Steam Power Plants

Mitsubishi Heavy Industries, Ltd.
Energy Systems
3-3-1, Minatomirai, Nishi-ku, Yokohama,
Kanagawa, 220-8401, Japan
power.mhi.com

METP-01ST01E1-A-0, (1.0)21-09, ZEG

Mitsubishi Power is a power solutions brand of Mitsubishi Heavy Industries.

MOVE THE WORLD FORW>RD MITSUBISHI HEAVY INDUSTRIES GROUP

HOW TO POWER THE WORLD

OUR PLANET IS CALLING FOR AFFORDABLE, SUSTAINABLE, HIGHLY RELIABLE AND CLEAN POWER. TOGETHER WE CAN ACHIEVE IT.

Power grows when we all work together.

There is a strong demand for energy decarbonization in the world today. One in ten people is forced to live without reliable access to electricity, while global demand for power continues to grow. Mitsubishi Power addresses such needs by providing stable, highly reliable, and clean energy solutions.

Mitsubishi Power, a power solutions brand of Mitsubishi Heavy Industries based on a long history of product development and supply for more than a century, has been dedicated to designing, manufacturing, verifying, engineering, installing and providing services for a wide range of proprietary power generation systems.

One of our products is gas turbine combined cycle (GTCC) power plants, which provides incredibly efficient electric power while reducing CO_2 emissions.
We also provide next-generation power systems, such as integrated coal gasification combined cycle (IGCC) power plants, steam power plants, geothermal power plants, air quality control systems (AQCS) and intelligent solutions TOMONI™.

Mitsubishi Power combines cutting-edge technology with deep experience to deliver innovative, integrated solutions that help to realize a carbon neutral world, improve the quality of life and ensure a safer world.

Steam Power Plants

Mitsubishi Power designs and delivers highly efficient and environmentally friendly power generation facilities, including boilers, steam turbines, and generators.

Up to 1,200 MW

Large Capacity Power Plants

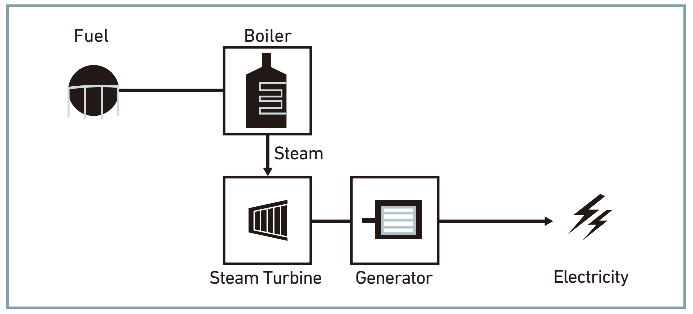
Integrated Customer Service

From Design to Delivery of an Entire Power Generation Facility

Co-generation Power Plants

Effective Use of Electricity and Steam

What is a steam power plant?



A steam power plant consists of a boiler, a steam turbine, a generator, and other auxiliaries. The boiler generates steam at high pressure and high temperature. The steam turbine converts the heat energy of steam into mechanical energy. Through proper integration of all equipment, Mitsubishi Power designs and delivers highly efficient and environmentally friendly power plants.

Large Capacity Power Plants

Applying ultra-supercritical pressure technology for highly efficient power generation

Mitsubishi Power has an impressive track record in the field of supercritical and ultra-supercritical pressure coal-fired power plants and has achieved a high level of trust in the market due to the high efficiency and reduced emissions of these plants. Capitalizing on its successful operating experience with this advanced technology, Mitsubishi Power will continue to contribute to the stable and reliable supply of electric power globally, while minimizing the environmental impact.

What is ultra-supercritical pressure?

Under normal atmospheric pressure [0.101 MPa], water boils at 100°C. As the pressure increases, so does the boiling temperature of water. When the pressure is increased to 22.12 MPa, and at a temperature of 374°C, water converts directly from liquid to steam, without the intermediate boiling stage. This is called the critical point, and the pressure above this critical point is called supercritical pressure. Supercritical pressure with a temperature equal to or more than 593°C is called ultra-supercritical pressure.

