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Review Article

Energy Audit and Efficiency of a Complex Building: A Comprehensive Review

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Abstract: An energy audit determines where, when, why and how energy is used in a facility, and to identify opportunities to improve efficiency. Energy audits are a powerful tool for identifying operating and equipment improvements that will save energy, reduce energy costs, and lead to better efficiency. Energy audit is also known as 'Energy Assessment'. The present study intends to review energy audit and efficiency of a complex building and identified the ways of reducing waste of energy in a complex building. This research provides an overview on energy audit which comprises of energy audit team, types of energy phase and classifications of energy audit, then energy use index. The paper also focuses on past works of energy audit on hospital buildings, academics building and other buildings. Finally, the results reveal that air-conditioners consume more energy followed by office equipment and then lighting. It was also found that energy wastage was as a result of higher energy consuming equipment and its usage during unoccupied hours.

Keywords: Energy Audit, Air-conditioners, Lighting, Energy Use Intensity

1. Introduction

Energy has a major impact on every aspect of our socio-economic life. It plays a vital role in the economic, social and political development of our nation. Inadequate supply of energy restricts socio-economic activities, limits economic growth and adversely affects the quality of life. Improvements in standards of living are manifested in increased food production, increased industrial output, the provision of efficient transportation, adequate shelter, healthcare and other human services. These will require increased energy consumption. Thus, our future energy requirements will continue to grow with increase in living standards, industrialization and a host of other socio-economic factors [1].

To run equipment use in industrial, commercial, residential and utility application, AC supply is required as input. In the whole world energy crisis is one of the major problems. In developing countries like Nigeria, where electrical energy resources are scarce and production of electricity is very costly, energy conservation studies are of great importance. In order to reduce energy consumptions for sustainable and energy-efficient manufacturing, continuous energy audit and process tracking of industrial machines are essential. Energy Audit involves proper planning, directing and controlling of supply and input – output ratio of consumption of energy to maximize productivity and minimize energy costs [2].

As per the energy Conservation Act. 2001 "Energy Audit" is defined as the verification, monitoring and analysis of use of energy including submission of technical report containing, recommendation for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption [3]. Energy audit can also be defined as processes to identifies all the energy end-use within the buildings under investigation; estimates how much energy is used by each end-use, and to determines the amount of energy used in relation to the budgeted or designed values [4].

Some of the common energy carriers or sources are coal, petroleum, natural gas, nuclear fuels, biomass etc. Of all these, the most widely used energy sources are the hydrocarbon compounds or fossil fuels which account for more than 80% of global primary energy consumption [5]. Energy usage has become an important concern in the past years and there has been growth awareness and an increase in taking personal responsibilities in preventing environmental pollution by minimizing energy waste. Energy has been the key to economic development worldwide, but in the way it is sourced, produced and used, two major drawbacks have emerged. Climate change and environmental externalities associated with energy consumption have become a major international issue. It has been observed that among the various sectors contributing to green house gas (GHG) emissions, industrial sector contribution was significant; thus mitigating GHG emissions from the sector offers one of the best ways of confronting the climate change problem. Energy efficiency is a major key in this regard. An estimated 10-30% reduction can be achieved at little or no cost by improving efficiency of energy use in the industry [6].

2. Theoretical Fundamentals

This section will highlight the energy audit definition and detail information on energy audit and also provide overview on energy use index

2.1. Energy Audit

Energy Audit usually referred to as an energy survey or energy inventory which is an examination of the total energy used in a particular property [30]. The analysis is designed to provide a relatively quick and simple method of determining not only how much energy is being consumed where and when, the energy audit will identified deficiencies in operating procedure and in physical facilities. Once these deficiencies are been identified, it will be apparent where to concentrate effort in order to save energy [19].

Energy audits consist of a detailed survey by a specialist of the energy used in an industrial firm. The objective is to provide technical and financial information to consumers about what actions can be taken to reduce their energy bills and at what costs.

Energy audits are used to identify cost-effective actions for energy efficiency improvements in existing buildings and facilities. Through normal failures and attrition, existing equipment is replaced with more advanced equipment. Energy audit is a way to accelerate this replacement process and to consider the most advanced equipment available on the market.

