VOLUME ONE

Introduction to Energy Auditing

Introduction

Energy market transactions have financial and environmental cost implications. The market consists of the supply, transmission, distribution or transportation and the consumption sides, as indicated in Figure 1.

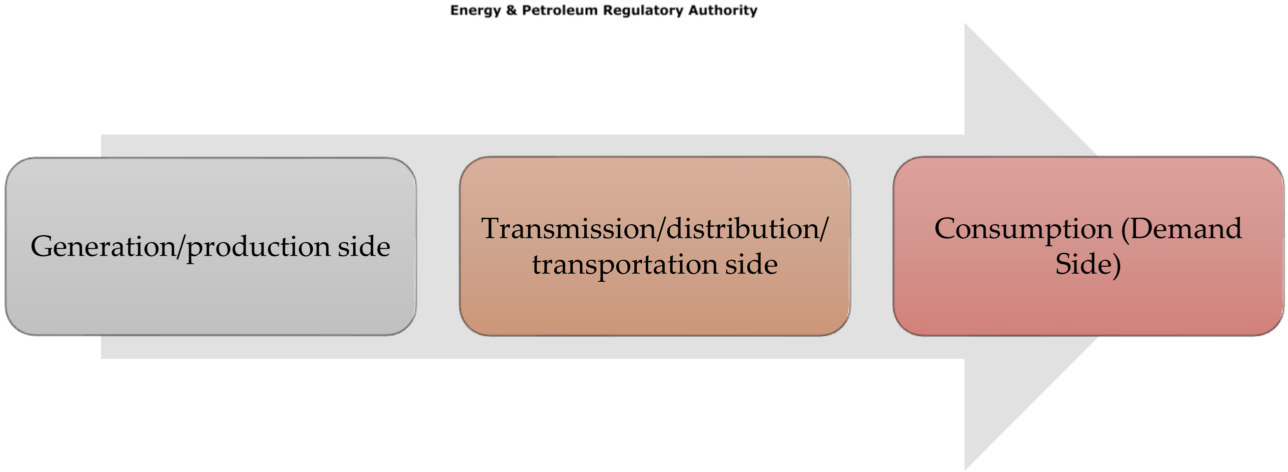

Figure 1: Energy Market

It is essential to establish interventions for reducing the cost implications in these sections of the market. The environmental cost component of energy use is related to both emissions due to generation and use of energy. Consider an example in steam generation. Here, a boiler fired by heavy fuel oil emits gases that are harmful to the environment. Increasing cost of energy in the demand-side section leads to high cost of production, which results in increased prices of goods and services.

There is a global consensus that energy efficiency should play a key role in addressing some of these costs. Currently, these consensuses are domiciled in the Sustainable Development Goal Seven and Nine (SDG 7 and SDG 9), Paris Agreement 2015 and Africa Union's Agenda 2063. Countries have ratified these agreements under various national policy instruments, and are implementing programs towards improving energy efficiency. Energy Management Systems are some of the instruments adopted by countries to improve energy efficiency.

Energy auditing plays a central role in the Energy Management System. Energy auditors should be acquainted with the best practices of analyzing processes that consume energy in facilities, evaluating the energy consumption and coming up with energy conservation measures. Such knowledge and skills can be improved using energy auditing guidebooks, which are important instruments for capacity building. This guidebook seeks to familiarize the existing and upcoming energy auditors with the basics of energy auditing.

Before considering carrying out auditing, the energy auditor should understand energy systems used in the consumption facilities.

The energy systems are in three parts as presented in figure 2.