Integrated Customer Service

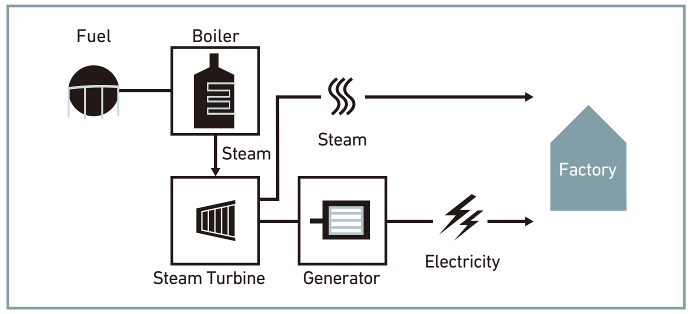
Supplying power plants matching customers' needs

As an EPC contractor, Mitsubishi Power will design, manufacture, deliver, and install entire power plants. From main plant equipment to auxiliary air quality control systems, Mitsubishi Power can integrate the complete plant system to optimize equipment design and efficiency. Main plant equipment, such as boilers, steam turbines and generators, is custom designed to meet customers' needs. New units added to an existing power generation station will be seamlessly integrated with existing plant equipment and optimized to meet the specified requirements.

Cogeneration Power Plants

Paving the way for effective use of energy

In some industrial applications, excess energy is produced as part of the normal operating process. In many cases this energy is wasted. If economically justifiable, another option is to utilize this free source of energy to produce steam and electric power. Utilization of surplus energy as fuel for the production of steam and electrical power is called cogeneration. When optimized and properly integrated with the industrial process, power supply stability improves and impact to the environment is minimized.



Manjung 5 — One of the world's most advanced power plants

Manjung Unit 5
World-class high electrical output and highly efficient power generation

Mitsubishi Power provided ultra-supercritical variable pressure once-through boiler, a steam turbine/generator and flue gas desulfurization (FGD) system, including a seawater FGD for a power plant construction project in Malaysia.
A Korean company, Daelim Industrial Co. Ltd. concluded the package contract through a consortium to build an ultra-supercritical coal-fired power plant in 2013.
The equipment was delivered to a Malaysian power company, Tenaga Nasional Berhad (TNB) for an ultra-supercritical coal-fired power plant built in Manjung, Perak, located about 300km northwest of Kuala Lumpur, the capital city of Malaysia. This plant is capable of generating 1,000 MW and is the largest of its kind in Malaysia.

Mitsubishi Power signed a supply contract to deliver equipment for this first ultra-supercritical coal-fired power plant in Malaysia and dispatched technical advisors as well as support staff, with many years' experience working with overseas power plants, for installation and operation. It began commercial operations on September 28, 2017, three days ahead of its target date. On October 16, 2017, Mitsubishi Power received a letter of appreciation from Mr. Young Cook Kang, CEO of Daelim Industrial Co. Ltd. In this letter, he indicated that TNB greatly appreciated the strong technical capabilities of the Mitsubishi Power team throughout the project.

Mitsubishi Power has a proven track record in the field of coal-fired power generation with its high-efficiency system for curbing CO_2 emissions. We will continue helping to provide stable power and to reduce environmental impact through our highly-efficient equipment and systems, while effectively responding to various market needs in Malaysia and Southeast Asia and around the world.

Project summary

Project	Malaysia TNB Manjung Five Sdn Bhd Fast Track 3A Project Manjung Unit 5
Customer	Malaysia TNB Manjung Five Sdn Bhd
Prime Contractor (EPC)	Daelim Industrial Co. Ltd. of Korea
Mitsubishi Power supplied equipment	Ultra-supercritical variable pressure once-through boiler, Steam turbine/generator, FGD
Steam turbine/generator output	1,065 MW x 1
Fuel	Sub-bituminous
Main steam/Reheated steam temperature	600°C/610°C
Start of operation	September 2017

Huadian Zouxian Unit 7 & 8 (China)

Customer	China Huadian Corporation
Output	1,000 MW x 2
Fuel	Coal
Start of operation	2007/2008

Hitachinaka Unit 1 & 2 (Japan)

Customer	JERA Co., Inc.
Output	1,000 MW x 2
Fuel	Bituminous coal & sub-bituminous coal
Start of operation	2003/2013

