Mitigating the Challenge of Energy Crisis via Energy Audit and Efficiency Measures: A Case of a Household in Nigeria

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***Abstract*— To meet goal 7 of the sustainable development goals (SDGs), developing countries like Nigeria face challenges in meeting energy demand due to inadequate generation, poor transmission and poor investment. Approximately 40% of Nigeria's residents do not have electricity access. Energy audits and efficiency measures, such as proper housekeeping, retrofitting lighting and pump systems, and installing renewable energy sources, can help to reduce energy consumption and mitigate the country's energy crisis. This study conducted on a residential building in Nigeria found that retrofitting the lighting system could save as much as 230kWh and have a payback period of 9 months with a return on investment (ROI) of 126%. The retrofit of the pump system is expected to save 182kWh within a payback period of 2 years and have an ROI of 50%. The installation of solar panels and retrofit of batteries is expected to save 3MWh at a capital cost of N300,000, with an ROI of 26% and a net present value of over N690,000. These measures would also reduce greenhouse gas emissions by 0.14, 0.10, and 1.73 tons per year.**

Keywords— Energy Audit, Lighting, HVAC, Building Envelop, Electrical system, Energy Efficiency

I. INTRODUCTION

Over 5.3 billion Mscf of gases, including hydrocarbons, were forecasted to be flared between 2015 and 2030 from oil exploration sites in Nigeria [1]. Despite this volume's electricity generation potential, Nigeria's utility power supply is still deficient due to inadequate generation, poor transmission networks, and insufficient investment [2]. According to the World Bank 2022 report, an estimated 733 million people are without electricity [3]; about 12.5% of this population lives in Nigeria [4]. Nigeria's energy crisis results from an insufficient energy supply to meet its demand. This crisis has led to power instability, blackouts, power shortages, and price spikes, which can negatively impact households, health, businesses, and economies. In extreme cases, energy crises can also cause civil unrest and conflict. Governments and organizations around the globe are working to address energy crises by developing new energy sources, improving energy efficiency through audits, and implementing policies and regulations to manage energy demand. An energy audit comprehensively evaluates a building or industrial facility's energy efficiency. It aims to identify ways to reduce energy consumption and costs and increase the use of renewable energy sources [5], [6].

Most of the country's residents have used fossil fuel-fired mobile generators [7], having adverse health and environmental effects [8]. In contrast, others have resulted in the use of inverters, as described in [9]. Whichever source is used, the efficiency of the use of energy is therefore paramount. This is achieved via effective audit involving analyses of the building's energy usage, systems, and equipment and identifying potential energy-saving measures. The main objective of audits is to identify opportunities for improving energy efficiency and provide recommendations for doing so. The audit results can be used to develop an energy management plan or inform decisions about energy-saving investments.

This study's building is a twin bungalow flat covering a total floor area of 164 square meters. Each unit has a similar layout, with a living and dining room, a main bedroom, two additional bedrooms, a kitchen, three restrooms, a lobby, and a front and backyard balcony. Other features of the building are represented in Table 1.

The building typically has a daily supply of public utility electricity for 12 to 15 hours. It previously had a 3.5kVA petrol-fired generator and a 3kVA inverter system with lead acid batteries, but these are currently not functioning. The building's electrical load consists of resistive and reactive components, as typical with household loads [10]; the utility company manages the reactive load to prevent it from affecting tariffs.

The article is divided into several sections, each focusing on a specific aspect of the study. Section I has provided an overview of the building's energy usage. Section II outlines the audit's goals and examines the building's energy systems. Section III presents the key findings of the assessment. Section IV discusses energy efficiency measures, while Section V

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outlines retrofit costs and their environmental benefits. Finally, concluding remarks were offered in section VI.

