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Understanding Various Technologies with Perspective of Energy and Environmental Audit: Review

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Abstract

The present paper is based on understanding the energy audit in a holistic approach. India is a great developing country, economy and energy plays a vital role as fuel for development. As the demand is increasing rapidly, production of energy on the same slope is somewhat difficult. With exponential rise in demands, energy deficit is also rising with each passing day. Hence, judicial use of energy and energy audit becomes an important. The energy audit helps in improving the overall efficiency of the system thereby lowering down energy consumption and the costs in terms of economics. It also helps us determining the energy inflows, outflows and inefficient components. The work has been emphasized on environmental audit along with its importance on protecting the environment. This paper explains various technological aspects, needs and positives related to energy and environmental audit thereby giving an overview of it.

Keywords: Energy audit; Environmental audit; Water conservation; Electrical devices; Mechanical equipment

Introduction

The cost of the energy is going up with the depletion in the current energy resources. The industrial sector is a major contributor towards this trend. So, an overall need arises to reduce down the energy costs which can be considerably achieved by enhancing the working efficiency of the various processes, equipment and operations involved in the industry. The energy efficiency can be further improved by switching over to the renewable sources of energy, creating awareness and a dedicated monitoring of the systems. The Government of India has passed various legislations and amendments to shift the focus towards energy efficiency. Bureau of Energy Efficiency (BEE) was made for defining certain energy standards, providing guidelines, accrediting various organizations for energy audits, carrying out the projects related to energy efficiency and carrying out the research activities related to the energy efficiency equipment [1].

Energy and Environmental Audit

Energy audit

Energy audit enables us to work upon the various inefficiencies in the existing system and analyzing the components thereby ensuring the energy conservation. It tells about the utilization of energy in a given system.

Environmental audit

Environmental audit surge in pollution levels in our country India has ensued in higher environmental risks. Hence the need for sustainable development is emphasized in every quarter be it policy formations, project clearances, future planning or management of already existing infrastructure and industry. While energy audit of a setups concentrates mainly on the energy efficiency of the system. Environmental audit will take care of preserving environment, natural resources such as water, air, land etc. Environmental audit cater to the issues such as Material balance, non-hazardous waste generation and disposal, hazardous waste generation and disposal, characteristics of waste for recycle or reuse along with short term and long term impact on local environmental conditions including air and water quality [1].

Main aim

Main aim of energy and environmental audit is to minimize the energy requirement and waste production with least environmental effect and without affecting the output during any process like residential, industrial, governmental and commercial or any other process.

Positives and need for energy and environmental audit are:

- Energy cost reduction
- Preventive maintenance and
- Quality control programs
- Waste prevention and reduction
- Compliance with regulatory requirements
- Option for adoption energy conservation technologies
- Profit maximization
- Optimization of available resources

Energy and environmental audit can be classified into the following two types

- Preliminary audit
- Detailed audit

Preliminary audit: Preliminary audit is a relatively simple exercise:

- Make energy consumption chart for every process in the organization
- Identify the scope for improvement in effectiveness (and the easiest areas for attention)

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- Look out for immediate (low cost) improvements
- Spot areas for more detailed and process specific study

Detailed audit: Detailed energy auditing is carried out in three phases: Phase I, II and III.

- **Phase I - pre audit phase:** Establishment is identified for audit. Basic information is collected regarding location, surrounding, climatic conditions, inputs of establishment in form of energy and raw materials, outputs, waste generation, management and disposal.
- **Phase II - audit phase:** Identification type of energy consumed in various departments include major processes, preparation of material balance sheets (includes raw materials, products, by products etc.), data regarding energy cost and tariff and latest regional energy policy. Process and material flow charts include sources of energy supply (e.g. electricity from the grid or self-generation). Potential for alternative energy sources such as solar energy, geothermal etc., process improvements and modifications and the induction of co-generation systems (combined heat and power generation).
- **Phase III - post audit phase:** After conducting audit energy manager/energy auditor should report and file observations to the top management about findings and possible recommendations if any, for effective communication and implementation.

The methods like present value criterion, average rate of return criterion and payback period criterion etc. are used for the economic analysis of the investments.

Electrical Energy Devices

Electrical energy devices collectively consume large amount of electrical power and also incurring large amount of distributed losses. In the current scenario when the energy deficit is large energy efficiency and audit are the need of the hour to plug these distributed losses one by one. Energy audit of these systems becomes essential so as to identify the inefficiencies in the system and can help in reducing this energy deficit.

