Module 5
INTRODUCTION

The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect.
As per the Energy Conservation Act, 2001, Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".
The objective of Energy Management is to achieve and maintain optimum energy procurement and utilization, throughout the organization and:
• To minimize energy costs / waste without affecting production & quality
• To minimize environmental effects.

Energy Audit: Needs
In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists.
The Energy Audit would give a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities. Such an audit programme will help to keep focus on variations which occur in the energy costs, availability and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc.
In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame.
The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a “bench-mark" (Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

LECTURE 1: Energy Audit: Types and Methodology

Energy Audit is the key to a systematic approach for decision-making in the area of energy management. It attempts to balance the total energy inputs with its use, and serves to identify allthe energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management program. As per the Energy Conservation Act, 2001, Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan toreduce energy consumption".

Type of Energy Audit

The type of Energy Audit to be performed depends on:
- Function and type of industry
- Depth to which final audit is needed, and
- Potential and magnitude of cost reduction desired

Thus Energy Audit can be classified into the following two types.
i) Preliminary Audit
ii) Targeted Audit
iii) Detailed Audit

Preliminary Energy Audit Methodology

Preliminary energy audit is a relatively quick exercise to:
Establish energy consumption in the organization
Estimate the scope for saving
Identify the most likely (and the easiest areas for attention
Identify immediate (especially no-/low-cost) improvements/ savings
Set a 'reference point'
Identify areas for more detailed study/measurement
Preliminary energy audit uses existing, or easily obtained data

Targeted energy Audit

Targeted energy audits are mostly based upon the outcome of the preliminary audit results.
They provide data and detailed analysis on specified target projects.
As an example, an organization may target its lighting system or boiler system or compressed air system with a view to bring about energy savings.
Targeted audits therefore involve detailed surveys of the target subjects/areas with analysis of the energy flows and costs associated with those targets.

Detailed Energy Audit Methodology

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems. This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost. In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use. This estimated use is then compared to utility bill charges. Detailed energy auditing is carried out in three phases: Phase I, II and III.
Phase I - Pre Audit Phase

Phase II - Audit Phase
Phase III - Post Audit Phase

Phase I -Pre Audit Phase Activities

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

Initial Site Visit and Preparation Required for Detailed Auditing
An initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity to meet the personnel concerned, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit. During the initial site visit the Energy Auditor/Engineer should carry out the following actions: -

- Discuss with the site's senior management the aims of the energy audit.
- Discuss economic guidelines associated with the recommendations of the audit.
- Analyze the major energy consumption data with the relevant personnel.
- Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.
- Tour the site accompanied by engineering/production

The main aims of this visit are: -

- To finalize Energy Audit team
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify any existing instrumentation/ additional metering required.
- To decide whether any meters will have to be installed prior to the audit eg. kWh, steam, oil or gas meters.
- To identify the instrumentation required for carrying out the audit.
- To plan with time frame
- To collect macro data on plant energy resources, major energy consuming centers
- To create awareness through meetings/ program

Phase II- Detailed Energy Audit Activities
Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.
The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected pay- back on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be per- formed to justify the implementation of those conservation measures that require investments. The information to be collected during the detailed audit includes: -

1. Energy consumption by type of energy, by department, by major items of process equipment, by end-use
2. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)

3. Energy cost and tariff data
4. Process and material flow diagrams
5. Generation and distribution of site services (eg. compressed air, steam).
6. Sources of energy supply (e.g. electricity from the grid or self-generation)
7. Potential for fuel substitution, process modifications, and the use of co-generation systems (combined heat and power generation).
8. Energy Management procedures and energy awareness training programs within the establishment
The ten steps for detailed energy audit

Step No	PLAN OF ACTION	PURPOSE / RESULTS
	Phase I –Pre Audit Phase	
Step 1	• Plan and organise • Walk through Audit • Informal Interview with Energy Manager, Production / Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments & time frame • Macro Data collection (suitable to type of industry.) • Familiarization of process/plant activities • First hand observation & Assessment of current level operation and practices
Step 2	• Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.)	• Building up cooperation • Issue questionnaire for each department • Orientation, awareness creation

	<u>Phase II –Audit Phase</u>	
Step 3	• Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	• Historic data analysis, Baseline data collection • Prepare process flow charts • All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	• Conduct survey and monitoring	• Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.

Step 5	• Conduct of detailed trials /experiments for selected energy guzzlers	• Trials/Experiments: - 24 hours power monitoring (MD, PF, kWh etc.). - Load variations trends in pumps, fan compressors etc. - Boiler/Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials Equipments Performance experiments etc
Step6	• Analysis of energy use	• Energy and Material balance & energy loss/waste analysis
Step 7	• Identification and development of Energy Conservation (ENCON) opportunities	• Identification & Consolidation ENCON measures ▪ Conceive, develop, and refine ideas ▪ Review the previous ideas suggested by unit personal ▪ Review the previous ideas suggested by energy audit if any ▪ Use brainstorming and value analysis techniques ▪ Contact vendors for new/efficient technology

Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step9	• Reporting & Presentation to the Top Management	• Documentation, Report Presentation to the top Management.
	Phase III –Post Audit phase	
Step10	• Implementation and Follow-up	Assist and Implement ENCON recommendation measures and Monitor the performance • Action plan, Schedule for implementation • Follow-up and periodic review

LECTURE 2: Energy Audit Instrumentation

The EAI types included in the directory were selected as a basic audit instrument set by RMA(Resource management association)staff following discussions with Indian energy consulting firm personnel. RMA staff and a team at the Mechanical Engineering Department of Indian Institute of Technology - Madras attempted to identify all EAI manufacturers and suppliers and sent surveys to each identified manufacturer or supplier. Much of the information supplied by the firms surveyed was incomplete.