Table 1: Facility description and properties

Facility item	Type
Type	Bungalow
Flat	Twin
Exterior window	Single glaze (14)
Wall type	Cement Block
Wall finish	Texcote paint
Interior colour	Cream
Exterior colour	Lime and white recess
Floor Type	Reinforce Concrete
Roofing Type	Gable Aluminium
Orientation	Length – West Entry – South-east
Floor Space	164 square meters
Electrical Power Supply and Load Systems	
Daily Power Supply	12 to 15 hours
Generator	1 (3.5 kVA)
Water pump	1 (800W)
Inverter system	1 (3 kVA)
LED Bulb	10 (86 W)
CFL Bulb	7 (178 W)
Fans	4(230W)
TVs	2 (185W)
Pressing iron	2 (2000W)
Kettles	2 (2000W)
Refrigerators	2 (300W)
Freezers	2 (300W)
Air conditioners	4 (4400W)
Washing machine	2 (200W)

II. Energy Use and Audit

A. *Energy Use Intensity*

Energy use intensity (EUI) in households refers to the amount of energy used per unit of floor area per year, typically measured in kWh/m²/year. A household with a higher EUI is generally considered less energy efficient, as it consumes more energy to heat, cool, and power the same amount of living space. The building in this study has an annual energy consumption of approximately 5087 kWh, with an average monthly consumption of 424 kWh, resulting in annual energy costs of N136,535.08 (about N11,380 per month). The EUI for this building is 31kWh/m²/year. When benchmarked to facilities of similar use in other countries, the EUI for this site is lower than that of similar structures in other countries. The indicators can be obtained by normalizing the energy use with floor area and operational hours. For instance, the authors have used a sample of energy consumption data and the floor area to calculate the EUI for school buildings and Singapore e-Energy Benchmark [11].

One way to compare the energy efficiency of buildings is to use the Energy EUI, which is calculated by collecting data on electricity consumption. However, in large buildings with extensive grounds, such as large houses, the use of the EUI may be less common as the floor area may not necessarily be related to the number of occupants. In these cases, a large, energy-inefficient house with few occupants may have a better EUI than a small, energy-efficient house with many occupants, as the presence of more people can increase the cooling load and electricity consumption for appliances [12]. This implies several factors ranging from building use and occupancy, can affect the value of the building EUI.

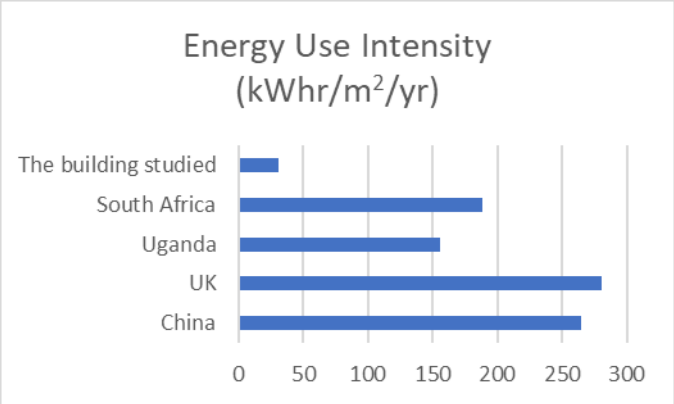


Fig. 1. Comparison of Energy Use Intensities

B. *Audit Goals and Objectives*

This building aims to operate efficiently and achieve 20% energy savings through the following objectives:

1. Identify and quantify specific opportunities to reduce the building's energy use by at least 20%.
2. Identify no-cost operational or maintenance adjustments that will save energy.
3. Recommend energy efficiency retrofits.
4. Propose an Energy Management System.

To achieve these objectives, the scope of work for the audit includes the following:

1. Discussions with the landlord and housekeepers.
2. Site inspection, inventory collation, and room-by-room audit.
3. Monthly details of the building's energy usage from energy bills.

III. Methodology and The Existing Energy Systems

A. *System Audit Process*

The audit process includes the following steps:

1. Briefing the occupants and housekeepers on the various facilities and their usage
2. Walking through the building to identify measurement points and inventorying the electrical systems and their operating profiles
3. Measuring the electrical energy supply from the utility and the output
4. Establishing a measurement baseline for weekdays, weekends, lockdowns, and public holidays
5. Evaluating the load profiles with the utility and generators, if any.

6. Identifying energy management opportunities, improvements, system redesigns/retrofits, and best practices to reduce energy costs and improve reliability
7. Identifying opportunities for operation and maintenance improvements
8. Evaluating the building envelope
9. Providing recommendations for identified opportunities for energy reduction
10. Outlining conceptual descriptions for implementing energy efficient measures, the baseline cost of current operations, savings estimates, and feasibility estimates for installation costs.

