Energy Waste Reduction in University of Ibadan, Nigeria's Water Factory Using Energy Audit Approach

Mojisola A. Bolarinwa and Adeoye P. Abodunde

Abstract — **The technical cost incurred in providing adequate services for drinkable water production and distribution is high in developing countries of which Nigeria is no exception. By analysing the energy aspect of this cost, with a view of eliminating non-value-adding energy wastes, the cost of production can be reduced. In this work, an energy audit of the University of Ibadan water factory has been carried out, as a means of reducing the electrical energy wastes within the factory, as well as the associated costs to these energy wastes. Data on equipment being used and their power ratings were collected via walkthrough audit, by means of interviews and personnel observation, and thereafter inputted into Excel spreadsheet in order to determine the extent of energy consumption of each of the factory equipment, areas of energy wastage and areas of energy conservation opportunities. The factory's structural data was obtained through the use of a 50m fibre measuring tape, in order to carry out lighting, air-conditioning and ventilation assessments on selected rooms in the factory, as means of proper energy conservation. Energy management measures were deployed by suggestion of more efficient equipment. Major equipment found includes automatic filling machine, pumps, steam generator, conveyor etc. The total electrical energy consumption of the factory was 9,280.899 kWh, of which equipment such as pumps took 20% (highest energy consumption). Areas of major energy consumption include pet blowing room, production room 1, production room 2 and the borehole area. While the current cooling capacities of most rooms in the factory were above the cooling requirement of each room, the luminosity requirement of selected rooms in the factory is surpassed by the current luminosity level found. Energy management measures were found to reduce the energy consumption of the factory by 17%, saving a sum of 87,906.207 naira of electrical energy cost monthly. In conclusion, the energy audit carried out on the University of Ibadan water factory was found useful in reducing energy waste and associated costs within the water factory. This approach can be applied in industries for electricity cost reduction, hence, production cost.**

Keywords **— Cost, Energy Audit, Energy Conservation, Energy Consumption, Energy Management, Energy Waste, Product Assessment.**

I. Introduction

The importance of energy audit in energy conservation for production plants cannot be over emphasized, and water processing plants are not exempted. Year after Year, electricity demand increases by up to 6-8%, while electricity production has not seen up to that amount of growth [1].

As a result of this, the gap between the supply and demand of electricity is constantly increasing. Two alternatives can prove useful in reducing the gap; one is to produce more electricity, which necessitates a huge investment and the other is to conserve electricity by making use of energy more efficiently and effectively by eliminating energy waste [1]. Energy Audit makes energy usage more efficient and effective by

identifying and reducing and energy wastage source or area without affecting growth rate and productivity in any way [1].

Water availability is crucial for the survival of man and other living things [17], [18], and consists of two elements, namely hydrogen and oxygen [18]. Impure or contaminated water and poor hygiene promotes sickness, increased healthcare cost, decreased productivity and mortality rate [19], [21]-[27]. Water, mostly sourced from streams, lakes, rocks and beneath the soil usually contains some number of impurities which may or may not be harmful [28]. Therefore, adequate quantity of drinking water must be available on daily basis [20]. Filtration and decantation processes are needed to discard unwanted natural elements from water [29]. No existing singular method of purification can completely get rid of contaminants from drinking water [30]. However, any drinking water is expected to be able to meet up with the WHO set standard [31]. In Nigeria, sachet water and boreholes have become important sources of drinking water [32]. Sachet and bottled water industries have recently become one of the most profitable and largest food brands globally, witnessing tremendous growth within the last ten years [33]. Findings show that an average Nigerian adult consume a minimum of one sachet water every day, especially in the dry season [34]. According to research, growth witnessed by the water packaging industries was as a result of constant availability and convenient packaging [35]. An understanding of manufacturing processes and water sources contribute largely to its management and distribution [36]. Sachet and bottled water first appeared in the Nigerian market in 1990, but by year 2000, it had circulated the whole country due to the registration of not less than 134 water packaging industries by NAFDAC [37]. Recently, energy and materials consumption are becoming major concern in water production factories [33]. For instance, up to 40% of consumed energy in many countries comes from buildings [38].

This demand has again been projected to be on the increase side till year 2050, by more than 50% [39]. In addition to cost, the use of energy-intensive equipment is detrimental to the environment, owing to greenhouse gas emissions [40], [57]. It has been emphasized that well-designed energy management programs can go a long way in reducing industrial energy consumption up to 70% [58]. Energy management entails the usage of energy by means of systematic and practical coordination in achieving economic and environmental objectives [41]. Energy management

Submitted on June 24, 2023.
Published on September 3, 2023.
M. A. Bolarinwa, University of Ibadan, Nigeria.
(e-mail: mojimolati@gmail.com)
A. P. Abodunde, University of Ibadan, Nigeria.
(e-mail: deoyebodunde@gmail.com)

concept is already popular with big buildings and is closely followed by homes [42]. Already, it has become an important issue in many countries, alongside reduction of CO_2 emissions [43], [44]. The provision of needed amount of without a reduction in productivity, efficiency is ascertained [45]. Energy efficiency is attained with efficient production process or technology [46]. The achievable savings in cost is the main justification for energy auditing [47]. Energy audit as a tool helps to appraise current performance(s) of electrical system(s), and thereafter benchmarks this to the manufacturer's standard [17]. It is noteworthy to emphasize doing energy audit just before carrying out a detailed layout [13]. As energy demand increases on daily basis, use of fossil fuel which produces energy and pollution harmful to humans may have to increase [48]. Fossil fuel usage for energy generation is a problem from human activities. Moreover, several fluctuations in oil prices over the last decade has upset the economy globally to a large extent [51], [11]. However, intervention of energy audit can make positive impact towards pollution reduction in the environment [49]. The belief is than an organisation's energy audit gives room for better energy management strategy in many industrial settings [50]. Therefore, energy auditing as a means of reducing energy consumption will no doubt lower the usage of fossil fuels, reducing contaminants in the atmosphere and saving a lot of money [41]. In essence, energy audit aims to estimate a plant's current energy consumption using systematic techniques to identify possible energy savings and reporting its findings. It serves as an important instrument which can be utilized in the implementation of energy efficiency approaches and achieves conservation in the industrial sector as well as the extension of electromechanical equipment life [2]. Energy audit is an assessment of electricity and fuel consumption with a view to managing and eliminating waste with the use of energy within a facility or a building space. The evaluation could be extensive or limited, depending on the nature of the business space, scope and purpose of the audit [3]. Energy audit can also be the inspection, survey, and analysis of energy flows in a building with the goal of identifying energy efficiency opportunities which will not negatively affect the output and operations of the building [2]. According to the European Standard [3], a building's energy consumption can be evaluated in two ways; one is through operational rating, which involves the use of standard input data related to climate and occupancy modes to calculate the energy used by a building for ventilation, lighting, heating, cooling *etc*. The second is through asset rating, which is the measurement of the electrical performance of a building as it is being used. It also includes variations in theoretical and actual energy consumption. Although more time consuming, it usually generates more useful information on the condition of the building, user behavior, as well as the appropriate measures necessary to reduce energy consumption [1]. Historical electricity and energy usage are plotted on charts and graphs after detailed data has been used to carry out an energy audit. These graphs would show certain patterns of usage that are corroborated by other information obtained. Upon interpretation of these patterns, it is possible to establish the accurate energy consumption for a building. Necessary improvement measures are suggested and backed up with simple financial payback models on implementation costs as well as operating cost savings. Energy is consumed in water factories by individuals and appropriate machineries for the treatment, packaging and distribution of safe and drinkable water in plastic or glass bottles. An energy audit then is a methodological approach that gives recommendations for power wastage reduction by analysing power flow. It is a study, inspection and review of energy flows within a facility, process, or system for the purpose of energy conservation, to cause a reduction in energy input of said facility or process, without affecting the output of the work being done [6]. Energy audit determines the most cost-effective ways to reduce energy consumption. For any firm to remain active, all components of her cost structure must be critically examined in order to minimize wasteful and unnecessary expenses [52]. This is made possible by either boosting the output or cutting down waste [53]. Some researchers, moreover, claimed that energy audits (also known as energy analyses or energy assessments), besides serving as the initial step in realising energy-efficiency prospects, most likely contribute to the implementation of its recommendations [5], [6]. Energy management is essential for the utilization and procurement of energy through an already optimized management system, throughout the area [8]. Energy audit and the resulting energy management is carried out to save cost by optimising energy consumption for various forms of institutions, industries, residential areas, hospital, *etc*., through suggestions and recommendations specified by an energy auditor [10]. Types of energy audit include Walk-through audit (preliminary/simple), mini audit (detailed/ general), maxi audit (investment grade audit), benchmarking (comparative audit). The Energy audit type to be selected is dependent on: i) Function and type of industry under consideration [8]; ii) Details available in the industry for assessment [8]; iii) Severity of the energy audit in question [9]; iv) Customer's request energy audits are often broken down into three phases [10], these areas are as shown.