Neurath Power Station (Germany)

Customer	RWE
Output	1,100 MW
Fuel	German lignite coal
Start of operation	2012

Rajpura Unit 1 & 2 (India)

Customer	L&T
Output	700 MW x 2
Fuel	Indian coal
Start of operation	2014

Paiton III (Indonesia)

Customer	PT Paiton Energy
Output	866 MW
Fuel	Sub-bituminous coal
Start of operation	2012

Kozienice Unit11 (Poland)

Customer	ENEA Wytwarzanie S.A.
Output	1,075 MW
Fuel	Bituminous coal & sub-bituminous coal
Start of operation	2017

Steam Turbines

Globally contributing to power generation for more than a century with our highly efficient and reliable steam turbines that have undergone strict in-house testing.

Combined Output: Over 360,000 MW (2,600 units)	Flexible Configurations	Provides Higher Efficiency
Proven Track Record	Meets Any Requirements	High Temperature Steam

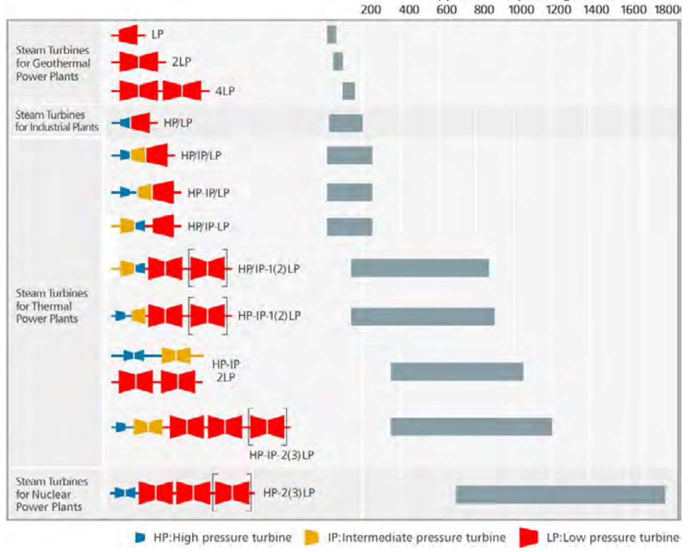
Contributing to power generation globally for more than a century
Mitsubishi Power steam turbines are built upon more than a century of R&D and manufacturing experience, and our track successful record of delivering strictly tested, highly reliable, and efficient steam turbines to customers globally is unmatched.

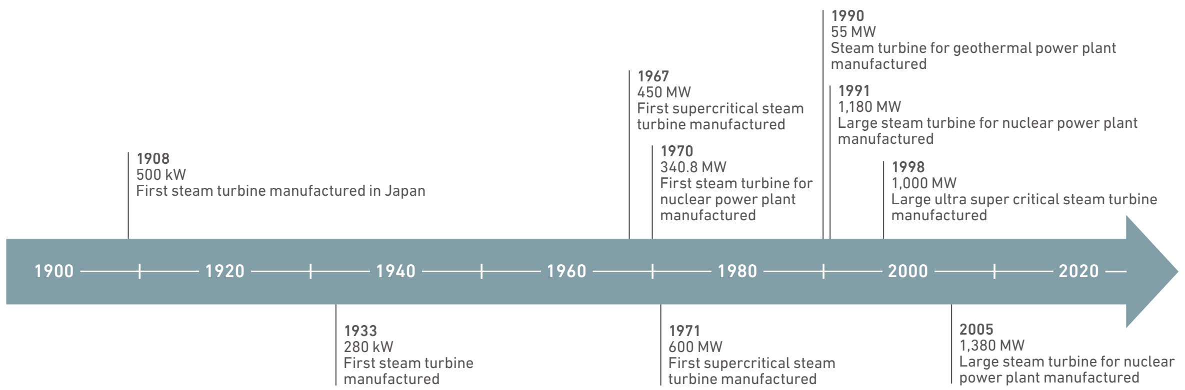
We offer a comprehensive lineup of steam turbines that include small and mid-sized steam turbines for industrial applications, large steam turbines for thermal power plants, nuclear power plants, and geothermal power plants.