Anemometers

Anemometers are essentially fluid flow measuring instruments. As energy audit tools, they are most commonly used to measure air flow from heating, ventilation, and air conditioning (HVAC) systems. Anemometers are classified into four types:

1. **Rotating Vane**
2. **Bridled Vane**
3. **Deflecting Vane**
4. **Hot Wire**

Rotating Vane: This instrument consists of a lightweight, fluid-driven vane, wheel or propeller, which is connected by a gearing system to a set of recording dials which display the amount of fluid passing through the wheel during a prescribed period. To compensate for the mechanism=s frictional drag at low fluid velocities, an A over-speeding@ gear train is often utilized. The over-speeding correction is usually additive at lower fluid velocities and subtractive at higher velocities.

Bridled Vane: The velocity measurement made by this type of anemometer does not depend on a time interval. It measures the instantaneous velocity and head, then displays the velocity.

Deflecting Vane : Instead of using a swinging vane to deflect the fluid flow and indicate a velocity reading, this instrument utilizes the pressure exerted on a vane. The deflecting vane is free to move in a circular tunnel and causes a pointer to indicate the velocity measurement on a scale. This type of anemometer is not dependent on fluid density because it senses pressure differentials to indicate velocities.

Hot Wire : The hot-wire anemometer is employed to measure mean and turbulent velocity components. A fine wire is heated electrically and placed in the flow stream. The heat transfer rate from the wire is a function of flow velocity. In the more common constant-temperature version, the temperature of the wire is held constant through a suitable electrical circuit. Complete commercial versions of hot-wire and hot-film anemometers are available. These instruments are complex and relatively costly. In the U.S. they are commonly used for energy auditing.

Application:

Anemometers are most commonly used to measure the airflow of HVAC systems, but are also used to measure other clean air flows. For example, when testing and tuning a HVAC systems it is important to insure that appropriate quantities of fresh air are delivered.

Combustion Analyzers and Other Combustion Gas Monitoring and Control Instruments

A combustion analyzer estimates the combustion efficiency of furnaces, boilers and other fossil fuel-fired devices. To estimate efficiency, the instrument measures the composition of the flue gas (typically CO2, CO and O2) and exhaust gas temperature. Oxygen levels are measured to ensure proper excess air levels. Each furnace design and fuel type has an optimal excess air level.

Two general procedures are used to determine combustion efficiency: a manual process through the Orsat procedure, or use of a (computerized) combustion analyzer. The combustion analyzer estimates efficiency by performing the concentration and temperature measurements and completing the necessary calculations to determine efficiency. The manual procedure, or Orsat method, requires the auditor to measure flue gas temperature and the concentrations of CO2 and O2, then calculate (or obtain from standard charts) the combustion efficiency.

The Orsat procedure provides an instantaneous measurement of the combustion products, while a combustion analyzer provides a continuous measurement of the combustion products. Continuous measurement allows for trending of combustion products as boiler load changes and as boiler adjustments and improvements are made. The Orsat procedure is relatively difficult and prone to human error.

A combustion analyzer requires a probe for stack measurements. The probe is inserted through a single stack or breathing hole to measure combustion product concentration and flue gas temperature. Combustion testing is used to gauge if the appropriate amounts of combustion air for efficient fuel combustion are being maintained in the boiler/furnace/kiln. Low CO measurements are indicative of excess air, whereas high CO concentrations are indicative of low oxygen or poor burnout conditions. Similarly, high stack temperatures (and thus high rates of heat loss) are indicative of excess air (O2).

Many of the combustion analyzers are also able to measure the concentrations of SO_2, NO_x , and soot, making these instruments valuable for measuring combustion air pollutant emissions. The typical range of concentration, measured by combustion analyzers in the flue gases, is 0% to 21% for O_2; from 0% to 20% for CO_2; and between 0% and 0.5 % for CO.

Application:

Combustion analyzers can be used for periodic combustion tuning of furnaces, boilers, and kilns and to insure optimal fuel combustion. Using a combustion analyzer to regularly maintain combustion efficiency can have a payback period of weeks to months for larger furnaces. For example, a 1% O_2 reduction can result in 2% fuel savings.

Ultrasonic Flow Meters

Ultrasonic flow meters are used to estimate fluid flow without having to penetrate piping. Ultrasonic flow meters operate based on one of two methods. Some use the the frequency shift (i.e. Doppler Effect) experienced by an ultrasonic signal as it is reflected by bubbles or particles (i.e., discontinuities) entrained by a flowing fluid. The magnitude of the frequency shift is indicative of the velocity of the fluid. Other ultrasonic flow meters are able to estimate the velocity of a clear (i.e., free of entrained particles or bubbles) liquid. Given the inside pipe diameter, the instruments then calculate flow rate (i.e., gallons/minute or liters/minute). Ultrasonic flow meter measurements can be relatively inaccurate.

Ultra sonic flow meter

Combustion analyzer

Combustion analyzer

Application: Ultrasonic flow meters can be used to estimate flow rates entering or leaving a pump. For example, the instrument can be used to ensure that flow rates are maintained as efficiency improvements (i.e., reducing motor size, and re-plumbing to reducing frictional losses) are made to plumbing systems.

Humidity and Temperature Meters

Most of the humidity meters included in the directory are electrical. Electrical humidity-measuring instruments use sensors which react to varying levels of humidity by causing a physical change in a material which changes its electrical properties (often resistance). The materials electrical property is calibrated to humidity. Often thermocouples are used to measure temperatures. Thermocouples utilize materials whose resistance is indicative of temperature.

Application:

Given processes have optimal humidity and temperature conditions. For office, commercial, and residential settings, a humidity between 40% and 60% is considered optimal. Low humidity results in respiratory problems and static electricity problems which can damage delicate electric components. High humidities can cause mildew, wood warping, and poor drying.