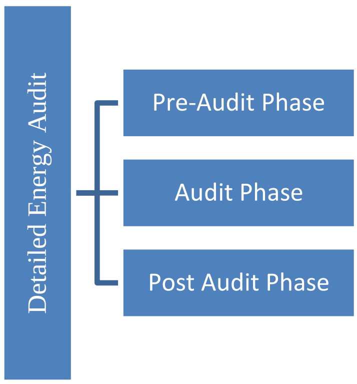

Fig. 1. Phases in an energy audit [58].

From Fig. 1, the pre-audit phase is for facts finding and information gathering prior to auditing proper. The second phase, which is the audit phase, involves the actual execution of the energy audit processes. The third and final phase, which is post audit, involves the collation and computation of data to report(s) in form of graphs, charts, etc. to generate accurate energy consumption of a building or facility, and make improvement suggestions where necessary. Overtime, energy audit has been carried out in several other sectors. For instance, some successfully conducted cases of energy auditing have been reported in fabrication and paper industries, as well as a water treatment plant [54]-[56]. With constantly increasing technical/production cost incurred in the production of packaged clean and drinkable water (bottle and sachet) to the populace, and which has even gone higher in recent times, it becomes imperative to have a holistic view of the energy aspect of this cost, in order to see how production cost of drinkable water can be reduced, thereby making packaged clean and drinkable water more affordable for the general public. Some of these energy wastages may be due to inefficient use of equipment, inefficient equipment sizing, improper factory lighting, improper ventilation and air conditioning of spaces, user behaviour, inefficient equipment, etc. Therefore, this research was aimed at using an energy audit approach to assess area(s) of wastage so as to cut down associated production costs in the University of Ibadan water factory, Ibadan. The study objectives thus include: (i) Walk-through auditing of the facility, energy consumption and electrical installation assessment; (ii) Identifying areas of energy wastage, as well as conservation opportunities; (iii) Carrying out for ventilation, air-conditioning, and lighting assessments for proper energy management measures and Cost reduction analysis. Since technical cost incurred in providing and distributing adequate drinking water is high in developing countries, including Nigeria [13], an analysis of the energy aspect of this cost, with a view to eliminating non-value adding energy wastes could lead to reduction of the production cost. The justification for this work therefore are: Fostered efficiency in factory's energy usage, reduction in expenditure on energy bills, improved lighting system, encouraged behavioural change in factory's usage, improved energy supply/demand management, extended life span of factory energy assets, enhancement in connection of sustainable energy systems, reduced CO_2 emissions in the building, minimization energy costs from the monthly energy charges, overall improvement of business competitiveness, volumes and profitability. In essence, the study involved the use of an energy audit, conducted at a sachet and bottled water production factory as a way to cutting cost and reducing waste at the water factory, by eliminating energy wastages areas or sources.

II. Materials and Method

The procedures for identifying, obtaining data, analysing the data, for carrying out the energy audit is as presented in this section. Some of the equipment and materials used include 50 m fiber measuring tape, interview questionnaire, log book, while the facility being assessed includes the University of Ibadan water factory.

A. Walkthrough Audit for Electrical Distribution and Energy Consumption Assessment to Identify Energy Wastage and Means of Conserving

A planned visit was made to the University of Ibadan's water packaging factory. An organized awareness program on energy audit was conducted with all divisional heads and operators. Also, the divisional heads and operators therein were interviewed, by means of interviews and physical interactions. Thereafter, monitoring and survey of all equipment followed. In addition, the building's specifications and details were obtained. The data obtained from the walkthrough audit were then collated using excel spreadsheet, after which further analyses were carried out on them to generate a myriad of information on electrical distribution and energy consumption analysis. Moreover, further analysis (computation) of the energy data generated from the walk – through audit was used to generate reports in order to establish accurate energy consumption of the facilities concerned in identifying the energy – intensive areas, which on further investigation deduced possible energy wastage areas and conservation opportunities. Charts developed were interpreted to give a better description of the occurrences in the factory, such that the energy intensive areas were identified. The energy intensive equipment and rooms were further investigated, in order to find possible energy wastage areas. Some other energy conservation opportunities were developed by carrying out other assessments on the factory, assessments such as Ventilation, air-conditioning and lighting assessments.

B. Lighting, Ventilation, and Air-Conditioning Assessments

The lighting assessment was carried out to assess the impact of artificial lighting on a space, as well as details of all external lights and when they will be used.The aim of the assessment was to determine the lighting requirement of each workspace or room in the factory, in order to efficiently size the proper lighting to each space. It involved the assessment of all the lighting currently utilized within the factory. To this effect, data obtained were inputted in an online lighting assessment database (Omni Calculator) to help determine the appropriate luminosity level for each space in relation to the collated data. And the best efficient lighting systems were proffered. For the ventilation and air-conditioning assessment, also known as the cooling load analysis, this assessment was carried out on each room in the factory to determine the cooling requirement of these spaces and to see if they were surpassed or under met. This served as an opportunity to reduce energy consumption by efficiently sizing air-conditioning system to spaces. The basis of the cooling load analysis is to determine the overall heat transfer in a building. There are five variables that make this up, this includes: Heat transfers due to transmission, Heat transfers due to solar gain through glass, Heat transfers due to ventilation, Heat transfers due to infiltration, Heat transfers due to internal load.