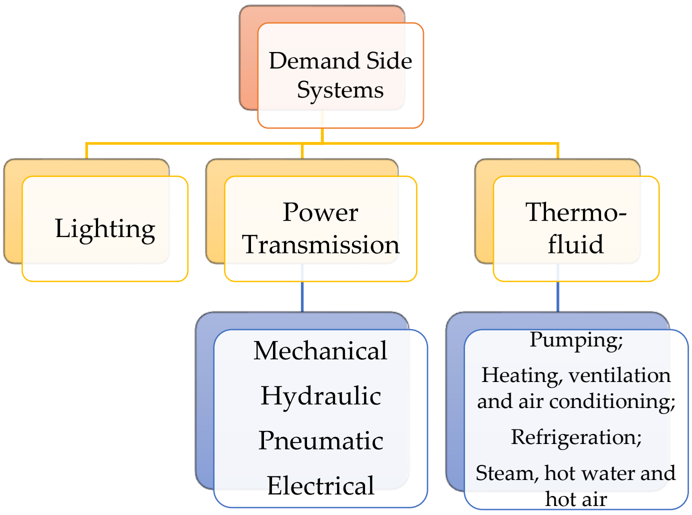

Figure 2: Parts of Energy Systems

A series of guidebooks will focus on the auditing of these systems in detail. This volume of the guidebook however focuses on the general guidelines of energy auditing. There are generally three types of energy auditing that an auditor should be familiarized with: Walk through audit; general audit and investment grade energy audit.

A walk-through audit entails the assessment of energy consumption in a facility, using visual and audio inspection, to identify energy saving opportunities. This is the precursor to the other types of audits. It forms a foundation for planning to conduct either the general or investment grade audit.

A general energy audit on the other hand, is a systematic analysis of energy consumption of a facility, a process or a system, with a purpose of identifying energy conservation measures. Let us recall however that the walk-through audit is a necessary antecedence to the general audit. The investment grade audit is an improvement of a general audit. The analysis in this type of audit involves further engineering and financial assessment to justify financing the project using funds from loans and equity. Whichever type of audit one undertakes, the nuances between them are often blurred. All the audits must at least have a cost benefit analysis for implementation of the identified energy conservation measures. Figure 3 illustrates the basic features of a general energy audit and investment grade energy audit.