Light Meters (Lux meter)

Light meters measure illumination or light level in units of foot-candles or lumens. Light emitted by the area of interest passes through a light-sensitive layer of cells contained in the meter. This light is converted to an electrical signal proportional to the light=s intensity. It differs from a conventional photographic light meter in that it is color- and cosine-corrected and measures lighting from a wide rather than a small field. Most lighting levels encountered during energy audits are less than 1,000 foot candles. (Note: 10.76 foot candles = 1 lux.)

Application:

Light meters are most commonly used to determine if interior lighting levels are appropriate, both before and after lamping upgrades are made. Lighting societies (e.g., the Illumination Engineering Society of North America) have developed guidelines for lighting levels for different work/interior areas. These guidelines were developed to minimize eye strain and maintain a safe environment, while not producing excess lumen levels and wasting energy. If lighting conditions are inappropriate, lumen levels should be adjusted.

Multimeters

Multimeters measure amps (electron flow) volts (Aelectrical pressure@) and ohms (resistance) of electrical equipment. These metering abilities can also be purchased as separate instruments: ammeters, voltmeters and ohmmeters. Ammeters are used to measure electric currents. A voltmeter measures the difference in electrical potential between two points in an electrical circuit. Multimeters, particularly the digital clamp-on designs, are considered the most versatile audit instrument. Analog instruments use a separate sensing circuit each to measure volts, amps, and ohms. Digital instruments transform the analog signals into binary signals which are counted and displayed in a digital format. The typical multimeter will measure 0 to 300 amps, 0 to 600 volts, and 0 to 1,000 ohms. The ability to measure Atrue RMS@, or root mean squared, voltage is vital when analyzing AC signals that may produce distorted wave forms.

Applications: Multimeters are commonly used to check that the proper voltage is supplied to equipment, or to determine the load on a wire or electrical device (e.g., a motor). Multimeters are also used to determine if three-

Lux meter

phase power supply is balanced. For example, a voltage imbalance of 3% at a three-phase motor can result in a 25% motor temperature increase, which reduces motor life and motor efficiency. A high-quality multimeter (or voltmeter) is required to determine voltage balance.

pH Meters

The pH of an aqueous solution is a value expressing the solution's acidity or basicity, based on the concentration of hydrogen ions present (where 0 is strongly basic, 14 is strongly acidic, and 7 is neutral). A pH meter uses the property of certain types of electrodes to exhibit electrical potential when immersed in a solution. The electrical potential is indicative of the solution=s pH. The instrument has three elements, an electrode or cell that measures pH, a reference electrode, and a resistance thermometer. (The thermometer is used to compensate for the effect of temperature on electrical potential.) Both electrodes are typically enclosed in thin-walled glass tubes. Inside the measurement electrode, is a solution of known pH. When the measurement electrode is placed in the unknown solution a voltage is generated. The reference electrode is then inserted into the unknown solution - providing a reference voltage. The voltages are compared and displayed on a calibrated pH scale.

Application:

Accurate measurements of pH are required to properly maintain water quality in order to protect equipment and materials that are in contact with the water (e.g., boiler tubes and heat ex-changers). Serious problems (e.g., precipitation of salts and corrosion) can occur if proper Ph levels are not maintained.

Watt Meters, Power Meters, and Power Analyzers

Watt Meter: The watt meter is employed to directly measure the amount of power used by a single-phase electric device. The basic watt meter consists of two voltage probes and a snap-on current coil which feeds the watt meter's movement. It measures true RMS (root mean squared) voltage, current and power factor. Based on the current and voltage measurements, a watt meter calculates and displays power (watts) consumption. Multiple measurements using a watt meter can be used to assess three-phase circuits. The typical watt meter has operating limits of 300 kW, 650 volts, and 6,000 amperes.

Power Meter: Power meters measure true RMS voltage, current, and the power factor and calculate power use by single-phase and balanced or unbalanced three-phase circuits. Some meters record a time history of the measurements.

Three Phase Power and Disturbance Analyzer: These meters can do everything that a power meter does and more. Power analyzers are used to determine parameters on the sine and nonlinear/distorted wave forms and harmonic distortion levels for both balance and unbalanced power systems. Many electronic devices cause harmonic distortions in both voltage and current waveforms. Because of these distortions, the measurements given by conventional power meters may be incorrect. Power analyzers compensates for harmonic distortions by using RMS methods to determine voltage and current.

Application:

These instruments are very useful for testing, measuring, servicing, and maintaining electrical equipment and facilities. For example a watt meter can be used to measure the power consumption of an individual motor to determine if it is properly sized for its application

Power disturbance information provided by power analyzers is used to diagnose problems which can reduce electronic device reliability. For example, phase sequencing problems can cause sluggish or overheated motors

(which results in premature equipment failure). Managing power quality prevents overloading conductors and minimizes the risk of problems resulting from voltage irregularities.

Power Factor Meters

Power factor meters are used to measure the power factor of electrical equipment, particularly three-phase motors. Power factor is a measurement of the electrical current in a wire which is doing useful work compared to the total electrical current in the wire. The non-useful component of the current creates magnetic fields in the end-use device. These magnetic fields are not detrimental or beneficial to the end-use device. But the non-useful component of the current requires generation, transmission, and distribution capacity, thereby causing inefficiencies in power systems.

Power factor measurements indicate the phase shift between the voltage and the current. A perfect 90o phase shift has a power factor of 1.0. If the phase shift is not 90o , then a fraction of the current is not useful and the power factor is less than unity. The larger the phase shift, the lower the power factor, and the greater the power system inefficiencies. Power factor meters typically measure power factor over a range of 1.0 leading to 1.0 lagging and see Aampacities@ of up to 1,500 amperes at 600 volts.