Our highly efficient steam turbine lineup features different applications to meet various operational requirements while contributing to the global CO_2 reduction.

History of Development
Mitsubishi Power has over a century of achievements in the manufacturing of steam turbines. By further developing and upgrading cutting edge technologies, we design and manufacture highly reliable "Japan Quality" steam turbines that hold up to long-term use and continue to gain the support of customers around the world.
The steam turbine has long been a crucial component of power generation plants and has played a vital role in their operation.
Mitsubishi Power has led the world in putting cutting edge technologies into practical applications, such as the manufacturing of a power generation plant capable of operating at steam temperatures of 600/620°C, thereby fulfilling customer expectations.
Mitsubishi Power will continue its ceaseless technology development and keep offering steam turbines that are environmentally friendly and highly efficient.

Steam Turbines Product Lineup





Steam Turbines

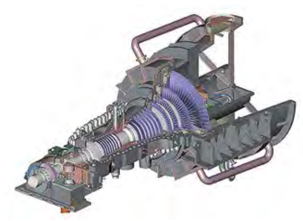
Up to 250 MW
Exhaust steam exits the turbine from only one direction (single-flow). By utilizing a longer last stage blade (LSB), a single flow turbine with axial exhaust is possible in comparison to a double-flow turbine with downward exhaust. An axial exhaust reduces hood losses, thus allowing higher efficiency to be achieved as compared to a downward exhaust.

In addition, as a single welded (or mono-block) rotor is used, the high pressure (HP), intermediate pressure (IP) and low pressure (LP) sections can be contained within a single casing. This compact frame turbine of (SRT: Single cylinder Reheat Turbine) can reduce construction costs for the turbine building and foundation. A smaller number of components also reduce time required for inspections and number of spare parts, thus allowing easier maintenance.

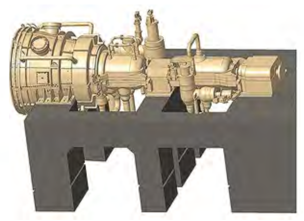
Specifications

No. of casings	Single casing (HP/IP/LP Turbine) Double casing (HP/IP Turbine - LP Turbine) Double casing (HP Turbine - IP/LP Turbine)
Output	Up to 250 MW
Main steam	Up to 16.5 MPa / Up to 600°C
Reheat steam	Up to 600°C
Revolutions per minute	3000 min^{-1} (50Hz) / 3600 min^{-1} (60Hz)

Downward exhaust can also be designed if the customer has such requirements.



Single Casing (SRT) Turbine
(HP/IP/LP Turbine)

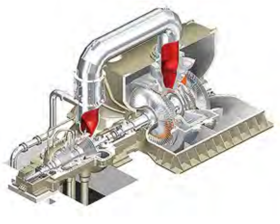


Two Casing Turbine
(HP Turbine - IP/LP Turbine)

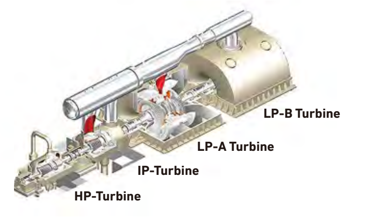
Up to 1,200 MW
The length of optimal last stage blade (LSB) and the number of casings are selected based on the steam exhaust conditions. By combining the high pressure (HP) turbine and intermediate pressure (IP) turbine into a single casing, the turbine can be made more compact, thus reducing the number of components and required area for installation. On top of reducing costs related to civil construction and installation work, maintenance is also easier due to both a reduced number of spare parts and required inspection periods. For steam power plants, to increase overall plant efficiency, up to nine extractions for feedwater heating is possible. For the low pressure (LP) turbine, exhaust direction is not limited to downward exhaust, but can also be designed for sideward exhaust.