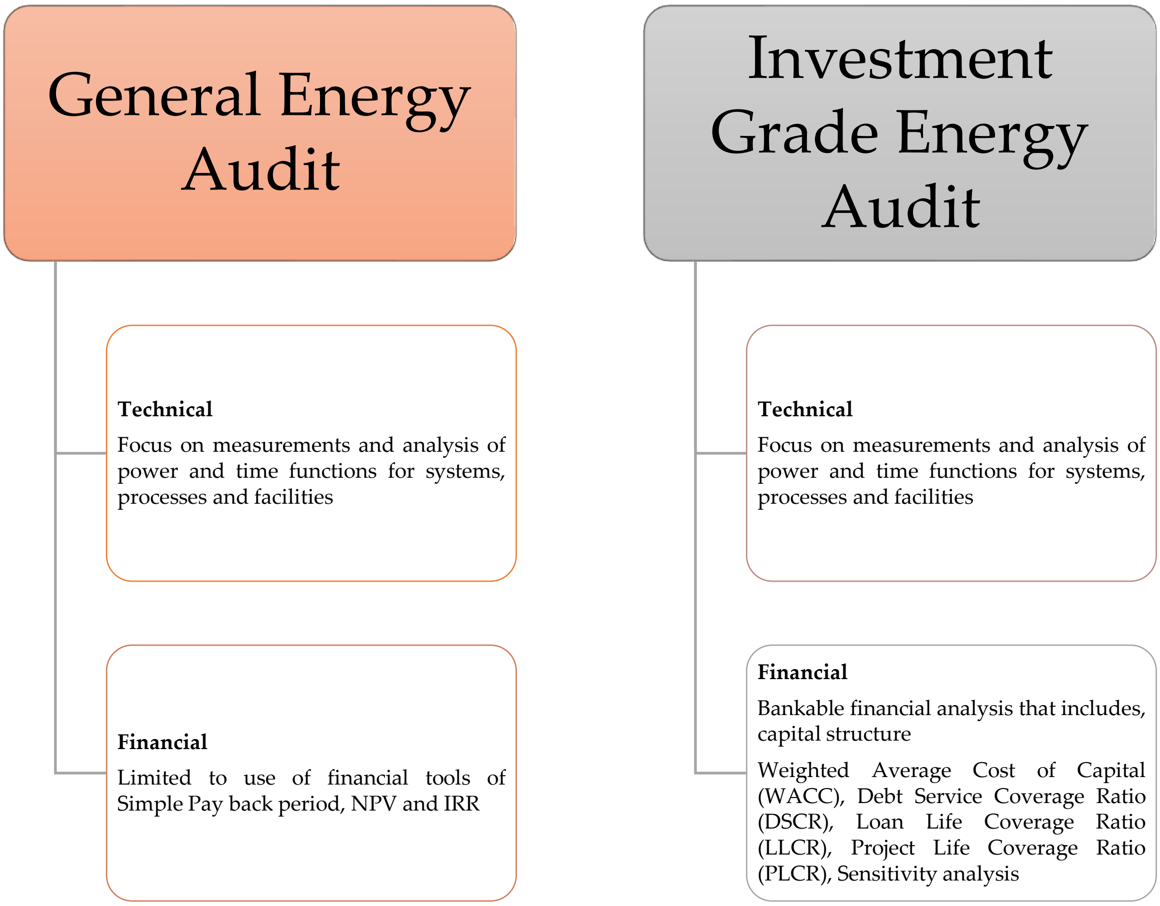

Figure 3: Features of General Energy Audit and Investment Grade Energy Audit

Energy Audits and Energy Audit Methodology

1.1. Fundamentals of Energy Audit

Oftentimes when the word audit is mentioned, attention is brought to financial systems and processes. However, auditing transcends this to include energy audits as was observed by Barney L. Capehart of university of Florida.

> *The energy audit is sometimes called an energy survey or an energy analysis, so that it is not hampered with the negative connotation of an audit in the sense of an Internal Revenue Service (IRS) audit. An energy audit is a positive experience with significant benefits to the business or individual, and the term "audit" should be avoided if it clearly produces a negative image in the mind of a particular business or individual.*

Energy auditing is one of the first tasks performed in energy management to accomplish effective energy cost control. It consists of examination and analysis of how a facility uses energy. After the examination, it recommends interventions for cost effective changes in operating practices or energy-consuming equipment to save energy.

Energy Audit Methodology

An audit process consists of three phases as illustrated in figure 4.

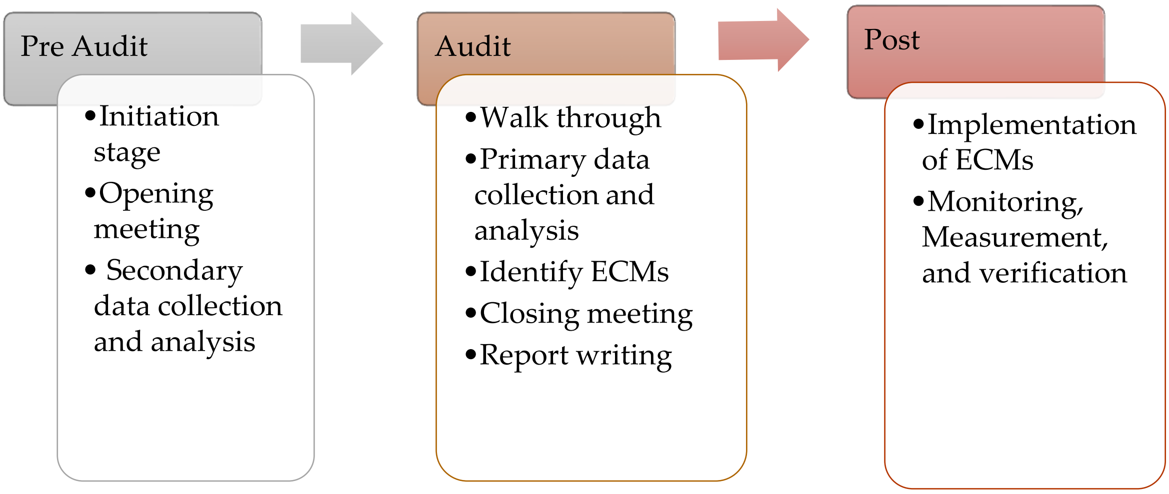

Figure 4: Energy audit phases

Pre-Audit Phase

The pre-audit phase begins with the initiation stage where the auditor establishes contact with the facility to be audited, via different channels. This could be through a successful response to request for proposals, direct sourcing by the facility or direct marketing by the auditor.