Power factor meters can be used on single- and multi-phase electrical circuits. Multi-phase instruments simultaneously monitor all phases of voltage and current when determining power factor.

Application:

Once a power factor meter has been used to identify low power factors and the scale of the problem, capacitors can be installed to correct power factor problems by adding more capacity to the wiring network. (Power factor measurements are required to properly specify capacitor requirements.) With power factor improvement, the cost of power generation is reduced; utility power factor charges are reduced (if levied); and transmission, distribution, facility connection, and conductor size needs are reduced (as the I2R losses are reduced).

Ultrasonic Steam Trap Tester

Steam traps used in condensate return systems are typically designed to fail in the open position. In the open position, they pass high-energy-content steam directly into condensate return lines. An open steam trap is difficult to identify by visual inspection. Three types of steam trap testers have been developed to identify malfunctioning steam traps: infrared, conductive, and ultrasonic.

Ultrasonic steam trap testers are the most popular and reliable. They operate as an electronic stethoscope@. They are able to pick up the very high-pitched sound indicative of freely blowing steam (condensate draining makes a lower-pitched sound). The advantage of ultrasonic testers is that they can listen to one pipe and hear if any of the nearby steam traps have failed.

Application: Experts estimate that about 15 to 30 % of installed traps are faulty. Faulty steam traps are often the largest single source of energy losses at an industrial facility. Steam trap maintenance programs, where steam traps are regularly checked using an ultrasonic steam trap tester are typically very cost effective.

Ultrasonic detecting devices can also be used to identify any type of gas or fluid leaks (including steam, nitrogen, CFCs, compressed air, and fuel), leaking valves, line blockages, damaged motor bearings, malfunctioning compressor heads, and missing teeth on gears.

Stroboscopic Non-Contact Tachometers

A tachometer is an instrument used to measure the rotational speed of a shaft or wheel in revolutions per minute (rpm). A stroboscopic tachometer employs a variable-frequency, flashing light which makes the rotating component appear to stand still when the frequencies match. This allows the users to measure the rotational speed without contacting the object in question.

Application:

Stroboscopes are typically used to determine the mechanical loading of motors. By measuring a motor speed in rpm and electrical consumption, its efficiency can be determined. Non-contact stroboscopes are also commonly used to measure fan speeds and determine fan output (using the design fan curve).

Non-Contact Infrared Thermometers (also known as radiation pyrometers)

These thermometers rely on the electromagnetic radiation emitted by solids or fluids. The radiation is characteristic of their temperature. A lens focuses the infrared energy on the active detecting surface. The heart of the infrared thermometer is the detecting surface, which absorbs infrared energy and converts it to an electrical voltage or current. The accuracy of temperature measurements by infrared instruments depends on the absorption, reflection, and transmission characteristics of the radiative flux. These instruments typically indicate thermal variations of

0.1oC and can cover a range of -30EC to 2,000EC (5EF-3,600EF). Corrections to apparent temperatures are made from knowledge of the emissivity of the object at the specified temperature.

Application:

Non-contact infrared thermometers, also known as heat guns, are very useful for measuring surface temperatures of steam lines, boiler surfaces, processes temperatures, etc. The primary use of infrared sensors in an energy management program is to detect building or equipment thermal losses, pinpoint insulation or weatherization needs, identify electrical hot spots, and locate unseen motor friction points

Contact Thermometers

Temperature is one of the most important properties determining the efficiency of thermal energy utilization. Several types of thermometers appropriate for energy auditing are available. The choice is usually dictated by cost, durability, range, accuracy, and application. Most HVAC applications require a thermometer with temperature of -50EC to 175EC (-50EF to 350EF). Boiler and oven stacks require thermometers able to measure up to about 500EC (1,000EF).

Contact thermometer

Thermometer types include:

Fluid-filled instruments: These thermometers use either a fluid or solid which expands with increasing temperature. A very common design uses a simple calibrated and evacuated glass tube filled with mercury or alcohol.

Resistance Instruments: Electronic thermometers operate on the principle that some materials change their electrical resistance as temperature changes. Typically, the sensing element consists of a long, coiled, heat-sensitive wire wound about a ceramic core and protected by a metal housing. The material=s resistance is scaled to temperature and displayed.

Thermocouple Instruments: The operation of this class of thermometer is based on the response of two wires of dissimilar metals which, when joined together and heated, generate electricity. A very small DC voltage is produced across the ends of the wires. The resultant voltage is calibrated to temperature and displayed. Inexpensive thermocouples typically measure temperatures up to 1,100EC (2,000EF).

Thermistor Instruments: These instruments utilize a solid-state semiconducting material which responds to temperature increases by decreasing the electrical resistance of the semiconductor. They are typically calibrated in the factory. A given current flow is indicative of a given temperature.

Application:

Temperature measurements are a useful method to determine process efficiencies (to assess appropriate heating levels, analyze boiler operation, and indicate building heat loss) and waste heat sources (determine the potential for waste heat recovery programs)

Power analyzers

Electrical Measuring Instruments: These are instruments for measuring major electrical parameters such as kVA, kW, PF, Hertz, kvar, Amps and Volts. In addition some of these instruments also measure harmonics. These instruments are applied on-line i.e on running motors without any need to stop the motor. Instant measurements can be taken with

hand-held meters, while more advanced ones facilitates cumulative readings with print outs at specified intervals.
Power analyzer