1) Heat transfers due to transmission

Heat is transmitted through different surface materials like walls, windows, floors and roofs. The total heat transmitted is a summation of all the below stated variables:

- H_{walls}= heat transmissions through walls;
- H_{floor} = heat transmissions through floor;
- H_{roof} = heat transmissions through roof.

a) Heat transmission through walls

Mathematically, (1) is used to calculate the heat transmitted through the walls.

$$H_{walls} = A \times U \times (t_0 - t_1) \text{or} [A \times \frac{(t_0-t_1)}{\sum R}] \quad (1)$$

where

A = area of wall in square metre m^2;
U = Heat transmission coefficient in Watts per square metre Kelvin w/m^{2}k obtained from table dependent on the material;
t_0 = atmospheric temperature in Kelvin, K (308 K);
t_1 = room temperature in Kelvin, K (298 K);
R= resistance to heat flow in each layer in square metre Kelvin per Watts m^{2}K/ w.

b) Heat transmissions through floor

Table I shows the heat loss of concrete floors at or near grade level.

TABLE I: HEAT LOSS OF CONCRETE FLOORS AT OR NEAR GRADE LEVEL (SOURCE: [15])

Outdoor design Temperature, C			Heat loss per metre of exposed edge W/m		
			R = 0.88 Edge insulation	R = 0.44 Edge insulation	No edge insulation
-30	To	-35	48	58	72
-24	To	-30	43	53	62
-17	To	-24	38	48	58
-12	To	-17	34	43	53
-6	To	-12	29	38	48
Outdoor design Temperature, C			Heat loss per foot of exposed edge BTU/hr ft		
			R = 0.88 Edge insulation	R = 0.44 Edge insulation	No edge insulation
-20	To	-30	50	60	75
-10	To	-20	45	55	65
0	To	-10	40	50	60
10	To	0	35	45	55
20	To	-10	30	40	50

Based on the values in Table I, we can calculate the heat loss using (2).

$$H_{floor} = L \times U \quad (2)$$

where
L= Perimeter of exposed surface boundary in m;
U= linear heat transmission coefficient in W/m (obtained from the above table).

c) Heat transmissions through roof

Similar to the calculation of heat transmission through walls the heat transmitted through roof is given as (3).

$$H_{roof} = A \times U \times (t_0 - t_1) \text{or} [A \times \frac{(t_0 - t_1)}{\sum R}] \quad (3)$$

where
A = area of wall in square metre m^2;
U = Heat transmission coefficient in Watts per square metre Kelvin w/m^{2}k obtained from table dependent on the material;
t_0 = atmospheric temperature in Kelvin, K (308 K);
t_1 = room temperature in Kelvin, K (298 K);
R = resistance to heat flow in each layer in square metre Kelvin per Watts m^{2}K/ w.

Since roof usually comprise of two major components; the ceiling and the roofing material, calculation was done for the U-value taking, into account the two components. This is given as (4).

$$U = \frac{1}{R} \quad (4)$$

where
U = Heat transmission coefficient in Watts per square metre Kelvin w/m^{2}k obtained from table dependent on the material;
R = resistance to heat flow in each layer in square metre Kelvin per Watts m^{2}k/ w, which is calculated using (5).

$$R = R_{ceiling} + R_{roof}(\frac{A_{ceiling}}{A_{Roof}}) \quad (5)$$

where
R = resistance to heat flow in each layer in square metre Kelvin per Watts m^{2}K/ w;
$R_{ceiling}$ - resistance to heat flow in ceiling layer in square metre Kelvin per Watts m^{2}K/ w;
R_{roof} - resistance to heat flow in roofing layer in square metre Kelvin per Watts m^{2}K/ w;
$A_{ceiling}$ = area of ceiling in square metre m^2;
A_{roof}= area of roof in square metre m^2.

2) Heat transmissions through solar gains

Sunlight on windows, skylights and glazed doors can contribute considerable solar heat gains to a building. These heat gains can be found using (6).

$$H_{solar\ gain} = A \times SF \times SC \quad (6)$$

where
A = area of glass in m^2;
SF = solar factor in W/m^2;
SC = shading coefficient.
Solar factor is the amount of heat per unit area entering the conditioned space through the glass, subtracted from the percent of shading done by the structure of the glass.

3) Heat transmissions through ventilations

Mathematically, heat loss due to ventilation is given as (7).

$$H_{ventilation} = C_p \times \rho \times \left(\frac{1}{3600}\right) \times q_v \times (t_0 - t_1) \quad (7)$$

where
C_p = specific heat capacity of air in j/Kg k (1005j/Kg k);
ρ = density of air in Kg/m^3 (1.2 kg/m^3);
q_v = air volume flow in m^3/h;
t_0 = atmospheric temperature in ºC;
t_1= room temperature in ºC.

Air volume flow q_v = no of people × 17 m^3 (an air requirement of 17 m^3 per person per hour was used and the maximum number of people in select spaces were determined).

4) Heat transmissions through infiltration

Infiltration is the uncontrolled movement of unconditioned air into a building through the building envelope.

Mathematically, (8) is used to calculate the heat transmission through infiltration.

$$H_{infiltration} = \rho \times \left(\frac{1}{3600}\right) \times q_v \times (h_0 - h_1) \quad (8)$$

where
ρ = Density of air (1.2 kg/m^3);
q_v = air volume flow in m^3/h;
h_0 = outside air enthalpy (j/kg) (100000 j/kg);
h_1 = inside air enthalpy (j/kg) (43000 j/kg).

5) Heat transmissions through internal load

People add quite a bit of heat to a space, this is something that can change dependent on the number of people and the activity being carried out in a space e.g., 117W per person might be for a typical office building but in the case of a gym that number will increase. For most spaces where the majority of the occupants are sedentary, we assume 117W per person.

Mathematically, (9) is used to calculate heat transmissions through internal load.

$$H_{internal\ load} = 177 \times no\ of\ people \quad (9)$$

The total heat transmission in the factory is then given by (10).

$$H_{total} = H_{walls} + H_{floor} + H_{roof} + H_{solar\ gain} + H_{ventilation} + H_{infiltration} + H_{internal\ \ load} \quad (10)$$

This was done for the selected rooms in the factory.

C. Energy Management and Cost Reduction Analysis

This involved applying behavioural changes or technology to eliminate and reduce energy wastage at the factory. A product assessment where each of the equipment was reviewed to determine the possible management solutions to proffer was carried out on equipment of interest. The product assessment was done by extensive research of equipment and through contacting experts in the field of that equipment (usually representatives from manufacturing companies). Furthermore, the data obtained from the ventilation and air-conditioning Assessment and lighting assessment was used to proffer better energy saving lighting equipment and ventilation and air-Conditioning equipment. A peak shaving profile was provided to illustrate the effects of each energy management measure on the peak load of the factory. The cost implications of the energy management measures were calculated and compared to the current energy cost of production to know to what level the cost was reduced.

III. Results and Discussion

This section contains the results obtained from the research carried out and data collected at the University Ibadan water factory as well as the discussions on the results.