Once the contact has been established, the energy auditor and the facility should schedule an opening meeting. For an effective audit to be conducted, the meeting should be inclusive of the relevant staff in the facility. Even though the relevance of staff differs from facility to facility, care should be taken to ensure that parties from finance, procurement, engineering, production and top management attend such a meeting. This composition is necessary to ensure the auditor gets support during the exercise and the facility embraces the outcome of the audit.

There are a number of issues that should be discussed during the opening meeting. These issues include;

i. The scope and objectives which define the type of audit (walk through, general or investment grade), the areas to be audited and the desired outcome of the audit.
ii. Overview of the processes in the facility which include process and energy flow, operation cycle, facility layout, and utility resources.
iii. Responsibility assignment. This will include the resource persons to guide the auditor and communication channels during the assignment. The auditor can consider using the RACI (Responsible, Accountable, Consulted and Informed) matrix.
iv. The secondary data requirements for the audit such as utility bills, equipment specification, designed plant capacity, production and occupancy data.

The outcome of the opening meeting is used as an input in the development of the audit plan and the energy audit contract.

Once the audit plan and the contract have been firmed up, the auditor should obtain the secondary data such as energy consumption, production and any other relevant data. Production data can be in terms of goods produced or services rendered. In a hotel industry for example, these can either be occupancy or food covers while in commercial buildings, it can be number of walk-in customers or sales volumes. The production data should consider the production cycle. Such a cycle should cover all production shifts, weather and event seasons.

Apart from production data, there are other variables that inform an energy audit. These variables are mostly related to meteorological data like temperature, relative humidity, rainfall patterns, wind, irradiance, and cloud cover. The inclusion of this data in the analysis depends on the type of audits at hand. Some of the variables may affect energy consumption while others have little effect on the same. This shall be covered in detail in subsequent volumes of this guide book.

Energy consumption data on the other hand, covers all forms of energy utilised in the facility. This includes both thermal and electrical energy. With the growth of captive power generation, care has to be taken so that both the internally generated and externally supplied energy are accounted for in the analysis. Similarly, thermal energy generated internally should be included in the analysis. Both internal and external sources of energy incur a cost and it is essential for the facility to be assisted to reduce their consumption.

The energy consumption, production and the other relevant data are necessary components for establishing an energy performance baseline. The baseline is a reference energy performance point in two ways: first, this information can be used to compare the performance of a facility and the peers in the industry; it can also be used as a reference point to measure the success of energy conservation measures implemented following an energy audit. Energy auditors can also use the baseline data for valuing their audit services.

As you have observed in figure 4, both the pre-audit and audit phases have analysis of data. The secondary data collected during the pre-audit phase must be analysed before the auditor starts the auditing process. This helps in a number of ways:

i. It helps the auditor to identify energy consumption anomalies within the period under review. Such anomalies could be an indication of potential areas of focus during the audit phase.
ii. The analysis guides the auditor to understand the facility utilization index and capacity factor.
iii. It helps the auditor in establishing the baseline against which the proposed energy conservation measures shall be evaluated.

The following examples demonstrate the secondary data analysis process and its application to the audit phase. We use real data obtained from a tea processing plant to illustrate this. The data is presented in table 1.

Table 1: Production and energy consumption data from a tea processing plant

Month	Electricity units (kWh)	Genset diesel (ltrs)	Genset diesel (kWh)	Total	Firewood (M3)	Made Tea (Kgs)
Aug-19	212,470	4,575	13,725	226,195	1,297	351,906
Sep-19	148,772	2,790	8,370	157,142	924	283,118
Oct-19	211,312	1,450	4,350	215,662	1,151	352,226
Nov-19	177,021	6,930	20,790	197,811	902	319,588
Dec-19	184,147	2,568	7,704	191,851	1,374	414,644
Jan-20	184,908	1,943	5,829	190,737	1,054	317,508
Feb-20	163,849	2,653	7,959	171,808	1,158	291,052
Mar-20	182,467	4,361	13,083	195,550	1,370	343,198
Apr-20	172,109	990	2,970	175,079	1,351	317,357
May-20	188,128	2,110	6,330	194,458	1,176	269,460
Jun-20	110,908	1,826	5,478	116,386	769	180,505
Jul-20	134,408	2,005	6,015	140,423	647	180,549