2.1.1. Energy Audit Team

The energy audit team may comprise the following:

A. Works Manager (Team Leader)
B. Material Manager
C. Electrical or Electronics Engineer
D. Mechanical Engineer
E. Civil Engineer
F. Accountant
G. Technician bearing knowledge of electrical/electronic/mechanical Engineering and Computer awareness

2.1.2. Types of Audit Phase

The type of Energy audit to be performed depends on various factors:

a) Type of industry
b) Type of Fuel/energy is being used.

Depth to which final audit is needed.

i. Function are performed in the industry
ii. Investment and time availability
iii. Potential and magnitude of cost reduction desired.

Most of energy Audit falls into the three categories:

I. Walk through: It involves going round the plant and identifying visible losses and negligence in operation and maintenance. It required one or three days for energy audit.
II. Mini audit: It involves collection of basic data, drawings, blue prints etc along with visual classifications. It requires one to three month for energy audit depending upon size of the plant.
III. Maxi audit: It involves preparation of total energy balance sheet, drawing energy flow charts etc

Energy audit can broadly be classified as:

A. Preliminary energy audit
B. Detailed audit

1. Preliminary Energy Audit

i. Gather records for the last 5years of the establishment's energy bills and the corresponding financial statements.
ii. Relate energy consumption to profitability of the establishment, such as energy cost to profit ratio, energy cost to revenue ratio, to establish the importance of energy in its operation.
iii. Familiarize on how these energy bills are computed to determine the composition of the charges.
iv. List all energy consuming equipment with detail of size, percent loading during the period, and hours of operation during the period.
v. Identify major energy consuming equipments.
vi. Inspect the major energy consuming equipment in the order of priority.
vii. Identify energy conservation opportunities (ECOs) by determining what condition may be modified/corrected to reduce the energy input to the equipment?
viii. What are the expected results in modifying/correcting these conditions?
ix. What are the steps necessary to modify/correct these conditions?
x. What is the cost involved?

xi. Perform a cost benefit analysis on the ECOs.
xii. List priorities depending on the net return expected from the proposed investment.
xiii. Write and describe these priorities in to an energy audit report.
xiv. Prepare a presentation of the energy audit report for the management.
xv. Present the energy audit report to the management for approval.
xvi. Organize the implementation of the energy conservation programme.
xvii. Implement no cost energy conservation measure.

2. Detailed Energy Audit

i. Prepare detailed audit and engineering study on approved energy conservation measures requiring additional investment.
ii. Review cost benefit analysis based on the updated figures.
iii. Revise energy conservation programme as required.
iv. Work out the payback period.
v. Secure management approval and funding.
vi. Organize the implementation of the revised energy conservation programme.
vii. Implement the energy conservation programme.
viii. Monitor and analyze the progress of the energy conservation measures.
ix. Report the progress of the energy conservation measure to management and determinate result to all concern.

2.1.3. Classification of Energy Audit

Energy audits are classified in order of increasing complexity based on levels:

a. Level 1: The walk-through audit

The walk-through audit is a tour of facility to visually inspect each system. The walk-through includes an evaluation of the energy consumption data to analyze energy use quantities and patterns, as well as to provide comparisons with industry averages or bench marks, for similar facilities. This is the least costly audit, but a cost saving opportunities through improvements in operational and maintenance practices. The information may be used for a more detailed audit later if the preliminary savings potential appears to warrant further auditing activity [7].

b. Level 2: Standard audit

These are quantities of energy use and losses through a more detailed review and analysis of equipment, system operational characteristics and audit measurement and testing. Standard energy engineering calculations are used to analyze efficiencies and calculate energy and costs saving based on improvements and changes to each system. The standard audit will also include an economic analysis of recommended energy conservation measures (ECMs) [8].

c. Level 3: Computer Simulation

This is the most expressive level of energy audit, includes more detailed energy use by function and a more comprehensive evaluation of energy use patterns. Computer simulation software is used to predict building system performance and account for changes in weather and other conditions. The goal is to build base for comparison that is consistent with the actual energy use of the facility. The auditor will make changes to improve the efficiency of various systems, measure the effects compared to the base line. This method also accounts for interaction between systems to help to prevent over estimation of saving [7].