Flue gas analysers
Fuel efficiency monitor: Fuel efficiency is the efficiency of a process that converts chemical potential energy contained in a carrier fuel into kinetic energy or work. This measures Oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency
Fyrite: A hand bellow pump draws the flue gas sample into the solution inside the fyrite. A chemical reaction changes the liquid volume revealing the amount of gas. Percentage Oxygen or CO_2 can be read from the scale.
Flow measuring instruments
Pitot Tube and manometer: Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows.
Leak Detectors:
Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible to detect with human abilities.
LECTURE 3: Introduction to Cogeneration and types of cogeneration
Cogeneration or Combined Heat and Power (CHP) is the combined generation of heat and power. It is not a single technology, but an integrated energy system. Cogeneration first involves producing power from a specific fuel source, such as natural gas, biomass, coal, or oil. During fuel combustion, cogeneration captures the excess heat which would have otherwise been wasted.
The captured heat can be used to boil water, create steam, heat buildings, etc. For instance, in the oil sands, steam is required to produce bitumen. By using cogeneration, energy companies can simultaneously produce steam for production and electricity on site. By minimizing waste, cogeneration plants generally convert 75-80% of the fuel source into useable energy, in comparison with conventional systems which only covert about 45%.
When the heat captured is used to produce electricity, the process is referred to as combined cycle.
Fuel efficiency monitor
Fyrite

Pitot Tube and manometer
Leak Detector
Combined cycle

Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85 per cent and above in some cases. For example in the scheme shown in Figure 7.2, an industry requires 24 units of electrical energy and 34 units of heat energy. Through separate heat and power route the primary energy input in power plant will be 60 units (24/0.40). If a separate boiler is used for steam generation then the fuel input to boiler will be 40 units (34/0.85). If the plant had cogeneration then the fuel input will be only 68 units (24+34)/0.85 to meet both electrical and thermal energy requirements. It can be observed that the losses, which were 42 units in the case of, separate heat and power has reduced to 10 units in cogeneration mode.

Along with the saving of fossil fuels, cogeneration also allows to reduce the emission of greenhouse gases (particularly CO2 emission). The production of electricity being on-site, the burden on the utility network is reduced and the transmission line losses eliminated.

Cogeneration makes sense from both macro and micro perspectives. At the macro level, it allows a part of the financial burden of the national power utility to be shared by the private sector; in addition, indigenous energy sources are conserved. At the micro level, the overall energy bill of the users can be reduced, particularly when there is a simultaneous need for both power and heat at the site, and a rational energy tariff is practiced in the country.

Types of Cogeneration Systems (Technical Options for Cogeneration)

There are different types of cogeneration system some of them are listed below:

1. Steam Turbine Cogeneration systems
2. Gas Turbine Cogeneration Systems
3. Reciprocating Engine Cogeneration Systems

Steam Turbine Cogeneration systems

A steam generated power station is a power plant where water after its heated turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed and recycled back in to the same place where it was originally heated.

This cycle is known as a Rankine cycle named after the engineer William Rankine, a civil engineer who developed the theory and process.

Almost all large scale steam cogenerating power plants today still adopt this steam cycle in order to operate the turbines efficiently and provide high levels of constant electrical power generation.

The two types of steam turbines most widely used are the backpressure and the extraction-condensing types as shown in figure 7.3. The choice between the both turbines depends mainly on the quantities of power and heat and economic factors.

In a backpressure turbine, the outlet of the turbine is connected to a header that distributes steam to the various process. In a condensing turbine, outlet steam is sent to a condenser operating under vacuum. These simple backpressure or condensing turbines are typically only used in simple steam systems. In more-complex applications, multiple backpressure turbines can be combined in series to form a single turbine with multiple steam outlets.

Turbines with multiple outlet ports are called extraction turbines; these are frequently used for cogeneration because they allow steam to be extracted at one or more intermediate points in the turbine casing.
The other type of steam turbine used in CHP applications is called an extraction turbine. In these turbines, steam in extracted from the turbine at some intermediate pressure. This steam can be used to meet the facilities steam need. The remaining steam is expanded further and condensed. Extraction turbines can also act as admission turbines. In admission turbines, additional steam is added to the turbine at some intermediate point.
Another variation of the steam turbine topping cycle (In a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.) cogeneration system is the extraction-back pressure turbine that can be employed where the end-user needs thermal energy at two different temperature levels. The full-condensing steam turbines are usually incorporated at sites where heat rejected from the process is used to generate power. The specific advantage of using steam turbines in comparison with the other prime movers is the option for using a wide variety of conventional as well as alternative fuels such as coal, natural gas, fuel oil and biomass.
The power generation efficiency of the cycle may be sacrificed to some extent in order to optimize heat supply. In backpressure cogeneration plant there is no need for large cooling towers. Steam turbines are mostly used where the demand for electricity is greater than one MW up to a few hundreds of MW.
Gas Turbine Cogeneration Systems
A cogeneration system drives a gas turbine by using primary energy (fuel), and produces multiple types of secondary energy (e.g., electricity, steam) continuously. In a gas turbine cogeneration system, fuel is used as the primary energy, and multiple types of energy are produced in order to use energy more effectively. Furthermore, the system curbs NOx production and reduces environmental impact by using a gas turbine as the drive source.

Just like a diesel or gasoline engine, a gas turbine is a type of internal combustion engine and operates using the cycle of intake, compression, combustion (expansion) and exhaust. One major difference, however, is that the basic movement. A gas turbine is rotary movement, in contrast to the back-and-forth movement of a reciprocating engine.
The basic principle of a gas turbine is as shown in the diagram below. First, air is compressed by a compressor, and this compressed air is guided into the combustor. Here, fuel is continuously combusted to produce gas at high temperature and pressure. What a gas turbine for industry does is the gas produced in the combustor is expanded in the turbine (a vaned rotor made by attaching multiple blades to a round disk), and as the result, the rotational energy, which operates the compressor at the previous stage, is produced. The remaining energy is delivered with an output shaft.
Gas turbine cogeneration systems can produce all or a part of the energy requirement of the site, and the energy released at high temperature in the exhaust stack can be recovered for various heating and cooling applications (see Figure 7.4). Though natural gas is most commonly used, other fuels such as light fuel oil or diesel can also be employed. The typical range of gas turbines varies from a fraction of a MW to around 100 MW.