A. Observations from Walkthrough Audit

With the planned visit, which enhanced access to the UI water packaging factory; organised awareness programme conducted, which enhanced consent, cooperation, and active participation from the factory staff; monitoring of operations, physical structures and equipment, as well as the interview of production manager and workers, which aided data collection; results, as shown in Fig. 2a and 2b and Table III-Table VI were obtained. The physical structures, facilities and equipment therein were found to include automatic filling machine, pumps, steam generator and conveyors, among others, while data obtained include structural dimensions, equipment power rating data, hour of usage of each equipment, factory working hours, power frequency, number of equipment, equipment models etc. Information gathered include process flowchart, equipment schedule, load summary, load distribution chart, energy consumption chart, load intensity chart, energy intensity chart, peak load profile, base load profile and load profile (base and peak load) among others, as shown in Table II. Fig. 2a and 2b show the flow diagrams for the sequence of operations within the University Ibadan water packaging factory. While Fig. 2a shows the bottling line, Fig. 2b shows the sachet water line. The raw data obtained for each of the equipment in the water packaging factory during the walkthrough audit are presented in Table III-Table VI.

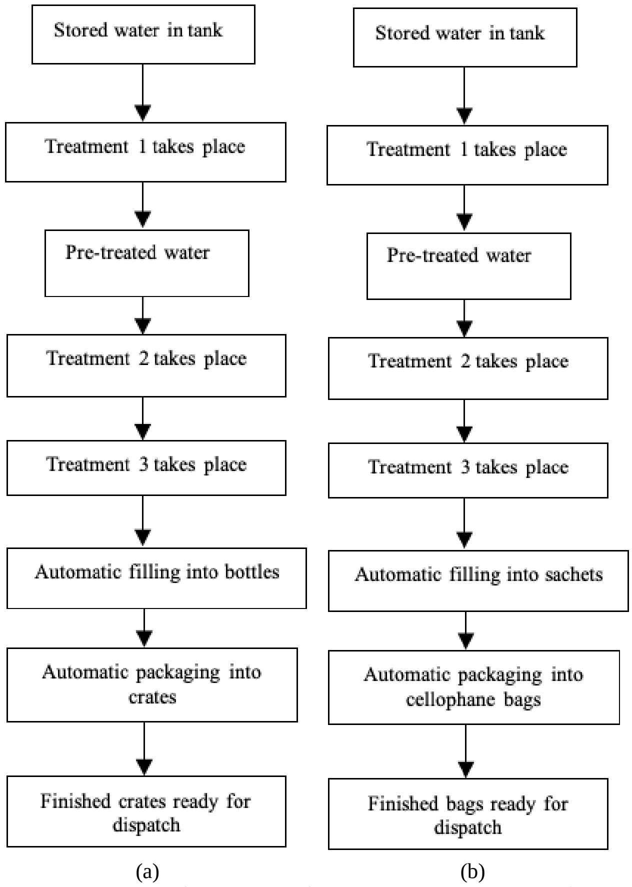

Fig. 2. Flow diagrams for sequence of operations in theUniversity of Ibadan water factory; a) Bottle water line: b) Sachet water line.

Table III gives the structural dimensions of rooms in the water factory, this includes: the wall height of room, the wall length of room, the breadth of room, the working height of room and the total area of window in each room. This data was used in carrying out the lighting and air-conditioning assessments. Table IV gives a summary of the load supported by the equipment utilised in the factory. Table V presents the summary of the energy consumption breakdown in the water factory.

Table VI presents a summary of each equipment used in the factory classified into equipment classes and their energy consumption (daily, weekly, and monthly), as well as the total energy consumption of the factory.

For instance, air-conditioners utilized in the factory jointly consume a total energy of 56.430 kW hour daily, 338.580 kW hour weekly and 1467.180 kW hour monthly, this is given for all equipment class utilized at the factory.

With Table IV and Table V, energy intensive equipment was determined. Fig. 3 shows energy distribution within the factory.

TABLE II: INFORMATION TYPE GENERATED FROM THE ENERGY AUDIT

S/n	Information generated	Definitions
1	Process flowchart	A diagram that shows the sequence of operation
2	Equipment schedule	The collation of each equipment that is being used.
3	Load summary	This is a concise summary of total load of each equipment class used in the factory and also the total load as well as the number of all the appliances in factory, it gives a quick look at the what the heavy-duty appliances are.
4	Load distribution chart	This is graphical representations of the load summary via pie chart. It shows the relationship between each equipment and their loads
5	Energy consumption chart	This is a bar chart and pie chart representation of the energy consumption pattern; it shows the relationship between each equipment class and their energy consumption
6	Load intensity chart	Sets of charts that determines what the load intensive space/room are in the factory, by comparing the amount of load in each space to the area of the space
7	Energy intensity chart	Sets of charts that determines what the energy intensive space/room are in the factory, by comparing the daily, weekly or monthly energy consumption of each space to the area of the space
8	Peak load profile	The peak load curve is a graphical representation of the load to time period relationship of peak load equipment (equipment connected for both short and long periods of time). It gives a snapshot of energy consumption per time period in a day of peak load Equipment.
9	Base load profile	The base load curve is a graphical representation of the load to time period relationship of base load equipment (equipment connected for a long period of time). It gives a snapshot of energy consumption per time period in a day for base load equipment
10	Load profile (Base and Peak Load)	Chart that compares the base load profile and peak load profile.

TABLE III: WATER FACTORY STRUCTURAL DIMENSIONS

S/n	Room	Length of wall (m)	Breadth of wall (m)	Height of wall (m)	Working height (m)	Total area of window (m²)
1	Production Room 2 (Bottle Water)	14.050	9.360	2.600	1.700	8.816
2	Production Room 1 (sachet water)	6.300	7.800	3.300	1.700	9.660
3	Inventory Room	6.060	12.160	3.200	0.810	19.229
4	Security Office	3.300	3.300	2.560	0.810	2.842
6	pay point	3.500	4.500	3.300	0.910	1.415
7	Auditor office	5.950	2.000	2.870	0.910	2.296
8	Accountant Office	5.950	2.000	2.870	0.910	2.296
9	Deputy Director Office	5.950	2.000	2.870	0.910	8.280
10	Director Office	5.950	6.000	2.870	0.910	8.280

TABLE IV: LOAD SUMMARY OF WATER FACTORY

S/n	Equipment class	Quantity	Wattage	Total load (kW)
1	Air Conditioners	10	7910	11.580
2	Ceiling Lamp	67	578	2.190
3	Television & Decoder	2	55	0.055
4	Standing Fan	2	220	0.220
5	Refrigerators and Freezers	3	325	0.325
6	Microwave	1	700	0.700
7	Printers, Monitors and UPS	7	1425	1.425
8	Vents	2	550	1.100
9	Automatic Filling Machine	2	1740	1.740
10	Automatic liquid packaging Machine	6	1600	9.600
11	Compressors	4	25700	25.700
12	Labelling & Coding Machine	1	15	0.015
13	PE Thermal Shrink-Packaging Machine	2	3740	3.740
14	Pet Blowing Machine	2	22000	22.000
15	Pumps	12	7850	12.300
16	Reverse Osmosis Machine	3	9000	9.000
17	Steam Generator	2	18000	18.000
18	U.V Light	4	60	0.120
19	Conveyor	4	1740	1.740
	Total	136	103208	121.550