Plant Maximum Production Capacity (Per Month)	1,250,000

Given such kind of data in table 1, the energy auditor should carry out performance analysis and infer areas of intervention prior to the audit phase. It has always been common practice for auditors to analyse this data after carrying out the audit. This approach is incorrect for it denies the auditor prior insights into areas they could conduct further analysis during the audit.
The first insight the auditor can get from this data is the determination of energy use index (EUI). The EUI can be determined using the following equation:

$$Energy\ Utilization\ Index = \frac{Energy\ Used}{Total\ Production} \tag{1}$$

From equation 1, the variables can be presented as demonstrated in figure 5.

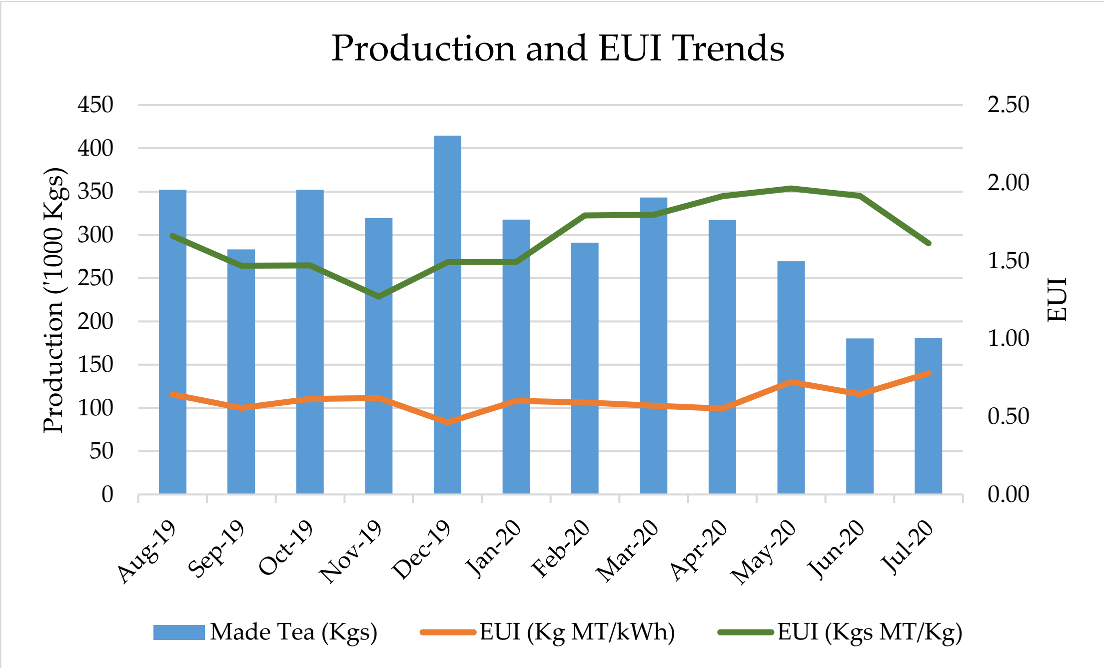

Figure 5: Production and EUI Trends

Figure 5 presents important highlights that an auditor can use as a beginning point of inquiry during the auditing process. Normally, when production is high, the EUI should be low. However, in this figure there are instances where high EUI is recorded during high production. For example, let us examine the month of August and September 2019 for electricity EUI. The production for August is 351,906 Kgs while that for September is 283,118 Kgs. Ordinarily August should record a better EUI compared to September. This is not the case in this instance. Similarly, such inconsistencies have been observed for the production and firewood EUI for the month of November and December. In this scenario, the production in December was higher than that of November. Ideally the EUI in December should be lower than that of November.

This identified inconsistencies could be as a result of a number of factors:

i. This could be a case of inconsistent loading of raw materials on the production lines, which could lead to either overloading or underloading of the machines. This leads to inefficiencies.
ii. Machines running without load. For example, conveyor belts running without load.
iii. Fuel quality in case of biomass EUI. This could mean the facility is using different quality of fuel during that period.