The international standard organization (ISO 50002) and American society of heating, refrigeration, and air conditioning engineers (ASHRAE standard 211) set the standards for types of energy audits [13], [14] that may be carried out in buildings which are:

- Level 1: A basic audit that assesses the building's energy use and identifies low-cost/no-cost energy conservation measures.
- Level 2: A more detailed audit that reviews the building's systems and equipment, analyzes potential energy-saving measures, and assesses the potential for renewable energy sources.
- Level 3: A comprehensive audit that includes a detailed analysis of the building's systems and equipment, an evaluation of potential energy-saving measures, and an analysis of the economic feasibility of various options. It may also include simulations of the building's energy use under different scenarios.

This research will employ a Level 2 audit reviewing existing energy systems and analysing the financial and environmental implications of identified energy-saving measures to be implemented.

B. *Existing Electrical System Observations and Research*

The building's electrical system primarily consists of a water pump. There is a moribund 3.5kVA generator in poor condition and a 3.0kVA inverter that charges two parallel 100Ah batteries from the utility. This inverter system is used to power the TV socket in the sitting room, one light in the sitting room and main bedroom, and the two kitchens of each flat in the household. The main driver of energy usage was the house's occupancy, as shown in Fig. 2, rather than the cooling-degree days (CDD). On a typical day measurement was taken, a conservative total of 11.42kWh was used for electricity, as shown in Fig. 3. The housekeeping practice of turning off some loads overnight seemed to be the best practice among the occupants. This is a typical average daily energy usage.

C. *Existing HVAC System Observations and Research*

HVAC systems generally contribute to nearly 40% of the energy used by commercial buildings and over 50% of total energy consumption in IT buildings [15]. Enhancing the efficiency of HVAC systems should be a top priority for any building's energy efficiency. However, the building's heating, ventilation, and air conditioning (HVAC) systems are not in use. Each flat has a single 1.2kW and 1kW unit. This report will not analyze the potential energy savings from the HVAC system because they have not been in use in the building for a

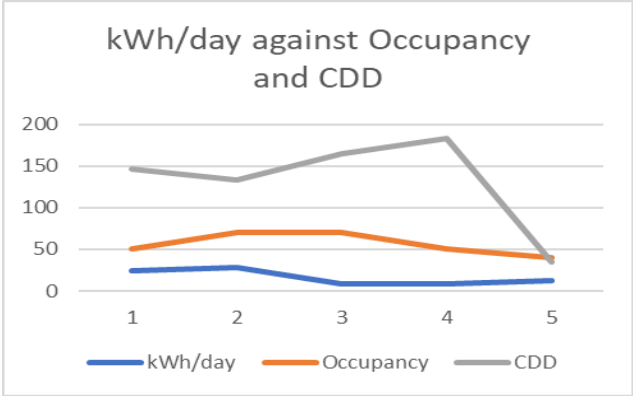


Fig. 2. Energy consumption driver

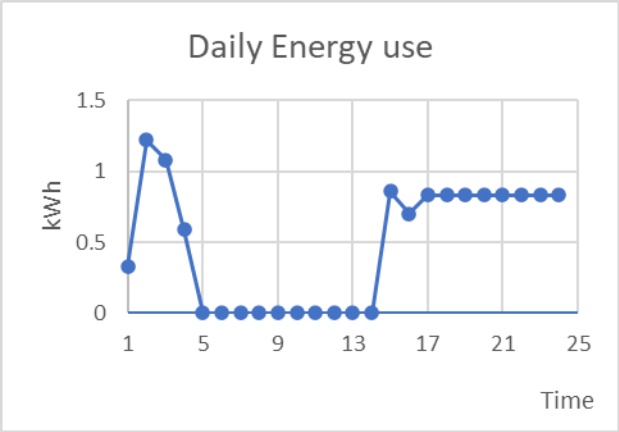


Fig. 3. Typical day energy use

while, and the occupants are not interested in revamping them.

D. *Existing Lighting System Observations and Research*

The audit of the lighting infrastructure at the building revealed that the building was adequately lit for a residential building (as measured on the Lux meter) but was not designed to utilize natural daylight optimally. Other lighting points installed but not in use were only examined and noted for possible housekeeping measures and were not included in the analysis. Fig. 4 shows the types of lighting technologies used and their power consumption. A good practice of the occupants

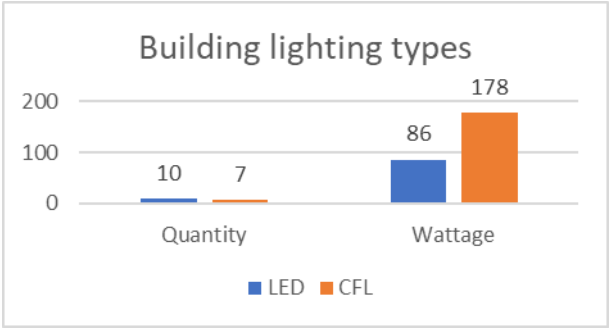


Fig. 4. Comparison of Energy use intensities

shows the light emitting diodes (LEDs) surpass compact fluorescent lights (CFLs), but the wattage of the CFLs doubles the LEDs.