TABLE V: ENERGY SUMMARY OF WATER FACTORY

S/n	Equipment class	Daily energy consumption (kWh)	Weekly energy consumption (kWh)	Monthly energy consumption (kWh)
1	Air Conditioners	56.430	338.580	1467.180
2	Ceiling Lamp	27.360	164.160	711.360
3	Television & Decoder	0.385	2.310	10.010
4	Standing Fan	1.520	9.120	39.520
5	Refrigerators & Freezers	6.500	39.000	169.000
6	Microwave	0.117	0.700	3.034
7	Printers, Monitors and UPS	0.828	4.968	21.527
8	Vents	0.913	5.478	23.738

S/n	Equipment class	Daily energy consumption (kWh)	Weekly energy consumption (kWh)	Monthly energy consumption (kWh)
9	Automatic Filling Machine	3.915	23.490	101.790
10	Automatic liquid packaging Machine	21.600	129.600	561.600
11	Compressors	35.400	212.400	920.400
12	Labelling & Coding Machine	0.120	0.720	3.120
13	PE Thermal Shrink-Packaging Machine	8.415	50.490	218.790
14	Pet Blowing Machine	49.500	297.000	1287.000
15	Pumps	72.000	432.000	1872.000
16	Reverse Osmosis Machine	27.000	162.000	702.000
17	Steam Generator	40.500	243.000	1053.000
18	U.V Light	0.540	3.240	14.040
19	Conveyor	3.915	23.490	101.790
	TOTAL	356.958	2141.746	9280.899

TABLE VI: Load and Energy Consumption of Each Room in Water Factory

S/n	Room	Total load (kW)	Daily energy consumption (kWh)	Weekly energy consumption (kWh)	Monthly energy consumption (kWh)
1	Director's Office	2.439	11.352	68.113	295.157
2	Deputy Director Office	1.100	5.500	33.000	143.000
3	Accountant Office	1.100	8.800	52.800	228.800
4	Auditor Office	1.416	10.231	61.383	265.993
5	Auditor Office Corridor	0.177	2.916	17.496	75.816
6	Toilet 1	0.052	0.416	2.496	10.816
7	Toilet 2	0.160	1.280	7.680	33.280
8	Director Office Corridor	0.078	0.624	3.744	16.224
9	Pay Point Office	1.621	1.769	10.616	46.001
10	Pet Blowing Room	44.500	79.500	477.000	2067.000
11	Production Room 1 (Sachet Water)	21.864	55.770	334.620	1450.020
12	Production Room 2 (Bottle Water)	37.416	110.878	665.268	2882.828
13	Inventory Room	0.539	1.414	8.482	36.756
14	Inventory Corridor	0.186	3.720	22.320	96.720
15	Treated Tank Area	0.052	1.040	6.240	27.040
16	Raw Tank Area	3.300	16.500	99.000	429.000
17	Borehole Area	4.500	33.000	198.000	858.000
18	Security Office	0.106	0.920	5.520	23.920
19	Security Lights	0.944	11.328	67.968	294.528
	Total	121.550	356.958	2141.746	9280.899

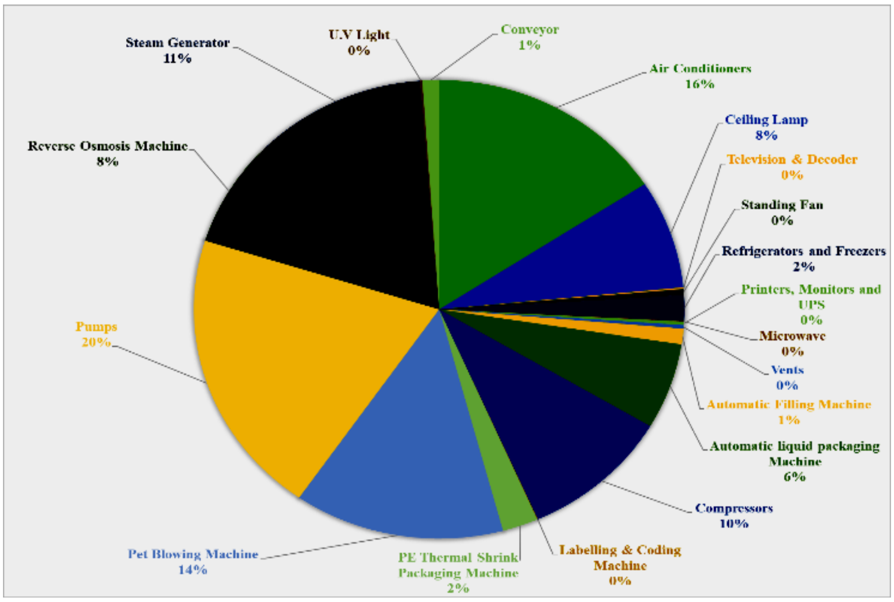

Fig. 3. Energy distribution chart of equipment in water factory.

Fig. 3 presents a pie chart of Energy distribution of equipment classes being utilized in the factory with the pumps taking the highest energy consumption in the factory at 20% of total factory energy consumption, the air conditioners at 16% of total factory energy consumption, pet blowing machine at 14% of total factory energy consumption. The factory has a monthly electrical energy consumption of 9280.899 kWh.

Table VI presents the total amount of energy (daily, weekly, and monthly) being consumed in each room in the factory, with this we were able to see the most energy intensive room, which is production room 2 (sachet water), that consumes a total of 110.878 kW hour of energy daily, 665.268 kW hour of energy weekly and 2882.828 kW hour of energy monthly.

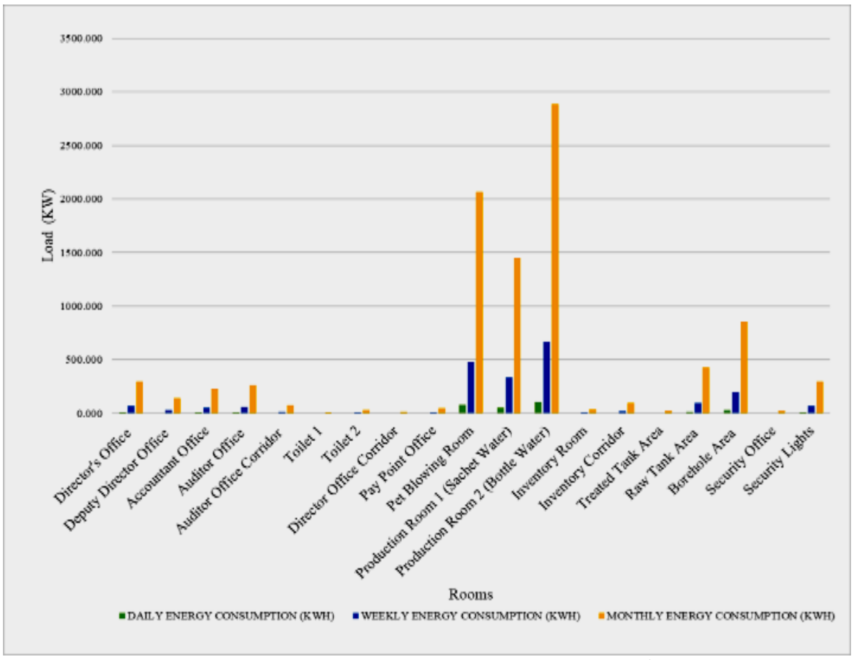

Fig. 4. Energy consumption (daily, weekly, monthly) chart for each.