The auditor will therefore focus on these three issues as some of the areas of interest during audit phase.
Regression analysis can be used to further analyse the observations in figure 5. The regression model from the tea processing data is presented in figure 6.

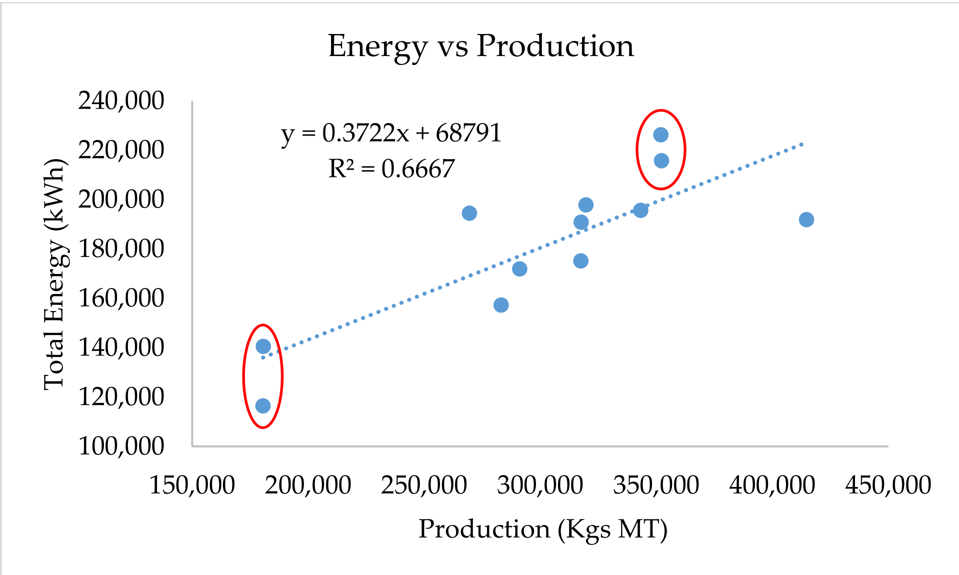

Figure 6: Regression analysis of production data

From the regression model in figure 6, the four highlighted data points further illustrate on the anomalies identified in figure 5. For each set of the data points the production is the same whereas the energy consumption differs. The auditor should focus on the months corresponding to these data points with a view of trying to establish the cause of the variation. The highlighted data points are also good visual illustrations to the management on the need to adopt energy efficiency practices.

The regression model helps the auditor understand the energy that is not related to production. From this model, 68,791 kWh of energy is not related to the monthly production. This accounts for 38% of the average monthly energy used in the facility.

The auditor should focus on the measures that can reduce amount of energy not related to production. An in-depth analysis of these measures will be discussed in subsequent volumes of this guidebook.

Additionally, the coefficient of determination R^2 is an indicator of energy performance. In this model, the R^2 is 67% which is below the recommended minimum value of 75%. The coefficient of determination indicates the portion of the energy consumption model that is due to the production.

Caution however should be taken when dealing with models from different facilities. Let us look at the horticultural sector as an example. In these facilities, the month where the most energy is used may not necessarily be the same month where production is realized. The R^2 established by regressing monthly production against energy consumed may not meet the 75% threshold. So, what should the auditor conclude in this case? In this case, the auditor can split the energy consumption data into different operation cycles. For example, during irrigation season, the regression should be between energy and water consumption. While during harvesting, the regression should focus on energy consumption and the flower stems harvested (this energy is used in the pack house and cold rooms).

The other important factor that can be inferred from the regression model is the plant utilization factor. The plant utilization factor can be determined using the following equation.

$$Plant\ Capacity\ Factor = \frac{Actual\ Production}{Maximum\ Production\ Capacity} \tag{2}$$

From the data in table 1 the total annual production is 3,621,109 Kgs MT while the maximum production capacity is 15,000,000 Kgs MT. This gives a plant capacity factor of 24%. This implies that the equipment in the facility is under utilised thus resulting in inefficiencies. It is recommended that the plant utilisation factor should be above 75%.