Other key lighting observations:

1. Almost half of the lighting energy usage comes from compact fluorescent lighting, which can be easily replaced with more energy-efficient LED lighting. The occupants of the building should be commended for incorporating more LED lighting in their building.
2. The audit revealed good housekeeping and reasonable utilization of mechanical switches in areas that are not occupied. This should be encouraged.
3. Some of the fittings that use CFLs and halogen bulbs have burnt out, are no longer in use, and should be disconnected to prevent energy waste.
4. The entrance foyer has ample natural lighting, making artificial lighting during the day unnecessary.

E. Existing Building Envelop System Observations and Research

- Walls: The external walls are made of concrete/cement blocks and are painted with white emulsion in the recess and lime on the exterior. The walls are somewhat reflective due to the cream colour of the wall paint finish. The ample roof space over the columns provides shading for the front wall.
- Windows: The windows are monotonous, single-glazed, sliding aluminium frames with sliding nets. This window design is repeated on all four facades of the building. Although the overall building has a window-to-wall ratio (WWR) of 23%, which is slightly higher than the recommended 20% in the Nigeria building energy efficiency codes (NBEEC) [12], the kitchen and all toilets in the building have a low WWR. These rooms will require more lighting during the day and ventilation.
- Floors: As observed from the drawings, the floor type used in the construction of the building is reinforced concrete. The floor finish material in most areas is tiled; the tiles are dark in colour and do not promote energy efficiency by enhancing illumination.
- Roofing: The roof, as observed from the drawing and accessed, is a simple gable aluminium roof. Few leaks were noticed, but the occupants generally believe that the roof is in good condition.
- Orientation: The building's length is oriented towards the west, but the entry face is located due southeast and is prone to solar heat gain from the first flat in the morning. The second flat receives sunlight from midday to sunset. Curtains are used to shade solar irradiance in the building all day.

F. Existing Energy Management System Observations and Research

Historical energy data was collected from the family members. We obtained consistent records for utility bills from February 2020 to May 2020, and the cost per kWh was a fixed tariff of N26.90/kWh. The energy usage from the utility showed an average monthly usage cost of slightly over N12,000. The findings from the analysis of the collected data will be reported in the next section.

IV. Key Findings

The breakdown of the annual energy consumption among the various types of loads is shown in Fig. 5. It can be seen from the figure that three main load types; pump, refrigeration, fan, TVs, and washing machine - account for over 75% of the annual energy consumption. This indicates a great potential for energy savings and suggests that occupancy and cooling degree days will be significant factors in determining annual energy consumption.

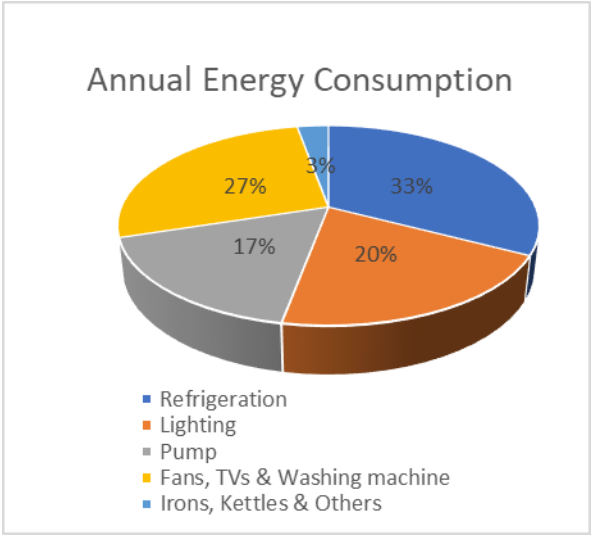


Fig. 5. Percentage of annual energy consumption breakdown

The pump system was identified as a significant source of energy waste. In addition to the pump, refrigerators and electronics such as fans and TVs account for 60% of the energy used in the building. While the lighting fixtures only consume 20% of the total energy, they still use compact fluorescent lamps (CFLs) in some areas. These lamps can be replaced with LEDs to reduce total energy consumption.