Gas turbine cogeneration has probably experienced the most rapid development in the recent years due to the greater availability of natural gas, rapid progress in the technology, significant reduction in installation costs, and better environmental performance. Gas turbine has a short start-up time and provides the flexibility of intermittent operation. Though it has a low heat to power conversion efficiency, more heat can be recovered at higher temperatures. If the heat output is less than that required by the user, it is possible to have supplementary natural gas firing by mixing additional fuel to the oxygen-rich exhaust gas to boost the thermal output more efficiently.

On the other hand, if more power is required at the site, it is possible to adopt a combined cycle that is a combination of gas turbine and steam turbine cogeneration. Steam generated from the exhaust gas of the gas turbine is passed through a backpressure or extraction-condensing steam turbine to generate additional power. The exhaust or the extracted steam from the steam turbine provides the required thermal energy.

Reciprocating Engine Cogeneration Systems

Also known as internal combustion (I. C.) engines, these cogeneration systems have high power generation efficiencies in comparison with other prime movers. There are two sources of heat for recovery: exhaust gas at high temperature and engine jacket cooling water system at low temperature (see Figure 5.4). As heat recovery can be

quite efficient for smaller systems, these systems are more popular with smaller energy consuming facilities, particularly those having a greater need for electricity than thermal energy and where the quality of heat required is not high, e.g. low pressure steam or hot water.

Classification of Cogeneration Systems

Cogeneration systems are normally classified according to the sequence of energy use and the operating schemes adopted. A cogeneration system can be classified as either a topping or a bottoming cycle on the basis of the sequence of energy use. In a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other thermal requirements. Topping cycle cogeneration is widely used and is the most popular method of cogeneration.

Topping Cycle

The four types of topping cycle cogeneration systems are briefly explained in Table 7.1.

Bottoming Cycle

In a bottoming cycle, the primary fuel produces high temperature thermal energy and the heat rejected from the process is used to generate power through a recovery boiler and a turbine generator. Bottoming cycles are suitable for manufacturing processes that require heat at high temperature in furnaces and kilns, and reject heat at significantly high temperatures. Typical areas of application include cement, steel, ceramic, gas and petrochemical industries. Bottoming cycle plants are much less common than topping cycle plants.

The following Table 7.5 gives the advantages and disadvantages of various co-generation systems:

LECTURE 4: Operating Schemes of Cogeneration

The operating scheme of a cogeneration system is very much site-specific and depends on several factors, as described below:

Base electrical load matching

In this configuration, the cogeneration plant is sized to meet the minimum electricity demand of the site based on the historical demand curve. The rest of the needed power is purchased from the utility grid. The thermal energy requirement of the site could be met by the cogeneration system alone or by additional boilers. If the thermal energy generated with the base electrical load exceeds the plant's demand and if the situation permits, excess thermal energy can be exported to neighboring customers.

Base Thermal Load Matching

Here, the cogeneration system is sized to supply the minimum thermal energy requirement of the site. Stand-by boilers or burners are operated during periods when the demand for heat is higher. The prime mover installed operates at full load at all times. If the electricity demand of the site exceeds that which can be provided by the prime mover, then the remaining amount can be purchased from the grid. Likewise, if local laws permit, the excess electricity can be sold to the power utility.

Electrical Load Matching

In this operating scheme, the facility is totally independent of the power utility grid. All the power requirements of the site, including the reserves needed during scheduled and unscheduled maintenance, are to be taken into account while sizing the system. This is also referred to as a "stand-alone" system. If the thermal energy demand of the site is higher than that generated by the cogeneration system, auxiliary boilers are used. On the other hand, when the thermal energy demand is low, some thermal energy is wasted. If there is a possibility, excess thermal energy can be exported to neighboring facilities.

Thermal Load Matching

The cogeneration system is designed to meet the thermal energy requirement of the site at any time. The prime movers are operated following the thermal demand. During the period when the electricity demand exceeds the generation capacity, the deficit can be compensated by power purchased from the grid. Similarly, if the local legislation permits, electricity produced in excess at any time may be sold to the utility.

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Case Study

Economics of a Gas Turbine based co-generation System

Alternative I – Gas Turbine Based Co-generation

Gas turbine Parameters

Capacity of gas turbine generator : 4000 kW

Plant operating hours per annum : 8000 hrs.

Plant load factor : 90 %

Heat rate as per standard given by gas.turbine supplier : 3049.77 kCal / kWh

Waste heat boiler parameters – unfired steam output : 10 TPH

Steam temperature : 200 °C

Steam pressure : 8.5 kg /cm2.

Steam enthalpy : 676.44 kCal / Kg.

Fuel used : Natural gas

Calorific value – LCV : 9500 kCal/ sm3

Price of gas : Rs 3000 /1000 sm3

Capital investment for total co-generation plant : Rs. 1300 Lakhs
Cost Estimation of Power & Steam From Cogeneration Plant
1. Estimated power generation from Cogeneration : PLF × Plant Capacity × no. of operation hours
plant at 90% Plant Load Factor (PLF) = (90/100)×4000×8000
= 288.00 × 105 kWh per annum
2. Heat input to generate above units : Units (kWh) × heat rate
= 288 x 105 × 3049.77
= 878333.76 × 105 kCal
3. Natural gas quantity required per annum : Heat input / Calorific value (LCV) of natural gas
= 878333.76 x 105 / 9500
= 92.46 × 105 sm3
4. Cost of fuel per annum : Annual gas consumption. × Price
= 92.46 × 105× Rs.3000./1000 sm3
= Rs. 277.37 lakhs
5. Cost of capital and operation charges/annum : Rs. 298.63. lakhs
6. Overall cost of power from cogeneration Plant : Rs. 576.00.lakhs per annum
7. Cost of power : Rs. 2.00 /kWh
Alternative-II: Electric Power from State Grid & Steam from Natural Gas Fired Boiler
Boiler Installed in Plant:
Cost of electric power from state grid – average electricity : Rs. 3.00/kWh
cost with demand & energy charges
Capital investment for 10 TPH, 8.5 kg/sq.cm.200)°C : Rs. 80.00 lakh
Natural gas fired fire tube boiler & all auxiliaries