From Fig. 4, it could be seen that the pet blowing room, production room 1, production room 2 and the borehole area are the most energy intensive areas (areas with high energy consumption), this led to the further investigation of these areas and the equipment used therein.

B. Lighting, Ventilation and Air-Conditioning Assessment

Having carried out lighting assessment of the factory rooms, the following results, as shown in Table VII were obtained.

In Table VII, the luminosity requirement and current lighting capacity of each room in the factory in lumens, from the table we see that the luminosity requirement of select rooms in the factory is surpassed by the current luminosity level, for instance the current luminosity level of the auditor office, accountant office, deputy director office and director office are each greater than the required luminosity for each room. This also provides an energy conservation opportunity.

Similarly, having carried out ventilation and air-conditioning assessment of rooms in the factory, results, as shown in Table VIII, were obtained.

Table VIII shows the cooling requirement, as well as the current cooling capacities of the air conditioners in select rooms in the factory in Watts and it is observed that for most rooms the current cooling capacities of the air conditioners installed in the rooms, is above the cooling requirement of the room. For example, the auditor office has a cooling requirement of 2233.720 W, and it is being supplied with 2725.561 W, over 491.8 Watts above required. This provides energy conservation opportunity.

Table IX shows the energy consumption reduction implication after energy management measures are deployed, a reduction of 1585.038 kWh in the monthly energy consumption was noticed from the factory's initial 9280.899 kWh.

TABLE VII: LIGHTING REQUIREMENT FOR THE ROOMS IN THE WATER FACTORY

S/n	Room	Area of floor (m^2)	Height of wall (m)	Working height (m)	Lighting type	Lighting quantity	Current luminosity level (lumens)	Required lighting luminosity (lumens)
1	Production Room 1 (sachet water)	49.140	3.300	1.700	CFL	4	6800	5307.000
2	Inventory Room	73.690	3.200	0.810	CFL	5	9400	7958.000
3	Security Office	10.890	2.560	0.810	CFL	1	1700	1176.100
4	pay point	15.750	3.300	0.910	CFL	1	1700	1701.000
5	Auditor office	11.900	2.870	0.910	CFL	1	1700	1285.200
6	Accountant Office	11.900	2.870	0.910	CFL	1	2600	1285.200
7	Deputy Director Office	11.900	2.870	0.910	CFL	1	2600	1285.200
8	Director Office	35.700	2.870	0.910	CFL	4	6800	3855.600

TABLE VIII: COOLING REQUIREMENT FOR THE ROOMS IN FACTORY

S/N	Room	Cooling requirement (w)	Cooling capacity of air conditioners (w)	Air conditioner model	Air conditioner quantity
1	Production Room 1 (Sachet Water)	6817.280	7033.706	LG HS-C1264SA3	2
2	Pay point	2075.240	2725.561	LG HS-C0964SA9	1
3	Auditor Office	2233.720	2725.561	LG HS-C0964SA9	1
4	Accountant Office	2233.720	2725.561	LG HS-C0964SA9	1
5	Deputy Director Office	2233.720	2725.561	LG HS-C0964SA9	1

TABLE IX: ENERGY WASTE REDUCTION IMPLICATION DUE TO AIR CONDITIONING SYSTEM, LIGHTING SYSTEM, STEAM GENERATOR AND AIR CONVEYORS

S/N	Equipment	Quantity	Total load (kW)	Daily energy consumption (kWh)	Weekly energy consumption (kWh)	Monthly energy consumption (kWh)
1	Air Conditioners	10	10.100	49.630	297.780	1290.380
2	Ceiling Lamp	64	1.300	16.532	99.192	429.832
3	Television & Decoder	2	0.055	0.385	2.310	10.010
4	Standing Fan	2	0.220	1.520	9.120	39.520
5	Refrigerators and Freezers	3	0.325	6.500	39.000	169.000
6	Microwave	1	0.700	0.117	0.700	3.034
7	Printers, Monitors and UPS	7	1.425	0.828	4.968	21.527
8	Vents	2	1.100	0.913	5.478	23.738
9	Automatic Filling Machine	2	1.740	3.915	23.490	101.790
10	Automatic liquid packaging Machine	6	9.600	21.600	129.600	561.600
11	Compressors	4	25.700	35.400	212.400	920.400
12	Labelling & Coding Machine	1	0.015	0.120	0.720	3.120
13	PE Thermal Shrink-Packaging Machine	2	3.740	8.415	50.490	218.790
14	Pet Blowing Machine	2	22.000	49.500	297.000	1287.000
15	Pumps	12	12.300	72.000	432.000	1872.000
16	Reverse Osmosis Machine	3	9.000	27.000	162.000	702.000
17	Steam Generator	2	18.000	0.000	0.000	0.000
18	U.V Light	4	0.120	0.540	3.240	14.040
19	Conveyor	4	1.110	1.080	6.480	28.080
	TOTAL	133	118.550	295.995	1775.968	7695.861

The energy management measures deployed include:

i. A product brochure for the Air-conditioning system manufacturer LG was consulted and the following LG Air-conditioning system were suggested as replacement for the existing ones utilized in the factory: LG Dual cool Inverter Ac S4-Q09WA5QG which as a wattage of 880 Watts were suggested to replace the LG HS-C0964SA9 Ac in select room, which still met the cooling requirements of the rooms. LG Dual cool Inverter Ac S4-Q12JA3QG which has wattage of 1170Watts was suggested to replace the LG HS-C1264SA3 Ac in select room, which still met the cooling requirements of the rooms.

ii. Light emitting diode (LED) type lighting of equivalent luminosity were also suggested to replace Compact fluorescent lamp (CFL), and the number of bulbs for each room was also adjusted in areas where the lighting requirement.

iii. It was suggested to shut down the steam generator during operations, due to the fact that the steam generator is serving a redundant purpose, and most sachet and bottled water production factories operate efficiently without it, whilst still maintaining quality of bottled water produced.

iv. The air conveyor was suggested to be replaced with a belt conveyor which still performs the same function at a lesser energy consumption rating.

Computed cost implication of energy management measures is as presented in Table X.

TABLE X: COST IMPLICATION DUE TO ENERGY MANAGEMENT MEASURE DEPLOYED

	Daily	Weekly	Monthly
Initial factory rating (kwh)	356.958	2141.746	9280.899
Final factory rating (kwh)	295.995	1775.968	7695.861
Difference in rating (kwh)	60.963	365.778	1585.038
Saving percentage (%)	17.078	17.078	17.078
Cost implication (#)	3381.008	20286.048	87906.207

Table X presents the cost implication of the energy management measures deployed. It is noticed that using the deploying the energy management measures energy consumption in the factory was cut down by 17% and a sum of 87906.207 naira is saved monthly.