A. Baseline Operating Parameters

The building currently consumes 5087kWh per year and has an energy use index of 62kWh/m^2/yr, which is very much below the global average for an administrative building type.

On the supply side, the building has a generating set which is no longer used because of its high capacity for the loads it supplies, cost of maintenance over time and its fuel consumption compared to the use of the utility. It also has an in-efficient 3kVA inverter system with two 100Ah deep cycle batteries, which can power the connected load for only 2hrs

after charging for about 4hrs. On the load side, 27% of the energy consumed annually is taken by Fans, TV, and Washing machines, 33% goes for refrigeration and 17% for Pump, 20% for lighting, while 3% goes to Kettles, Irons, and others. Further analysis of the energy consumption of the two flats in

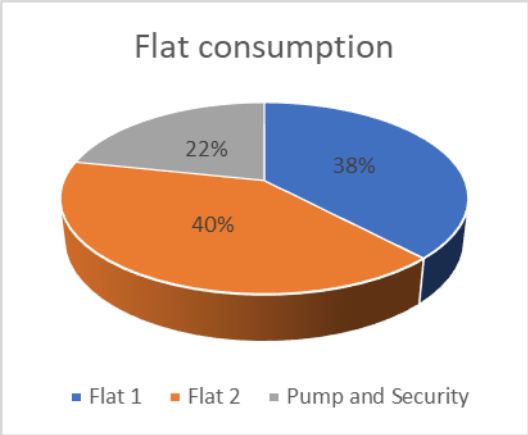


Fig. 6. Consumption of each flat

Fig. 6 revealed that flat 1 consumes 38% of the total annual energy use, flat 2 consumes 40%, while the Pump and security outfit consumes 22%.

B. *Energy Efficiency Measures (EEMs) and Cost Savings Opportunities*

The combined effect of the improvement measures discussed in the report provides energy reduction and cost savings opportunities.

1) EEM #1 Overview – Electrical System

For improved efficiency, major energy-consuming appliances such as fans, televisions, washing machines, and refrigeration loads should be downsized and retrofitted. It is recommended to incorporate a solar charging system with the existing 3kVA inverter and to purchase and install two 220Ah batteries to significant loads. Timers should also be installed to extend the life of the pump. In the long run, an efficient premium pump may be necessary.

2) EEM #2 Overview – HVAC System

Recommendations for replacing three air conditioning units with more efficient technologies were proposed. However, the occupants prefer fans for ventilation instead of air conditioners.

3) EEM #3 Overview – Lighting System

Approximately 40% of the building's lighting consists of CFLs, which can be replaced with more energy-efficient LEDs. Housekeeping measures, such as switching off lamps in unoccupied rooms and timely switching off unused appliances, were advised to be maintained to save energy and costs. Retrofitting with LEDs is a cost-effective way to increase energy efficiency and reduce global emissions.

4) EEM #4 Overview – Building Envelop

The analysis of the building envelope revealed that the structure covers about 164 square meters and has a good energy use intensity. However, retrofitting the walls, windows, and roof was a significant investment with limited benefits. As such, retrofits to the building envelope were not recommended.

V. Investment Grade and Environmental Impact

Implementing housekeeping measures such as turning off lighting and appliances when not in use are no-cost measures that can help reduce energy consumption.

Low-investment retrofits of the lighting and pump systems can lead to energy savings. For example, replacing the current lighting system with more efficient LEDs will save 230kWh of energy, with a payback period of 9 months and a return on investment of 126%. Similarly, investing N10,000 in a pump retrofit will save 182kWh, with a payback period of 2 years and an ROI of 50%.

A medium investment in solar panels and batteries for the building's power supply, at the cost of N300,000, will bring a saving of 3MWh over 3.8 years, with an ROI of 26% and a net present value of over N690,000. These retrofits will also reduce greenhouse gas emissions of 0.14, 0.10, and 1.73 tons per year. By conducting energy audits and implementing proper efficiency measures, buildings and industries can reduce their demand for electricity from inadequate generating stations. As a result, excess electricity can be transmitted to higher-demand areas, contributing to energy conservation and sustainability. This helps alleviate energy crises, reduces greenhouse gas emissions, and mitigates global warming.