Motors

An electric motor converts electrical energy into mechanical energy. They are classified as DC (Direct Current) motors and AC (Alternating Current) motors. Further AC motors are classified as AC induction and AC synchronous motors. They are mainly used to provide power to the various equipment. While selecting an electric motor for a process, aspects like reliability, inventory, availability, breakdown torque and operating conditions should be considered.

The efficiency of an electric motor can be written mathematically as:

$$Efficiency(\%) = \frac{Watts(input) - Watts(output)}{Watts(input)}$$

Losses: Losses can be described as the energy fees charged by the motor in order to convert electrical energy into the mechanical energy. They can be further classified into four categories

- Power Losses includes stator and rotor losses which can account for even more than half of the total losses occurring in the motor.
- Friction losses
- Magnetic core losses
- Stray load losses

Conductivity of the material, operating conditions, overall weight of the machine and lubrication are the major factors influencing the efficiency of motors. By giving considerable attention to above losses can be minimized.

Conservation of energy: The amount of energy consumed can be saved by operational improvements which include - balanced supply, improved controls, maintenance and retrofit improvements which look for the replacement of old, oversized and inefficient motors with the new and efficient ones.

Induction motors operate at lagging power factor because of the magnetizing current that is drawn by the motor, the incorporation of capacitors helps in enhancing the power factor thereby reducing energy charges, kVA demand and voltage drop and increased overall efficiency. Use of flat belt drives, variable speed drives and energy-saving controllers also contributes towards the saving of energy.

Illumination

A lumen can be defined as a measurement of light output from a tube or a bulb whereas illumination is the distribution of light on a horizontal surface which is measured in lux or foot-candles. Efficacy can be defined as the ratio of the light output to the electric power the lamp consumes. Efficacy is measured in Lumens per watt (LPW). It should be noted that efficacy should not be confused with the term efficiency which is unit-less quantity.

Quality of illumination: Quality is basically the visibility factor during work conditions and denotes how much people feel visually comfortable. Glare, which is the extra brightness from a direct light source, should be removed for having good quality lighting. The ability of the light source to render the same colors as sunlight does is termed as CRI (Color rendering index).

Types of illumination source: The four basic types of lighting lamps are as follows

- **Incandescent:** Most common types of incandescent lights are tungsten halogen, reflector lamps and standard incandescent.
- Fluorescent
- Compact Fluorescent
- **High intensity discharge:** Common types are mercury vapour, high pressure sodium and metal halide.

Increasing efficiency: Energy efficiency can be improved by replacing the lamps or entire fixtures thereby lowering the wattage, using day lighting, improving light controls, preserving illumination and ensuring simple maintenance. The devices used for regulating the lights are called lighting control like snap switches, timers, photocells, occupancy sensors and dimmers etc.

Transformer

Transformers are used to step up or step down the AC (Alternating Current) voltage. Transformers operate on the Faraday's law of induction. Operating losses in the transformers are namely no-load loss and load loss. No-load losses can be further categorized as eddy current losses, hysteresis losses, I^2R losses and di-electric losses whereas load losses are basically the coil losses.

The net losses for a transformer can be described mathematically as:

$L_P = L_N + (P/P_R)^2 \times L$

Where,

L_P = Total power loss in kW

L_N = No-load loss in kW

L = Load loss in kW

P = Actual load on transformer in kVA

P_R = Rated power of transformer in kVA

Identifying the load is an important factor in determining system load curve which will also provide us with the information of peak loads and base load periods. Proper monitoring of the load curves can help to manage the peak loads.

The demands can be controlled in a centralized manner, in a timed bound manner and can also be controlled manually. The prime objective of the transformer audit is to ensure that quality of power to different load centers is high and overall efficiency is better.

Power quality

Power quality is the severity of variations in the power supplied to the customers and deviations from the standard frequency of 50 Hz. If the power received has a pure sinusoidal waveform, it is considered as the clean power. Nowadays a term 'dirty power' is used to describe the contaminations in the clean power.

A harmonic is basically a part of the waveform having a frequency which is an integral multiple of fundamental power line frequency. Harmonic problems should be corrected or prevented from an industrial facility.

Harmonics can be reduced by the following methods:

- Power system design
- Isolation transformer
- Line reactors
- Harmonic trap filters
- K-factor transformers
- Applying tuned filters

Energy Management

Energy Management is the program aimed at reducing the organization's electricity bills and negative environmental impacts. The important hardware components of any energy management information system are:

- Field Transducers
- Power monitor modules
- Programmable logic controllers
- Communications network
- Centralized personal computer

Mechanical Energy Devices

Boilers

Boilers are employed in the industries to act as a heat source for various process applications. Boilers are basically classified as fire tube and water-tube boilers.