2.2. Energy Use Index

Energy use index is expressed as energy per square foot per year. It is calculated by dividing the total energy consumed by the building in one year (measured in kBtu or GJ) by the total gross area of the building.

3. Review on Energy Audit

3.1. Energy Audit on Hospital Buildings

In 2003, HU *et al.* [9] presented the study of energy consumption and cost in a large acute hospital in subtropical Taipei city of Tawan, from August 2001 to July 2002. The result showed that air-conditioning is the major electricity end use, accounting for more than 50% of the total building energy use. The highest monthly energy use intensity (EUI) value comes out in July with a value of $25.5 kWm^{-2}month^{-1}$ and the annual EUI value was $259.45 kWhm^{-2}year^{-1}$.The highest overall demand use Intensity value (DUI) was $45.7 Wm^{-2}$ that relates to the electricity contract capacity, appears in August 2001. The highest EUI value found in the region of operation theater (OT), in which the EUI value is about three times higher than that in general place.

Deepalakishmi [10] studied the energy consumption in Ruby Hall Clinic in Pune, the result revealed that there is a reduction in the consumption by over 27% by installing of solar heating panels, water treatment plant, utilizing west heat recovery from air conditioning systems, optimizing indoor and street lighting, checking the air conditioning system and implementation of effective automation and control.

In 2008, Da'as [11] presented the potential for energy saving in the Palestinian hospitals sector by implementing energy conservation measures they have achieved average total saving of 17% for hospitals and 14%, 43% and 17% for cooling and heating, oxygen generation units, power factor correction and 5% for lighting system respectively.

Global Green and Healthily Hospital (GGHH) network [12], presented study on energy saving and carbon reduction policy at the Taiwan National Cheng Kung University Hospital, the results indicated that luminosity increased by 30%, energy saving rate was 46.53% with a cost recovery period of 2.6 years. The annual power saving was nearly $129,700; lowered air conditioning load by 82.9 RT/year; reduced 1,362 tons of CO_2 emission per year; the total energy saving rate is 52%. In adopted heat pump/hot water system progress, the annual power saving was nearly $157,705; annual CO_2 emission reduction 1,228.9 tons/year; energy saving rate was 64.6%. In conducting air condition renovation, the results were achieved energy saving rate of 33.56%; estimated annual cost saving 2012 is nearly \$432,491, estimated annual CO_2 emission is 2,668tons/year.

Janos *et al.* [13] in their studies presented result for an estimated reduction of 957.227kwh or about 17% of the electrical use and a reduction in fuel oil consumption of approximately 27,191 liters or about 10%, with total identified cost saving of \$60,303,600/GYD (\$301,518 USD) per year. At a total estimated cost of \$103,918,800 GYD (\$519,594USD) these project have a combine payback period of about 1.7 years.

Tukur [14], performed a research on the amount of energy consumed in General hospital Katsina over a period of four years (2009-2012) and identified areas where energy is wasted and recommended energy saving measures. Identified energy consumption from the combination of AGO in diesel powered generations contribute 65% and energy used from the national grid has 35% with proposed annual saving measures of 35% if implemented. Consumption of the three major energy end users revealed that ventilation and air conditioning had a higher energy consumption of 58.50% followed by lighting and electrical equipment, with percentage consumption of 32.22% and 29.25% respectively. It was observed that the major energy wastage was as a result of leaving energy consumptions equipment such as Air-conditions, Fans, Lightings and other electrical equipment on during low occupancy or unoccupied hours.

Umar [15] carried out a research that the amount of energy consumed in Gumel General Hospital, in which the monthly electricity data was gathered and analyzed. Results showed an average electricity consumption of 1,445,448Wh with an average energy use index of 216.97kWh/patient/year was obtained. Analysis was performed on the data to identify energy conserving measures (ECMs), which resulted in 37% saving of the annual energy consumption.

Teke and Timur [16] presented results on over view of energy savings and efficiency strategies at the hospitals. The results indicate hospital represent approximately 6% of total energy consumption in the utility building. Heating, ventilation and air conditioning (HVAC) system are the major part of electrical energy consumption at the hospitals. The air conditioning system is responsible for around 70% of total electricity consumption. Electric motors and lighting systems in a hospital represent approximately 19% and 21% of the total energy consumptions respectively.