Estimation of cost for electric power from grid & steam from direct conventional fired boiler:
1. Cost of Power from state grid for 288 lakh kWh : Rs. 864.00 lakh per annum
2. Fuel cost for steam by separate boiler
(i) Heat output in form of 10 TPH steam per annum : Steam quantity × Enthalphy × Operations/annum
= 10 × 1000 × 676.44 × 8000
=541152 × 105 kCals
(ii) Heat Input required to generate 10 TPH steam :Heat output/boiler per annum @ 90% efficiency efficiency
= 541152 × 105/0.90
Heat Input : 601280 × 105 kCal per annum
(iii) Natural Gas Quantity : Heat Input/Calorific value (LCV) of natural gas
= 601280 × 105/9500
= 63.29 × 105 sm3 per annum
(iv) Cost of fuel per annum : Annual gas consumption × price
= 63.29 × 105× 3000 /1000 sm3
= Rs. 189.88.lakh per annum
(v) Total cost for Alternative-II : Cost of grid power + fuel cost for steam
= Rs. 864+ Rs.189.88 (lakh)
= Rs.1053.88 lakh per annum
Alternative I - Total cost : Rs. 576.00 lakh

Alternative II - Total cost : Rs. 1053.88 lakh
Differential cost : Rs. 477.88 lakh
(Note: In case of alternative-II, there will be some additional impact on cost of steam due to capital cost required for a separate boiler).
In the above case, Alternative 1 gas turbine based cogeneration system is economical compared to Alternative 2 i.e. electricity from State Grid and Steam from Natural Gas fired boiler.
LECTURE 5: Optimal Operation of Cogeneration / Combined Heat & Power Plants
Modeling of Cogeneration (CHP) Plant
Basic Diagram of Combined Heat and Power
The main characteristic of CHPs is that they reuse waste heat from prime mover during electricity generation processes to serve thermal loads, which is superior to traditional boilers. Extraction-condensing steam turbine-based CHP is very popular because the ratio between heat and electricity output could be adjusted according to various loading ratios between the two loads, providing more flexibility during peak and off-peak hours.
A typical CHP system consists of a combustion chamber, a turbine generator and a heat recovery boiler according to SIMO model of CHP can then be established, shown in Figure 5.5.

Figure 5.5 Single input and multi-output (SIMO) model of combined heat and power (CHP).
In the SIMO model of CHP, two key parameters should be determined first: overall energy conversion efficiency and Hear to power ratio (HTPR)
Overall Energy Conversion Efficiency
As shown in Figure 5.5, the output of a CHP system mainly includes four parts: electricity, heat, and unavoidable heat loss and exhaust gas emissions, while only the heat and electricity output are called useful energy. The overall energy conversion efficiency of a CHP is expressed as:.
---- 1
Where η is the overall efficiency; QΣ is the useful energy converted from natural gas, which is also the total energy of heat and electricity, in kJ; G is the energy of natural gas, in kJ.
In most existing research, the nominal value of η is adopted. However, η is found to be changing with different loading levels and operating modes of CHPs. The overall efficiency is mainly determined and affected by the loading level and generally they are expressed as:
----- 2
where L is CHP's loading condition.
Heat to Power Ratio
Although CHPs are able to provide heat and electricity simultaneously, there is a fixed relation between the two products. To study the ratio between heat and electricity, γ E and γ H , are introduced.
----- 3
where ECHP is the energy of electricity generated by CHP, in kJ; HCHP is the energy of heat generated by CHP, in kJ; γ E and γ H are just used to describe the energy proportion of ECHP and HCHP, respectively, and there is no practical significance for them.
By substituting Equation (1) into Equation (3), the output of CHP can be expressed in another form:
----- 4

where γ E η is usually called electric efficiency of CHP, also denoted by η_E; and γ H η is usually called the heat efficiency of CHP, also denoted by η_H.

Apparently, γ E and γ H naturally satisfy:

------ 5

The HTPR of CHPs is defined as the ratio of the heat output to the electricity output, which reflects the ability of CHPs to meet heat and electric demand. The HTPR of CHPs, denoted by ξ, expressed as:

------ 6

Optimal Operation of Cogeneration / Combined Heat & Power Plants

The optimization on CHP operation mainly concentrate on achieving economic goals (e.g., low operation cost, reduction of fuel consumption) and environmental goals (e.g., low carbon dioxide emission). The output of CHP is optimized to minimize the annual operating and maintaining costs of the whole system. When optimizing the operation strategy of CHPs to achieve maximum profits, energy prices should also be determined.

Various optimization algorithms are available to achieve real-time energy management of CHP. A discrete operation optimization model is explained here for CHPs in real-time, where the profits reach the maximum.