Evaluation of boiler efficiency: Efficiency of the boilers can be evaluated by either the direct methods or the indirect methods.

The formula used for the direct method is

Boiler Efficiency = (Heat output/ Heat input) × 100 = (Steam flow rate × (Steam enthalpy- feed water enthalpy) × 100)/ (Fuel firing rate × Gross calorific value).

Indirect methods aims at calculating the various heat losses, namely dry flue gas loss (L_{fg}), heat loss due to the moisture in the fuel (L_{mf}), heat loss due to moisture from burning hydrogen in the fuel (L_{hf}), heat loss due to the moisture in air (L_{ma}), heat loss due to Carbon monoxide (CO) in flue gas (L_{co}), heat loss due to un-burnt carbon in bottom ash (L_{ubb}), heat loss due to un-burnt carbon in fly ash (L_{ubf}), heat loss due to sensible heat in fly ash (L_{sf}) and loss due to surface radiation and convection (L_{rc}). All these losses are calculated in terms of percentage, added and then subtracted from 100 to obtain the thermal efficiency of the boiler.

Thermal efficiency of boiler (%) = 100-(Total losses in %)

Energy conservation measures for a boiler:

- **Excess air flow rate:** Stoichiometric flow rates are possible only for theory calculations and certain amount of excess air flow rates are required for the complete combustion of fuel. This additional amount of air is known as excess air flow which is also to be controlled as large amount of excess air can negatively impact the working of boiler by reducing the average temperature of the fire ball, reduces radiative heat transfer, increased stack losses by reducing the flue gas temperature and increase in the flue gas flow rate will also contribute to losses.
- **Burner and nozzle size:** The size of burner and nozzle must be adequately designed for optimal performance and cost effective maintenance. We should replace the nozzles with the better designed advanced burners where ever possible for advantage.
- **Control of temperatures of working fluid as well mass flow rate of heat carrier:** There are circumstances when a single source of heat is used for different process and there temperature may be different. Hence its adequate design may maximize efficiency of the system.
- **Proper insulation:** This is the first and easiest way to minimize losses. Where ever required proper insulation must be given to minimize heat loss to the environment as heat losses mainly occur at higher temperatures and this result in direct loss in availability of the system.

Waste heat recovery: Waste heat recovery from the flue gases can be done by:

- **Feed water preheating using economizer**: The water entering the boiler is pre-heated using the thermal energy of the flue gases in the equipment known as economizer before the flue gases are exhausted.
- **Combustion air-preheat:** The combustion chamber is provided with the air which is pre-heated in the air preheater utilizing the waste heat from the flue gases.

- **Improvement of condensate recovery:** Feeding the boiler with the steam condensate will also reduce the load of sensible heating for boiler.
- **Optimization of blow-down:** Though blow- down is necessary for the efficient working of boiler but frequency of blow-down is also an important factor.

Compressed air network

Compressed air is used in almost all types of industrial applications and accounts for a major share of electricity used in some of plants. Compressors are mainly classified into dynamic or centrifugal compressors and positive displacement types which are further divided into categories on the basis of principle of functioning. The distribution of compressed air is equally important as its generation. Normally the compressors are located at a central place in the plant and the compressed air travels a long distance through pipes to the point of usage. This results in large pressure drops due to long pipe lines and large number of pipe fittings. An efficient compressed air distribution system must include the proper pipe sizing, surface finish of the duct, minimum number of sudden bends and fittings for minimum pressure drops and leakages [2].

Compressor selection: Selection of compressor must be done considering the main factors [1] such as number of units required, cost of operation, installation cost and quality of air to be delivered by the compressor.

Monitoring performance and testing: Monitoring performance and testing of the working of compressor must be done on the factors stated [1]:

- Pump-up or capacity test
- Specific power consumption
- Compressor efficiency or isentropic efficiency
- Quality of air intake
- Compressor cooling
- Compressor operating pressure
- Capacity control and power consumption

Steam distribution systems

Steam has always been the most preferred working fluid for numerous plants for heating and drives, but the ever rising cost of fossil based fuels has made it necessary to adopt measures to reduce energy losses in steam distribution network. Some of the major considerations for designing a steam distribution network are named below [3,4]:

- **Pipe layout in plant:** Layout network must be so designed to minimize the steam travel from point of steam generation to utilization. Generally underground piping is not preferred.

- Pipe sizing
- Steam quality
- Moisture separation
- Insulation

All sections of hot pipes, valve bodies, unions, flanges and mechanical traps, such as floats, buckets and bodies of disc traps should be insulated.