In 2015, the energy performance indices for hospital buildings in Nigeria was done by Nwanya and his colleagues [17]. The results of the analysis show that an average hospital in Nigeria, depending on it category, uses energy as follows: rural 66.936kwh, urban 343.23kWh/day; specialist hospital 459.872kWh/day and Teaching Hospital 1944.394kWh/day. Lighting shown as critical energy function and accounts for as much as 15%, 36%, 40.5% and 69.5% of daily energy use in rural, urban, Specialist and Teaching Hospitals, respectively. A productivity based energy performance indicator for each hospital category was out to be 3.346kWh/bed space/day, 2.367kWh/bed space/day, 4.548kWh/bedspace/day and 19.443kWh/bedspace/day, respectively for typical rural, urban, specialist and teaching hospitals. The respective building index (BEI) values for the categories of hospital are as follows: rural 0.13kWh/m^2/day; urban 0.077kWh/m^2/day; specialist 0.088kWh/m^2/day and teaching 0.277kWh/m^2/day respectively.

Rohde and Martinez [18], in their study on equipment and energy usage in a large teaching hospital in Norway presented the results of total consumption was up to 50% of the whole building energy consumption. Much of this is due to increasing energy intensity of hospital specific equipment. Measured power and reported usage patterns for equipment in the studied departments show day time energy intensity of equipment at about 90kWh/ m^2 per year compared to building code standard value of only47kWh/m^2 per year for hospitals.

Abbas and Enaburekhan [19] carried out the energy audit of Murtala Muhammad Specialist Hospital from its record of fuel expenditure and electricity bills for a period of four years (2012-2015). The investigations carried out are the energy consumption pattern of energy carriers and the energy end users, the energy use index of the facilities and the energy conservation measures in the hospital. The results show that the energy consumption pattern of the hospital showed distinct seasonal variations indicating highest electricity demand during the hot humid months from April to August resulting in high cooing/air conditioning requirement. The average annual consumption and demand of the electricity of the hospital are 2492637.18KWh and 5030953.92KWh respectively and the overall percentage contribution of the energy carriers were 32.09% and 67.91% from national grid and AGO respectively of the years under investigation. The annual demand showed that air conditioners have the highest percentage consumption of 47.03%, followed by office equipment, medical machines and equipment, and the lighting with 19.91%, 1.28% and 14.78% respectively.

3.2. Energy Audit on Academic Buildings

Sani [20] study the energy audit of Kaduna State Polytechnic, the work revealed that the consumption pattern showed distinct seasonal variation indicating peak electrical demands during the hot summer months (June to September) due to significant air-conditioning requirement. Based on the average monthly electrical use data, the annual electrical use per student per annum was found to be 216.97KWh with a yearly estimated saving of 37% of the total annual consumption.

Abubakar [21] studied the amount of energy consumed in the Federal College of Education, Katsina, over a period of four years (2006-2009) and identified areas where energy is being wasted and subsequently came up with energy saving measures. Results showed that air-conditioners has the highest rate of 41.2% followed by electrical equipment and then lighting with percentage consumption of 32.22% and26.50% respectively. The consumption of energy carriers are AGO with 5.0% and National Grid 42.20% with yearly savings of 35% if all recommendations are implemented.

Muhammad and Budaiwi [22] carried out a study on strategies for reducing energy consumption at a student's cafeteria of King Fahad University of Petroleum and Minerals, Saudi Arabia, found that, through various conservation measures with a combine design saving of 27.40%, HVAC system saving 10.6%, implementation of standard saving about 16.7%, lighting 6.6%, equipment 2.6%, insulation 2.5% and glazing 1.4%.

