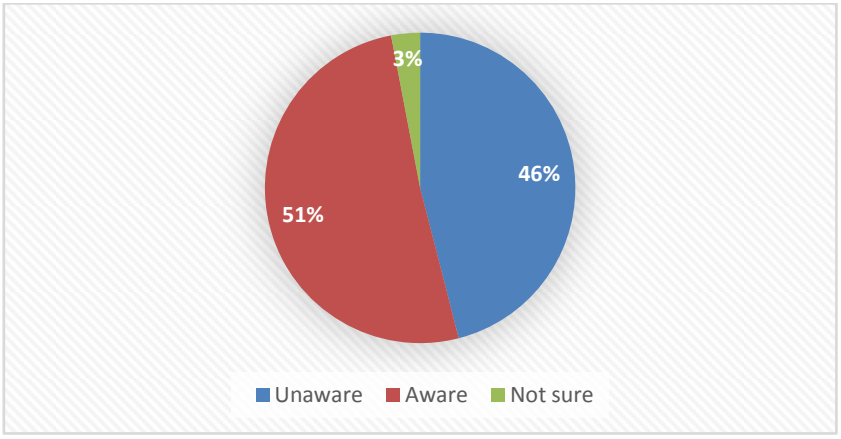

Figure 2: Pie chart showing level of awareness of respondents on the term 'energy efficiency'

The results revealed that majority of the respondents are familiar with the term "energy efficiency", 68% of respondents claimed that they are familiar with the term, however, many of those who claimed to be familiar with the term could not define it properly. Awareness creation will go a long way to help people understand the concept and change their behavior

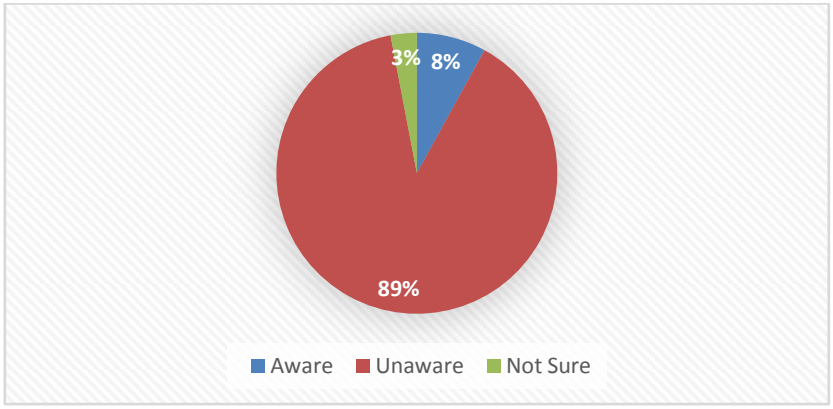

Figure 3: Pie chart showing respondents awareness on the benefits of energy efficiency and the harmful effects of energy wastage and the use of generators

The results also revealed a certain amount of ignorance among respondents with regards to the benefits of energy efficiency and the negative impact of generators on the environment. Most respondents that used generators in their homes/offices were not aware of the CO_2 emissions that come from their generating sets and its harmful effects on the environment. Respondents were also not aware that energy saved in one area can be used in another area to achieve an entirely different purpose.