Refrigeration and air-conditioning

The process of taking heat from a source of lower temperature and delivering it at a relatively high temperature level with the help of an external agent is known as Air conditioning and same concept can be used to either keep the desired space at a temperature lower or higher than surroundings depending on the requirement.

Main mechanisms: Mainly two mechanisms namely vapour compression system and vapour absorption system are employed for the job.

Vapour compression system: The heat absorbed by the evaporation of a liquid refrigerant in the evaporator at a controlled lower pressure after that increase the pressure of low-pressure vapour coming from the evaporator, with the use of compressor, heat removed from the high-pressure vapour in the condenser so that vapour can liquefy or condenses after this reduces the pressure of the high-pressure liquid to a level needed in the evaporator by using the throttling device [5].

Vapour absorption system: This refrigeration system is a heat-operated system. In this system two pressure levels like evaporating and condensing pressure levels are to be created. Compressor in this system is replaced by absorber and generator. A solution is known as absorbent is circulated between the absorber and generator with the help of a solution pump. The absorbent in the absorber draws the refrigerant vapour formed in the evaporator, thus maintaining a low pressure in the evaporator. In generator, the absorbent is heated, therefore releasing the refrigerant vapour at a high pressure and to be condensed in condenser. Thus the suction function of the compressor is performed by the absorbent in the absorber and the generator performs the function of compression and discharge [6].

An air-conditioning and refrigeration plant is efficient when all the system components like compressor and the condenser, the evaporator and the condenser cooling are working in matched conditions. This means that under peak operating conditions they must perform to their optimum output.

Energy conservation opportunities [1]:

Changes on system operating parameters:

- Increasing the chilled water temperature set point
- Installation of variable speed drives
- At air-handling units in fan motors
- At cooling tower fan motors

Changes on system operation:

- Enthalpy control/dry bulb economizer
- Dry bulb economizer
- Enthalpy control
- Reduced minimum outdoor air
- Exhaust air control

Changes on system design:

- Retrofit of central fans for variable air volume usage
- Forward-curved fan systems

- Fans with vortex vanes
- Conversion of dual-duct constant volume to variable air volume
- Heat recovery system
- Use evaporative cooling for comfort cooling in dry areas

Fans and blowers

Fans and blowers are widely used in industrial and commercial applications for ventilation and industrial process requirements. These are categorized into two different types based on the path of the airflow (centrifugal and axial) and blade shape (centrifugal and axial fan). Blowers are also classified into centrifugal and positive displacement type.

Performance: Performance is typically defined by plot of developed pressure and power required over a range of fan generated airflow. Performance of fan is also strictly depends upon the fan enclosure and duct design

Fan efficiency: Fan efficiency is the ratio of power imparted to the air streams to the power delivered by the motor.

In any fan system, the resistance to airflow (pressure) increases when the flow of air is increased. Bends and elbows in the inlet or outlet ducting can change the velocity of air, thereby changing the fan characteristics. Fans often serve a wide range of operating conditions. To accommodate demand changes, flow is controlled by four principle methods: vanes, pitch, outlet dampers and fan speed control [1].

Cooling tower

Cooling tower is a waste heat rejection device which is employed to reject the heat into the atmosphere. It basically removes the heat with the help of cooling water. Hence the performance of the tower is directly related to the temperature of the cooling water.

Categories: Cooling towers can be further categorized according to the way in which air is fed to the tower as 'natural draft' and 'mechanical draft'.

Mechanical draft:

- **Forced draft:** In this type of tower the fan is placed at the bottom from which air is forced into the tower. It is well suited for indoor applications.
- **Induced draft:** The movement of air in this arrangement is either counter flow or crossed flow.
- **Wet dry tower:** It employs an air-cooled heat exchanger, suited for high temperature applications.

Natural draft:

- **Atmospheric tower:** The movement of air in this type of tower is in horizontal fashion.
- **Spray pond:** Two arrangements with fan which involves spraying of the warm water for evaporation and without fan which works on the ejector principle.

Range, approach, cooling tower effectiveness and Performance of the cooling tower: Range of a cooling tower can be mathematically expressed as,

Range (°C) = Temperature of the water out from the cooling tower - Temperature of the inlet water

Whereas approach is,

Approach (°C) = Temperature of the water out from the cooling tower- Design wet bulb temperature

Cooling tower effectiveness (%) = Range/ (Range + Approach)

Performance of the cooling tower depends upon the heat dissipation(Kcal/h), heat load, approach, wet bulb temperature, size of the tower and fill media (film fill, low-clog film fill and splash fill).

There are various instruments which are used during the energy audit of cooling towers.