Altamsh and Alan [23], carried out a study on energy modeling of an energy efficient building (library) with gas driven absorption heat pump system in Tweed Ontario. Through the eQuest simulation a baseline model for the building was created for the years 2012, 2013, 2014, on average the simulated annual electricity consumptions were 1.5% less than the actual electricity consumptions. The average difference for annual natural gas consumption was 7%. This building is a single-storey 469.8 square meters builds in 2011, the geographical coordinates of the library are 44-28N and 77-18W and maximum occupancy is 100 people. The results from eQuest simulations, all the three simulation runs electricity consumption predicted by eQuest was found to be very close to actual electricity consumption. The largest percentage difference between overall simulated annual consumption is 1.5% below the actual electricity for the year 2014. For the years 2012-2014 the annual difference ranged between 1.1% and 2.0%. On a monthly basis, the largest difference occurs in June of 2014 with difference of 1.84%. The results show that eQuest is capable of simulating annual electricity consumption with reasonable accuracy. The Normalized Mean Bias Error (NMBE) values for 2012, 2013 and 2014 were -2.0%, -1.5%, and -1.1% respectively. Note that the results from natural gas were less accurate than the ones for electricity.

Oyedepo*et al.* [24] in their study on energy demand and consumption in Covenant University, Ota, Nigeria, presented results as; space cooling (29%), and lighting (29%) have the highest percentage electricity consumption in the university. In the academic buildings, maximum power is consumed by space cooling (49%). In the staff quarters, lighting applications consumed maximum power (39%), followed by space cooling application (18%). The annual energy and cost saving potentials for replacing traditional Fluorescent Tube Light (FTL) and incandescent bulbs with Compact Fluorescent Lamps (CFLs) in the student's hostels and in the staff quarters are about 394Wh, equivalent to ₦4.8million ($30,000) and 64MWh, ₦7.9million equivalent to ($49.375) respectively. For space cooling systems, the annual energy and cost saving potentials for replacing conventional resistance electric regulator fans with electronic regulator fans is about 367MWh and ₦9.8million ($61,250) respectively.

A research on energy auditing and management at Ahmad Bello University Zaria, Nigeria on student's hostel was performed by Modu *et al.* [25]. The authors presented result of retrofitting which accounted that lighting energy consumption per year before retrofitting was 58% equivalent to 47,888kWh/yr was reduced to 19,165.40kWh/yr after retrofitting, which resulted to energy saving of 8,213.8kWh/yr. if implemented properly with an efficient energy saving which will reduced their utility saving by 60%.

3.3. Energy Audit on Other Buildings

Galadima [26] carried out an analysis of electrical energy consumption of in a government housing estate in Zamfara State for effective utilization. The consumption data are for lighting, air-conditioning, and household equipment. It was revealed that air-conditioners have over 77% of the energy consumption, equipment accounted for over 21%, and lighting for about 1%. The author suggested that retrofitting of 1.5hp instead of 2hp air-conditioners could save a lot of energy.

The energy consumption in commercial buildings in South Africa was carried out by Mathews *et al.* [27]. The study indicated that 20% of all Municipal electrical energy is used in commercial and office building. Moreover, the result shows that air-conditioning was 50% for a substantial share of energy use.

For effective energy utilization, Rabi'u performed study on effective energy utilization in Katsina state secretariat complex building in 2005 [28]. It was found that the annual electricity use per unit gross floor area was 85.84kWh/m^2 with a mean of 37.38kWh/m^2. The consumption of the ventilation, air-conditioning and electrical equipment and lightings in percentage were found to be 58.12%, 23.71% and 18.17% respectively.

Harpreet K. and Kamal D. [29] described that Energy conservation ultimately leads to economic benefits as the cost of production is reduced. In some energy-intensive industries like steel, aluminium, cement, fertilizer, pulp and paper. The cost of energy forms a significant part of the total cost of product. Energy cost as a percent of total cost of product in the entire industrial sector in India varies from as low as 0.36% to as high as 65%. Using energy efficient technologies will reduce the manufacturing cost and lead to production of cheaper and better quality products.

4. Conclusion

In a country like Nigeria where electricity supply is not reliable and fuel price always on the rise, energy audit should be used to check for unnecessary losses in energy, to determine areas of energy savings and to establish conservation measures to cut down excessive energy usage. This will help to reduce spending on electricity. As in most of the results from the review, it can be seen that among the end-users, air-conditioners consume more energy followed by office equipment and then lighting. It was also found that energy wastage was as a result of higher energy consuming equipment and its usage during unoccupied hours.

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