IV. CONCLUSION

In this research work, the reduction of waste in the University of Ibadan Water Factory using an energy audit approach has been investigated. Data on equipment being used, their power ratings, hours of usage, hours of operation of the factory etc. were collected during the walkthrough audit by means of interviews and personal observations and inputted to excel spreadsheet in order to determine the behavioural patterns in the utilization of the factory, level of energy consumption of the equipment in the factory, areas of energy wastage, areas of energy conservation opportunities. Factory structural data was also obtained through the use of a 50m fiber measuring tape in order to carry out a lighting assessment and the air-conditioning and ventilation assessment on select rooms in the factory, to determine the lighting requirement and cooling requirement of select rooms in the factory. Energy

management measures were deployed in the form of product assessment (to determine product replacement potentials) and behavioural energy use changes by factory personnel. Based on the above, the following conclusions can be drawn:

i. The walkthrough audit proved to be effective in assessing the water factory system in terms of power rating (energy consumption) of the equipment therein.

ii. The University of Ibadan water factory contains some areas, such as pet blowing room, production room 1, production room 2 and the borehole area and equipment such as pumps, compressors and steam generators that provide energy conservation opportunities, these were areas and equipment expected to have the largest energy consumption.

iii. Likewise, some non-common areas of energy wastage, exist in the water factory from light and air

iv. conditioning sources which need to be looked into for energy management measure deployment

v. Energy management measure proves an effective tool in reducing the energy waste at the University of Ibadan water factory as well as the accompanying cost. Likewise, the cost reduction analysis showed a reduction in waste energy cost.

Appendix

A. *Energy Audit Interview Questions*

1) Energy consumption analysis and electrical installation assessment

Name of building: ………………………………………….
Address: ……………………………………………………
Floor area of factory: ……………………………………….
Approximate number of occupants: ………………………..
Hours of operation: …………………………………………
Energy tariff: ………………………………………………..

TABLE XI: ENERGY SUPPLY AND CONSUMPTION ANALYSIS

Working days	Operating time	Hours	Average hours of general electricity supply
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			
Saturday			
Sunday			
Annual Total Hours			

B. *Room and Equipment Schedule*

Room type: …………………………………………………
Room dimensions: ………………………………………….
Room area: ………………………………………………….
Door specification: ………………………………………….
Window specification: ………………………………………
Maximum number of Occupant: ……………………………

TABLE XII: EQUIPMENT CONSUMPTION ANALYSIS

S/n	Equipment	Name/model	Wattage	Daily average hour of use

References

[1] Srinath G, Uday Kumar N. Energy audit as a tool for improving system efficiency in industrial sector.*International Journal of Engineering Research Applications*. 2014; 4(6).

[2] Androutsopoulos A, AlexandriE. The Importance of Energy Audit in the Energy Certification of Buildings; 2008.

[3] Dall'O G. *Green Energy Audit of Buildings-A Guide for a Sustainable Energy Audit of Buildings*. Springer-Verlag; 2013. DOI: 146.10.1007/978-1-4471-5064-0.

[4] Lopez NS, Gonzaga J, Lim L. Energy audit and analysis of the electricity consumption of an educational building in the Philippines for smart consumption. In*2017 IEEE 9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*, 2017:1-4.

[5] CENE. EN 15217, Energy performance of buildings-Methods for expressing energy performance and for energy certification of buildings.Bruxelles: European Standardisation Organisation; 2007.

[6] Parthe SP, Kompeli SJ. Energy audit and conservation tool for energy efficiency. *International Research Journal of Engineering and Technology (IRJET)*. 2015; 2: 08.

[7] Kalantzis F, Revoltella D. Do energy audits help SMEs to realize energy-efficiency opportunities? *Energy Economics*. 2019;83: 229-239.

[8] Von Knorring H. Energy audits in shipping companies. *Transportation Research Part A: Policy Practice*. 2019; 125: 35-55.

[9] Abisha R, Ani P, Babitha J, Jeffrin N, Abragam SS. Energy Audit and Energy Management - An Overview. In *International Conference on Energy Efficient Technologies for Sustainability (ICEETS)*, 2018.Retrieved from: https://ssrn.com/abstract=3165967 https://www.pollux-fid.de/r/ssrn-3165967H1 - Pollux (Fachin formations dienstPolitikwissenschaft).

[10] Thollander P, Ottosson M. Energy management practices in Swedish energy-intensive industries. *Journal of CleanerProduction*. 2010; 18(12): 1125-1133.

[11] Chaichan MT,Abaas KI. Performance amelioration of a Trombe wall by using phase change material (PCM). *International Advanced Research Journal in Science, Engineering Technology*,2015; 2(4): 1-6.

[12] Bhatt MS. Energy audit case studies I—steam systems. *Applied Thermal Engineering*. 2000; 20(3): 285-296.

[13] Anger B. Poverty eradication, millennium development goals and sustainable development in Nigeria. *Journal of sustainable development*. 2010; 3(4): 138-144.

[14] Sánchez-García D, Rubio-Bellido C, del Río JJM, Pérez-Fargallo A. Towards the quantification of energy demand and consumption through the adaptive comfort approach in mixed mode office buildings considering climate change. *Energy and Buildings*. 2019; 187: 173-185. https://doi.org/https://doi.org/10.1016/j.enbuild.2019.02.002.

[15] TRANE 2008. Getting started: TRACE™ 700 Comprehensive Building Analysis, version 6.2. CDSPRM002.book-EN Retrieved from https:// https://software.trane.com/cds/trace%20700%20-%20getting%20started.pdf.

[16] Kay S, Franco J. The global water grab: A primer Trans.). *Green Planet Blues*. Routledge;2019: 342-356.

[17] Zhang W, Cui L, Liu J. Recent advances in cobalt-based electrocatalysts for hydrogen and oxygen evolution reactions. *Journal of Alloys and Compounds*. 2020; 821: 153542. https://doi.org/https://doi.org/10.1016/j.jallcom.2019.153542.

[18] Federal Ministry of Water Resources (FMWR), Government of Nigeria, National Bureau of Statistics (NBS) and UNICEF. 2020. Water, sanitation and hygiene: National outcome routine mapping (wash norm) 2019: A report of findings. FCT Abuja. Nigeria.

[19] Edema M, Atayese A, Bankole M. Pure water syndrome: bacteriological quality of sachet-packed drinking water sold in Nigeria. *African Journal of Food, Agriculture, Nutrition and Development*. 2011; 11(1).

[20] Wright J, Dzodzomenyo M, Wardrop NA, Johnston R, Hill A, Aryeetey G, Adanu R. Effects of sachet water consumption on exposure to microbe-contaminated drinking water: household survey evidence from Ghana. *International journal of environmental research public health*. 2016; 13(3): 303.

[21] Daniel E, Daodu A. Bacteriological analysis of sachet water vended in ugbor, benin city, nigeria. *SAU Science-Tech Journal*,2016; 1(1).

[22] Akpen G, Kpoghol I, Oparaku L. Quality assessment of sachet and bottled water sold in Gboko, Benue state, Nigeria. *Nigerian Journal of Technology*. 2018; 37(1): 241-248.