VI. Conclusion and Further Works

Overall, the energy audit of the building identified opportunities to reduce energy consumption and improve energy efficiency through various measures, including housekeeping practices, lighting and pump retrofits, and the installation of solar panels. According to our estimates, implementing the energy efficiency recommendations from this audit in residential, commercial, and industrial buildings and operations in Nigeria is expected to result in substantial energy savings and decrease greenhouse gas emissions. Not only will these measures improve the efficiency of operations, but they will also reduce energy costs and positively impact the environment. Additionally, implementing these recommendations has the potential to alleviate energy crises in Nigeria and the world.

REFERENCES

[1] O. A. Lawal, T. O. Akinyemi, and O. J. Ramonu, 'Mitigating the Challenges of Global Warming by Harnessing the Electric Power Generation Potential of Gas Flaring in Nigeria', vol. 9, no. 3, p. 7, 2018.

[2] O. A. Lawal, T. Sule, and A. Rasaq Atanda, *Power Flow solution for Voltage Stability Improvement using Static VAr Compensation and Genetic Algorithm Optimization (A case study of the Nigerian 330kV Power system Network)*. 2017.

[3] 'Downloads | Tracking SDG 7'. https://trackingsdg7.esmap.org/downloads (accessed Jan. 07, 2023).

[4] 'Nigeria | Tracking SDG 7'. https://trackingsdg7.esmap.org/country/nigeria (accessed Jan. 07, 2023).
[5] L. Murphy, 'The influence of energy audits on the energy efficiency investments of private owner-occupied households in the Netherlands', *Energy Policy*, vol. 65, pp. 398–407, Feb. 2014, doi: 10.1016/j.enpol.2013.10.016.
[6] G. Di Foggia, 'Energy efficiency measures in buildings for achieving sustainable development goals', *Heliyon*, vol. 4, no. 11, p. e00953, Nov. 2018, doi: 10.1016/j.heliyon.2018.e00953.
[7] O. A. Lawal, M. Z. Oba, and L. Kabiru, 'Analysis of Environmental Effects of the Major Stand-alone Power Generators Used in Nigeria and Sub-saharan Africa', *ATBU J. Environ. Technol.*, vol. 13, no. 2, Art. no. 2, 2020.
[8] A. Jimoh, A. Zinat, L. Kabiru, and A. Lawal, 'THE STUDY AND INVESTIGATION OF POTENTIAL FAILURE MODES, EFFECT AND CRITICALITY IN 4 KVA INVERTER SYSTEMS', vol. 1, pp. 2705–3865, Sep. 2020.
[9] O. A. Lawal, L. Kabiru, and A. Jimoh, 'Performance Equation Modeling for A 2 KVA Locally Designed and Constructed Inverter Systems', vol. 2, pp. 23–28, Oct. 2017.
[10] A. Lawal, O. Lawal, and A. Jimoh, 'Residential Building Load Rationing using Pareto-Efficient Optimization Approach', vol. 8, pp. 57–62, Sep. 2020.
[11] 'Benchmarking Energy Efficiency of Commercial Office Buildings in Kampala', in *2nd Intl' Conference on Advances in Engineering Sciences and Applied Mathematics (ICAESAM'2014) May 4-5, 2014 Istanbul (Turkey)*, Sep. 2017. doi: 10.15242/IIE.E0514065.
[12] 'Nigeria_BEEC-National Building Energy Efficiency Code.pdf'. https://rise.esmap.org/data/files/library/nigeria/Energy%20Efficiency/Supporting%20Documentation/Nigeria_BEEC-National%20Building%20Energy%20Efficiency%20Code.pdf (accessed Nov. 17, 2021).
[13] 14:00-17:00, 'ISO 50002:2014', *ISO*. https://www.iso.org/standard/60088.html (accessed Jan. 04, 2023).
[14] admin, 'Levels of Energy Audits', *Iso QA - GDPR Isle of Man and Compliance*, Apr. 03, 2018. https://www.isoiom.com/levels-of-energy-audits/ (accessed Jan. 04, 2023).
[15] 'ENERGY STAR Verified HVAC Installation (ESVI)'. https://www.energystar.gov/https%3A//www.energystar.gov/campaign/heating_cooling/esvi (accessed Nov. 17, 2021).

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