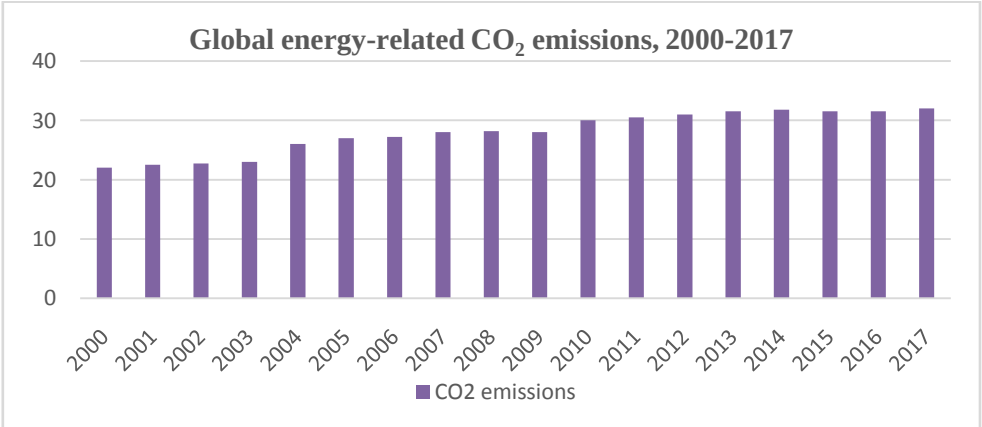

Figure 4: Global energy-related CO_2 emissions (Source: IEA, 2017)

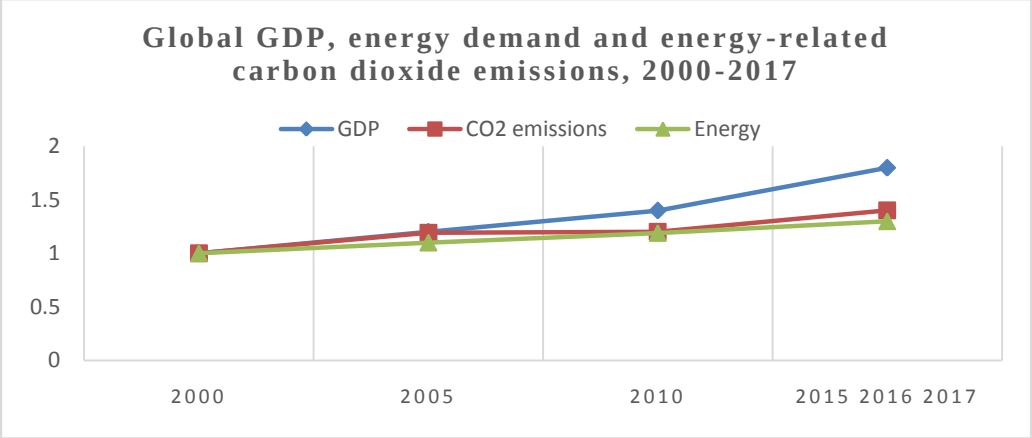

Figure 5: Global GDP, energy demand and energy-related carbon dioxide emissions (Source: IEA, 2017)

4. Discussion

Conventional construction methods have been linked to environmental damage, including depletion of natural resource, air and water pollution, toxic waste and global warming [5]. One obvious way to reduce the amount of greenhouse gas emissions is to reduce the amount of electricity used, since electricity generation is a major source of greenhouse gases. A lot of energy can be saved if Nigerians cultivate the habit of saving energy [14]. Well-designed energy-efficient solutions not only reduce costs and environmental impact, but can also improve occupant comfort, productivity, and the image of the organization. Key sustainable features such as the active design and passive design should be incorporated into new/existing buildings by designers to ensure not only energy efficiency in the building's performance but sustainability and also improving occupants' health [5,7]. Homes/offices in any climate can take advantage of solar energy by incorporating passive solar design features and decreasing carbon dioxide emissions. Even in cold winters, passive solar design can help cut heating costs and increase comfort [2]. Solar buildings are designed to keep the environment comfortable in all seasons without much expenditure on electricity 30 to 40% savings with additional 5 to 10% cost towards passive features [13,16].

On the issue of lighting, energy consumed in Nigeria can be drastically reduced if Nigerians replace their incandescent bulbs with energy efficiency bulbs [14]. If a particular household/office using 20 incandescent bulbs of 60W decides to replace them with energy saving bulbs of 20W, instead of spending 1200W/h (20 x 60W) for lighting, they will be spending 400 watts per hour (20 x 20W). Thus this saves approximately 67% of energy for lighting alone. This is a huge saving. On a larger scale, if Nigeria as a country phase out one million incandescent bulbs and replace them with energy saving bulbs, the country will be saving about 40MW of electricity. This is enough to provide electricity to many communities in Nigeria. If each of the 36 states and the FCT replace one million incandescent bulbs each, we can save up to 1480MW of electricity.