It should be noted that other parameters in addition to production volumes can affect energy consumption. For instance, in the commercial buildings and hotel sector, energy consumption can be affected by the ambient temperature and humidity, in addition to occupancy levels and plate covers. Amount of rainfall affects the energy used for irrigation in the agriculture sector.

The discussion in this section therefore points to the importance of holding an opening meeting with the facility, developing an audit plan, and acquiring and analysing relevant secondary data. The success of all these processes determines the quality of the work conducted during the audit phase. The auditor should therefore place importance on the pre-audit phase as a precursor to the subsequent phases.

Audit Phase

In some cases, auditors are faced with facilities they have never interacted with before. This uniqueness could be due to a new processes technology they have never encountered or a familiar technology in different set up. It is therefore inconceivable that an auditor would approach those facilities and start the audit process immediately. A familiarisation tour is important. That is why walk through audits have to be conducted.

During this walk-through stage, the auditor should understand the operation processes in the facility and identify the energy flows. This can be achieved by:

i. interviewing the facility operators.
ii. observation (visual, audio e.g. listening to leaks, vibrations and abnormal noise)
iii. taking photographs

The outcome of the walk-through stage should consist of : a process flow diagram, an energy balance, a list of focus during primary data collection and, where applicable, a walk through audit report. If the auditor had been contracted to conduct a walk though audit, the exercise ends at this point. For other types of audits (general and investment grade), the auditor gets tools and instruments for primary data collection based on the identified areas of focus.

Different facilities have different data collection requirements in the auditing phase. These requirements can only be comprehensively handled under specific process audits. However, there are common underlying principles that auditors can use during the data collection phase to improve the quality of auditing. These include:

The operation cycle	The energy consumption and production volumes in facilities vary over time. For example, in a hotel set up, the energy consumed on Monday could be different from the energy consumed on a Saturday. An auditor would therefore consider an operation cycle to be 7 days. If he were to only use Monday as the data collection day, this would misrepresent the energy consumed on Saturday. The same cycle applies for tea and dairy sectors. All these notwithstanding, the auditor

	should independently establish the actual operation cycle of the facility.
Sampling	Some facilities may have several energy consuming appliances, for example 150 motors of different sizes serving different purposes. It may not be practical to collect data from all of them. The science of sampling becomes important. An auditor can use various approaches to select the appliances for taking measurement. These include purposive sampling where the auditor uses professional experience to identify appliances for measurement. Other sampling methods like stratified random sampling and Slovin's formula can be used to determine the sample space and size respectively.
Data validity and reliability	Energy performance in energy systems and processes is informed by many variables. To ensure validity and reliability of energy performance data, the auditor should adopt unique approaches to collecting each of these variables. For example, some variables require spot measurements while others require continuous logging. Consider spot measurement of surface temperature of a steam pipe. A one-off measurement for this variable is likely to misrepresent the surface heat loss. The auditor should consider several spot measurements spread over a period and use the average for performance analysis. The quality of data obtained during audits is as good as the quality of the data collection instrument. The instruments should be calibrated and inspected for accuracy and consistency. Instruments have their range at which they operate. The auditor should ensure the appropriate instrument is selected.

As is with secondary data, the auditor should also analyse the primary data collected during the audit phase. Unlike the secondary data, the primary data analysis is solely dependent on the technical nature of the processes and systems under study and the audit objectives. Generally, the approach will be informed by the attendant engineering and economic analysis principles. For example, analysis of energy data for fan system performance would employ affinity laws and Bernoulli's principles. Auditors are therefore required to be well grounded in mathematical, scientific and engineering principles.

It should be noted the primary aim of conducting audit is to come up with cost effective energy conservation measures (ECMs). These measures should guide the facility to improve its energy performance. Primary and secondary data analyses are instrumental for recommending evidence-based measures. Let us use a pumping system to illustrate this.