- **Anemometer:** Used to measure the flow rate of air.
- **Power analyser:** It analyses the electrical parameters of the pump and fan.
- **Sling hygrometer:** Measures dry bulb and wet bulb temperatures of air.
- **Flow meter:** Measures water flow-rate.
- **Temperature indicator:** It uses a thermocouple and measures the water temperature.

Alternate working fluids

Water and steam are the most common heat carriers. However there are problems such as high operating pressures along with leakage losses etc. associated with such systems.

Alternative fluids such as mineral oil, synthetic oil and various other nanofluids are also being used and systems are proved to be much more efficient in its functioning. Some of the advantages of such a system are:

- High operating Temperatures such as 300°C at atmospheric pressure
- Wide range of temperature for stable working
- No need for feed water treatment
- No heat loss related to condensation or Flash steam
- No risk of corrosion
- No need for anti-freeze agents
- Lower maintenance cost
- Quite in operations
- Easy to operate
- Uniform pressures for complete cycle

Internal combustion engines

These engines although deliver High quality of power, but are relatively less efficient. Studies have shown that out of total energy supplied to the engine only 26-28% is available. Nearly 34% of energy is lost to exhaust, 30% in engine cooling and around 10% is dissipated to overcome frictional losses. There are several ways suggested to improve its efficiency by Fuel conservation by operating on design points, proper engine loading, proper lubrication which could reduce frictional losses. Waste heat recovery mechanisms such as turbo charger, hot water generation, vapour absorption refrigeration system are also advised for specific systems to maximize the efficiency of engine where ever possible. Further I.C. engines require regular servicing and timely renewal of lubricants and oil well for proper functioning.

Water Audit and Conservation

Water audit and conservation with the exponential urban and industrial development along with population, the available quantity of water and its quality has reduced drastically as compared to past decades. In a report by IWRS 2004 it was reported that there was demand of 22 bcm (billion cubic meters) of water in 1995-97 and according to National commission the estimated demand of water stand at 70 bcm by 2025 and 103 bcm by 2050. This data shows the urgency with which the issue of water conservation has to be dealt with:

Classification

The water conservation measures can be broadly classified into technological advancements and habitual practices. The former is used in industrial and commercial users where new installations in water management can significantly affect the setup profitability in future.

Technological advancements: Technological advancements majorly include water recirculation, reuse and recycle. There are few applications such as low flow fixtures, water less urinals, planned landscape irrigation, etc. are used in many commercial projects.

Habitual practices: Changes in behavior of individuals and society as a whole can contribute to great amount of water conservation.

The measures for water conservation may also depend upon the factor of usage of the conservation system by social or industrial/commercial establishment. As a social establishment may use this as a policy towards environment and responsibility towards nature and future generations but industrial establishments may also have ulterior motives of profit maximization of reduction in input cost etc. [7,8].

Conservation

There are several ways suggested for water conservations:

- Rain water harvesting
- Recycle, recirculate, reuse
- Low flow fixtures
- Planned landscape irrigation
- Alternative technologies

Solar Energy

Many reviews have been conducted by engineers and researchers are very important and informative to understand solar technologies [9]. As India is energy deficient country and the demand of energy is enormous and the deficit is also very large. This energy deficit can't be fulfilled by any single energy source but to a great extent can be controlled with the help of solar energy technologies applied to various uses such as power generation [10] or energy source for various industrial applications. There is huge potential for solar thermal and solar photovoltaic (PV) technologies to be applied in the industries which can reduce the demand of energy on the grid.

Some solar thermal technologies are:

- Flat plate collector
- Evacuated tube collector
- Parabolic trough concentrator
- Parabolic dish concentrator
- Compound parabolic concentrator

Solar thermal and PV technologies can be used for power generation, air-conditioning, water heating or process heating, waste heat recovery and many other methods [11] as discussed by S. Mekhilef and R. Saidur, which directly or indirectly utilize solar heat as energy source and reduce the energy budget for the setup.

Conclusion

Energy generation is a complicated issue than its expenditure and therefore it becomes very important to follow the judicious use of the available energy. Energy and environment conservation is not the responsibility of a single person or a group of persons. The society as a whole has to become aware and act aptly for sustainable development. Many government agencies are also working to spread awareness by means of advertisement campaigns such as Petroleum Conservation Research Association (PCRA), BEE and Green Energy Rating Agencies such as GRIHA etc. It has also been observed that with minor changes in Habitual practices by society major amount of energy waste can be plugged, this will also result in lower Energy bills for households as well as commercial establishments. Many electrical devices such as Motor, Transformer, illumination devices along with power quality issues have also been discussed.

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