Discrete Optimization Model for Combined Heat and Power

In the wholesale market, electricity, heat and natural gas prices all vary at 30-min resolution, denoted by pE, pH and pG, respectively. Thus, CHPs could be operated according to the combination of the three prices to maximize benefits in the 48 dispatching steps. In the kth dispatching step, the profit is calculated by:

PROCHP (k) = IH(k) + IE(k) - CG(k)------ 7

Where PRO is abbreviation of profit and PROCHP (k) denotes the profit in the kth step; IH(k) and IE(k) are the income from selling heat and electricity, respectively; CG(k) is the cost of buying natural gas. Equation (7) can be further written as follows:

---- 8

Where VG(k) is the volume of natural gas consumed in the kth dispatching step; pH (k), pE (k) and pG (k) are the prices of heat, electricity and natural gas in the kth dispatching step respectively. Usually, the energy contained in a cubic meter of natural gas is a constant, denoted by q, in kJ/m3. Thus the total energy injected into the CHP in the kth step is expressed as:

G(k) = q VG(k)----- 9

Through substituting Equation (5) into Equation (6), H and E are obtained and shown as follows:

------ 10

By substituting Equations (4), (9) and (10) into Equation (8), the objective function of CHP is obtained, given by:

LECTURE 6: Computer Aided Energy Management

Computerized energy management system (EMS) is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. The monitor and control functions are known as Supervisory Control and Data Acquisition (SCADA), followed by several on-line application functions. Energy Management Software (EMS) is a general term referring to a variety of energy-related software applications which may provide utility bill tracking, real-time metering and lighting control systems, building simulation and modeling, carbon and sustainability reporting , demand response, and/or energy audits. Managing energy can require a system of systems approach.

Objectives of EMS:

1. Maintaining the power system in a secure and stable operating state by continuously monitoring the power flowing in the lines and voltage magnitudes at the buses.
2. Maintaining the frequency within allowable limits.
3. Maintaining the tie-line power close to the scheduled values.
4. Economic Operation of the power systems through real time dispatch and Control.
5. Optimal control of the power system using both preventive and corrective control actions.
6. Real time Economic Dispatch through real power and reactive power control
7. Optimization of the power system for normal and abnormal operating scenarios.
8. Optimal control of the power system by appropriate using both preventive and corrective control actions
9. Maintenance scheduling of generation and transmission systems.

Evolution of EMS:

The evolution of EMS has a long past. It has started with control centers in 1960s to fully developed energy management systems

1960 – Termed as Control Centre's (CC) These control centers were initially termed a load dispatch centres. The important task was to control the power generation and load demand as to match the generation with load demand. Even today, the term load dispatch centre's are widely used in various state electricity boards as well as energy control centre's.

1970 – Energy Control Centre's. Here the main task was to control the energy rather than the power. Here energy monitoring is of main concern the matching of energy of power demand from that of power generation is of main concern.

1990 – Energy Management Systems (EMS) In EMS, the main task was to manage the energy through various techniques like load management (LM), demand side management (DSM), distribution management systems (DMS). EMS are computer based programs hat perform both computational tasks as well as decision making tasks so as to assist the operator for real time operation and control.

Functions and Benefits of EMS:

The important benefits of an EMS can be addresses as the following functions:

Control functions:

1. Real time monitoring and control functions.
2. Automatic Control and automation of a power system like Automated interfaces and electronic tagging
3. Efficient automatic generation control and load frequency control.
4. Optimal automatic generation control across multiple areas
5. Tie -line control.

Operating functions

1. Economic and optimal Operation of the generating system.
2. Efficient operator Decision Making Improved quality of supply

Optimization functions

1. Optimal utilization of the transmission network

2. Power scheduling interchange between areas.
3. Optimal allocation of resources
4. Immediate overview of the power generation, interchanges and reserves
Planning functions
1. Improved quality of supply and system reliability
2. Forecasting of loads and load patterns
3. Generation scheduling based on load forecast and trading schedules
4. Maintaining reserves and committed transactions
5. Calculation of fuel consumption, production costs and emissions
EMS Architecture:
Fig 5.6 Power and Information flow between Power systems, SCADA and EMS
Figure 5.6 shows the components in EMS-SCADA. Power Systems contain generators, transformers, transmission lines, different loads to industry and consumers. SCADA consists mostly of hardware components, which measure the quantities (Voltage, current, power, etc.) from various meters. SCADA consists of collection of information

from meters distributed throughout the area through Remote Terminal Units (RTUS). EMS consists of a network of computers or work stations which perform computational tasks for decision making in real time operation and control. Both On-line and Off-Line functions can be performed in an EMS. The operators in an EMS send signals to the power system through SCADA. On line functions include mainly closed loop control functions like automatic generating control (AGC), load frequency control (LFC), voltage reactive power control (volt-var control). Open loop functions like Economic Dispatch and Operator load flow, state estimation, security assessment, etc are also performed in real time as on line functions.
Practical EMS
Figure 1.4 shows the actual implementation of Power System Model, SCADA AND EMS in a laboratory environment. The power system model consists of scaled down components of three phase generators, transformers, transmission lines and loads. The SCADA modules consist essentially of hardware for measurement monitoring, control and protection of the power systems. SCADA monitors information from the power system through PT, CT, etc., collects data and sends them to the EMS. Both Analog (continuous) data and digital (discrete) information are collected by the Remote Terminal Units (RTU).
EMS consists of a network of computers or work stations which perform computational tasks for decision making in real time operation and control. Both On-line and Off-Line functions can be performed in an EMS. The operators in an EMS send signals to the power system through SCADA. On line functions include mainly closed loop control functions like automatic generating control (AGC), load frequency control (LFC), voltage reactive power control (volt-var control). Open loop functions like Economic Dispatch and Operator load flow, state estimation, security assessment, etc are also performed in real time as on line functions.
Working of EMS
The important working of an EMS is given below
1. Real time monitoring and control over the whole distribution network.

2. Enhanced customer service through a complete outage management package including trouble call taking, fault localization and restoration as well as outage statistics and customer notification.

3. Efficient work order handling via the built-in work management tools.
4. Better crew and resource management including support for crew scheduling and tracking, dispatching and assignments as well as follow-up and reports.
5. Optimal network utilization using the State Estimator functionality for optimal feeder reconfiguration and loss minimization in balanced networks
6. Better support for all reporting with retrieval of historical data archived in a data warehouse