The auditor should measure and record flow rate, pressure, rated pump efficiency, rated power, actual power consumption and water demand profile data. Thereafter, the auditor should undertake the analysis to establish the current operating point of the pumping system against the best operation point. This point informs the auditor how energy efficient the pumping system is. The auditor can then recommend informed energy conservation measures. These measures can include use of variable speed drives or storage tanks (to deal with varied water demand), resizing the pump (based on pressure and flow rate matching), installation of pressure vessels (to deal with pressure intermittency), redesigning the piping systems (to deal with pressure drop), or retrofitting the motor and pump to a higher efficient one (based on actual power, flow rate and pressure measurement). A bad practice would be recommending system retrofit without making scientific reference to the measured variables discussed in this example

For the success of the audit, the auditor requires the input of the facility staff and management. The input can be obtained during the auditing process and at the tail end during the audit closing meeting. In this meeting, the auditor presents preliminary results and obtains feedback from the audience. This feedback enhances their finding for the final report.

A good audit process can only be useful to the facility owner if properly documented in a report. The report is a reference point used by the facility owner, contractors, and financiers during implementation of the ECMs. The report should describe the background to the audit, the objective, and the methods used to conduct the audit. Additionally, it should record all the primary and secondary data analyses and the recommended ECMs. The auditor should draft an implementation plan to be used for implementation of the ECMs.

The energy audit report should have basic financial analysis in case of a general energy audit and engineering design analysis and advanced financial analysis as illustrated in figure 3.

Once the report has been submitted by the auditor, the facility adopts it and commences implementation of the recommended ECMs.

Post Audit Phase

In some cases, energy auditors can be involved in implementation of ECMs (in ESCO setup). However, in most cases, the energy auditing process is distinct from the implementation of ECMs and ends at the reporting stage. It should be noted that notwithstanding the arrangement between auditing and implementation, the auditor is legally bound to the outcomes of the ECMs. It is therefore necessary that the auditors acquaint themselves with the intricacies of ECMs implementation.

The first step towards implementing ECMs is the sourcing of finance. In this step, the facility acquires funds either through equity and/or debt. This funding mix will already have been discussed and agreed upon in the audit report in the financial analysis section. This therefore draws us to the importance of intensive consultation with the finance team of the facility during the financial analysis stage. It is a wrong practice for an energy auditor to come up with funding models without seeking consultation and concurrence with the facilities finance team.

An audit in a facility might have one or more ECMs covering different systems and process. It may not be possible to implement the ECMs at the same time, availability of the funds notwithstanding. Prioritisation is therefore necessary and may depend on:

i. Operation schedule
ii. Time required to implement
iii. Risk
iv. Complexity of retrofits
v. Availability of technology and expertise

The categorisation could be short term (what is commonly referred to as low hanging fruits), medium term and long term. All these should be captured in the implementation plan. For practical purposes of this implementation plan, the auditor should be in constant consultation with the engineering, operations, supply chain, finance and top management.

The monitoring, measurement and verification stage informs the success of the implementation of the energy audit. This is essential for tracking the actual energy savings achieved against the projected savings. To track this success, the baseline performance developed during the secondary data analysis is important. When developing the baseline therefore, the auditor should bare in mind the different types of measurement and verification techniques. In most cases facilities may require the services of energy auditors for this exercise. The auditor should be well versed with the different types of protocols and standards.

Chapter Summary

In this volume of the energy auditing guidebook, the fundamental principles governing the auditing process have been covered. The chapter has first dwelt on the linkage between the demand side of the energy market and the need to reduce environmental and financial cost of energy consumption. This linkage has been used to introduce the concept of energy management and energy auditing in facilities. This volume has approached the energy auditing process in three phases namely, pre-audit phase, audit phase and post audit phase. Further, it explains the intricacies of each phase required for a successful audit. In the pre-audit phase particularly, the guidebook points out to the importance of holding an opening meeting and conducting secondary data analysis before carrying out the audit phase. In the audit phase, it has focused on the importance of considering process and system cycles when planning for primary data collection. Additionally, the validity and reliability of data collection stage has been emphasized upon. The guidebook further emphasizes on the use of the collected data to recommend evidence based ECMs. This volume concludes by elaborating on the essence of the implementation, monitoring, measurement and verification of the ECMs. The discussed nuances point to the importance of technical and professional competencies of energy auditors.