[23] Ibrahim M, Umaru M, Akinsoji A. Qualitative assessment of sachet and bottled water marketed in Bauchi Metropolis, Nigeria. *Chemical Process Engineering Research*. 2015; 37: 11-23.

[24] Obioma A, Nnenna I,Golden O. Bacteriological risk assessment of borehole sources of drinking water in some part of Port Harcourt metropolis of Niger Delta, Nigeria. *Studies*. 2020; 5(6).

[25] Idogho PO, Yahaya O, Dagona A. Modelling water-sanitation relationship in Edo State, Nigeria. *Advancement in Scientific Engineering Research*. 2013; 2(1): 44-51.

[26] González-Gómez F, Lluch-Frechina E, Guardiola J. Water habits and hygiene education to prevent diarrhoeal diseases: the Zambezi river basin in Mozambique. *African Development Review*. 2013; 25(4): 563-572.

[27] Cheremisinoff PN. *Handbook of water and wastewater treatment technology*. Routledge; 2019.

[28] García-Marín R, Lozano-Parra J, Espejo-MarínC, Aparicio-Guerrero A. The Production and Marketing of Mineral Water in 21st Century Spain. *Water*. 2020; 12(8): 2311.

[29] Airaodion AI, Ewa O, Awosanya OO, Ogbuagu EO, OgbuaguU, Okereke D. Assessment of sachet and bottled water quality in Ibadan Nigeria. *Global Journal of Nutrition & Food Science*. 2019; 1(4): 1-12.
[30] Bhagwat VR. Safety of water used in food production Trans.). *Food Safety and Human Health*. 2019: 219-247.
[31] Amaesh F. Feasibility study report on small scale sachet water production at Isuaniocha, Awka north local government area of Anambra State; 2016.
[32] Parag Y, Opher T. *Bottled drinking water. water and health*. Encyclopedia of Life Support Systems (EOLSS); 2011.
[33] Sanni LO. Environmental impact of sachet water consumption in Saki, Oyo State, Nigeria; 2019.
[34] Stoler J, Tutu RA, Winslow KJHI. Piped water flows but sachet consumption grows: The paradoxical drinking water landscape of an urban slum in Ashaiman, Ghana. *Habitat International*. 2015; 47: 52-60.
[35] Howard K. Sustainable cities and the groundwater governance challenge. *Environmental Earth Sciences*. 2015; 73(6): 2543-2554.
[36] Abraham O, Osaru F. Externality effects of sachet and plastic bottled water consumption on the environment: Evidence from Benin City and Okada in Nigeria. *Policy*. 2020; 9(1): 1-9.
[37] Li Y, Kubicki S, Guerriero A, Rezgui Y. Review of building energy performance certification schemes towards future improvement. *Renewable and Sustainable Energy Reviews*. 2019; 113: 109244. https://doi.org/https://doi.org/10.1016/j.rser.2019.109244.
[38] Liu Z, Zhou Q, Tian Z, He B-J, Jin G. A comprehensive analysis on definitions, development, and policies of nearly zero energy buildings in China. *Renewable and Sustainable Energy Reviews*. 2019; 114(109314). https://doi.org/https://doi.org/10.1016/j.rser.2019.109314.
[39] Navidi A, Khatami F. Energy management and planning in smart cities. *CIRED-Open Access Proceedings Journal*. 2017;2017(1): 2723-2725.
[40] Mahdi A. Energy Audit a step to effective Energy Management. *International Journal of Trend in Research and Development.* 2018;5(2): 521-525.
[41] Al-Waeli A, Kazem H, Chaichan M. Review and design of a standalone PV system performance. *International Journal of Computation Applied Sciences.* 2016; 1(1): 1-6.
[42] Gordić D, Babić M, Jovičić N, Šušteršič V, Končalović D, Jelić D. Development of energy management system–Case study of Serbian car manufacturer. *Energy Conversion Management.* 2010; 51(12): 2783-2790.
[43] Kannan R, Boie W. Energy management practices in SME: Case Study of a Bakery in Germany. *Energy conversion management.* 2003; 44(6): 945-959.
[44] Diesendorf M. *Greenhouse solutions with sustainable energy*.Citeseer; 2007.
[45] Belussi L, Barozzi B, Bellazzi A, Danza L, Devitofrancesco A, Fanciulli C, Scrosati C. A review of performance of zero energy buildings and energy efficiency solutions. *Journal of Building Engineering.* 2019; 25: 100772. https://doi.org/https://doi.org/10.1016/j.jobe.2019.100772.
[46] El Iysaouy L, El Idrissi N, Tvaronavičienė M, Lahbabi M,Oumnad A. Towards energy efficiency: Case of Morocco. *Insights into Regional Development.* 2019; 3: 259-271.
[47] Rehman A, Rauf A, Ahmad M, Chandio AA, Deyuan Z. The effect of carbon dioxide emission and the consumption of electrical energy, fossil fuel energy, and renewable energy, on economic performance: evidence from Pakistan. *Environmental Science and Pollution Research.* 2019; 26(21): 21760-21773. https://doi.org/10.1007/s11356-019-05550-y.
[48] Lam JC, Li DH, Cheung S. An analysis of electricity end-use in air-conditioned office buildings in Hong Kong. *Building and Environment.* 2003; 38(3): 493-498.
[49] Fasiuddin M, Budaiwi I. HVAC system strategies for energy conservation in commercial buildings in Saudi Arabia. *Energy and Buildings.* 2011; 43(12): 3457-3466.
[50] Al-Maamary HM, Kazem HA, Chaichan MT. The impact of oil price fluctuations on common renewable energies in GCC countries. *Renewable and Sustainable Energy Reviews*. 2017; 75: 989-1007.
[51] Sahua B. Application of Lean Tools in different Industries: A review. *Turkish Journal of Computer Mathematics Education*. 2021; 12(13): 2428-2435.
[52] Ohno T, Bodek N. *Toyota production system: beyond large-scale production*. Productivity press; 2019.
[53] Oyelaran OA, Twada YY, Sanusi OM. Energy audit of an industry: a case study of fabrication company. *Aceh International Journal of Science Technology*. 2016; 5(2): 45-53.
[54] Saha BK, Chakraborty B, Dutta R. Estimation of waste heat and its recovery potential from energy-intensive industries. *Clean Technologies and Environmental Policy*. 2020; 22(9): 1795-1814. https://doi.org/10.1007/s10098-020-01919-7.
[55] Dubey B, Pusricha JS, Gupta B, Pandey M. Energy audit and energy conservation potential for water treatment plant. *Water Energy International*. 2012; 69(4): 42-46.
[56] Bolarinwa MA. Techno-economic evaluation of biogas generation from selected substrates in a teaching and research farm in Ibadan, Oyo State, Nigeria. *International Journal of Innovative Science and Research Technology*. 2018; 3(7): 699-704.
[57] Kluczek A, Olszewski P. Energy audits in industrial processes. *Journal of Cleaner Production.* 2017; 142(4): 3437–3453.
[58] Sharma P, Salkuti S, Kim S. Energy audit: types, scope, methodology and report structure. *Indonesian Journal of Electrical Engineering and Computer Science.* 2021; 22: 45-52. https://doi.org/10.11591/ijeecs.v22.il.