Refrigeration: Modern and energy efficient refrigerators can help save energy compared to the refrigerators designed 20-30 years ago. In many parts of the world, old and inefficient refrigerators are being replaced by energy-efficient refrigerators. Refrigerators are designed for different climates, for example there are refrigerators designed for the temperate region while others are designed for the tropical region [4]. Using a refrigerator designed for the temperate region in a tropical climate will lead to inefficient use of energy. Refrigerators should be used in the climate where they are designed to be used. In Nigeria, the use of secondhand refrigerators from Europe should be discouraged, because these refrigerators are designed for the European climate [14].

Cooling and Heating: It has been found that heating and cooling account for about 44% of utility bill. The energy spent on heating and cooling [14] can be reduced if households and owners of houses invest money for the proper insulation and weathering of their houses. Just by insulating walls and loft spaces you could reduce heat loss by over 50% and prevent wastage of energy. Also, there are modern and more efficient air conditioner and heating equipment [12]. By combining proper equipment maintenance and upgrades with insulation, weatherization and thermostat setting, energy consumption can be reduced drastically.

Without action by the international community, the expected demand for A/C in developing countries in the coming decades will substantially increase global GHG emissions [13]. Rising global temperatures resulting from climate change will only exacerbate the problem by increasing A/C demand and contributing to further climate change. These impacts will go unchecked unless the international community takes steps to reduce direct and indirect emissions from A/C usage.

Through landscaping, the environment can be kept comfortable, subsequently reducing energy bill. The planting of trees, vines, shrubs, etc in the environment is thus encouraged [5].

5. Recommendations

- Government should promote public awareness of sustainability.
- Government should make policy on power supply to phase out generators especially in Nigeria where owning a generator is now the norm. In Nigeria, most households and institutions that do not use generators simply cannot afford to buy them or fuel them (or in a case where they have it).
- The power situation in the country should be given urgent and serious attention to reduce the resort to informal power sources which contribute to global warming.
- Government should make policy to ensure that energy labels are comprehensive enough to provide adequate information to consumers.
- Government should include in their power policy incentives to encourage energy efficiency and penalties for power wastage. Awareness creation and enlightenment campaign is needed to erase this notion from the minds of Nigerians. People should be made to understand that if they save energy, there will be enough energy to go round everybody. This can help to solve the epileptic supply of electricity.
- In open-plan buildings, the most efficient lighting installations tend to have: well-designed lighting to suit the tasks and to make the spaces attractive; high-efficiency lamps (often high-frequency fluorescent) in efficient luminaires that emit a high proportion of the light and control its distribution well; good local, preferably individual, control – for example, using pull switches, hand-held infrared devices, or via the telephone – these can pay for themselves by simplifying wiring and minimizing alterations when layouts and partitions are changed; lights which can be switched on and off locally by occupants, and switched off automatically by occupancy sensors, or by a system which is properly programmed by a manager to take full account of occupiers' needs and opinions; efficient circulation area lighting which is controlled separately, to prevent switching on more lights than necessary; occupancy sensors in areas which are intermittently used, such as washrooms; daylight sensors to switch off lights when they are not required.
- Use of Renewable Energy Technologies (RETs): The use of solar heater to provide hot water in the house can help to reduce the amount of electrical energy spent on heating water. Solar heaters have been developed and used in other parts of the world to provide hot water in residential houses.

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Conflict of interest

The authors whose names are listed in this research certify that they have no affiliations with any organization or entity with any financial interest and as such there is no conflict of interest among the authors of this research.

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