Specifications

No. of casings	Two Casings (HP/IP Turbine - LP Turbine) Three Casings (HP/IP Turbine - LP Turbine ×2) Three Casings (HP Turbine - IP Turbine - LP Turbine) Four Casings (HP Turbine - IP Turbine - LP Turbine×2) Five Casings (HP Turbine - IP Turbine - LP Turbine×3)
Output	Up to 1,200 MW
Main steam	Up to 28.0 MPa / Up to 600°C
Reheat steam	Up to 630°C
Revolutions per minute	3000 min-1 (50Hz) / 3600 min-1 (60Hz)

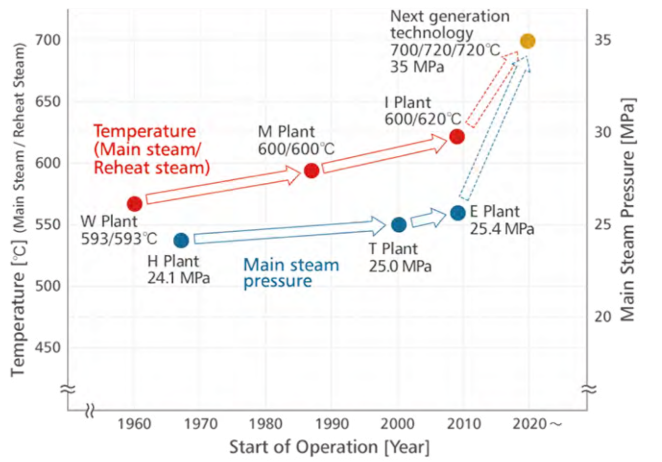


Two Casing Turbine
(HP/IP Turbine - LP Turbine)
For GTCC Plant Applications (312 MW)



Four Casing Turbine
(HP Turbine - IP Turbine - LP Turbine ×2)
For Conventional Power Plant Applications (1,000 MW)

Breakthroughs in steam conditions
Mitsubishi Power has steadily contributed to the development of highly efficient steam power plants by raising the operable temperature range of its steam turbines through technology development of turbines. We had already manufactured and delivered many turbines capable of operating at supercritical main steam temperatures of 600°C range, and currently reheat steam temperatures of 620°C is applied to commercial power generation. On top of this, Mitsubishi Power continuously strives for the next generation technology development with the aim of making turbines capable of operating at ultra-supercritical steam conditions in the 700°C range and 35 MPa for even higher efficiency.



Boilers

Mitsubishi Power supplies boilers that boast world-leading quality and performance based on stable quality developed over many years and state-of-the-art technologies.

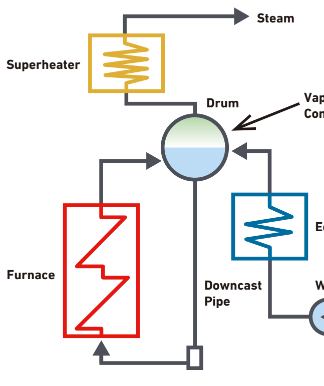
In 1968	More than 5,500 units delivered	Tower Boiler	Optimized for Various Types of Coal
Delivered the First Supercritical Pressure Boiler	Proven Track Record	Large and High-Efficiency Lignite Combustion	From Anthracite to Lignite

Boilers for power generation projects convert the chemical energy contained in fossil fuels such as coal, oil, and gas into heat energy through combustion reactions, and also convert this into high-temperature, high-pressure steam-based heat energy to be supplied to steam turbines used in power generation. This makes a boiler one of the key components of a thermal power plant. Large boilers can reach as many as 80 meters tall, weigh some 13,000 tons and comprise over one million components.

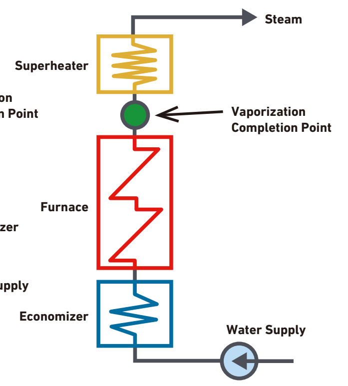
Types of boilers

While various types of boilers are produced depending on the amount, pressure and temperature of the steam they produce and the fuel they use, boilers generally come under one of two categories: drum boilers and once-through boilers.

The furnace that encloses the combustion field is the part of a boiler system exposed to the harshest conditions. Other key components include the superheater, which allows steam to pass through up to a designated temperature, and the economizer, which preheats the water supplied to the boiler.



Drum Boiler Fluid Path Diagram (Simplified)

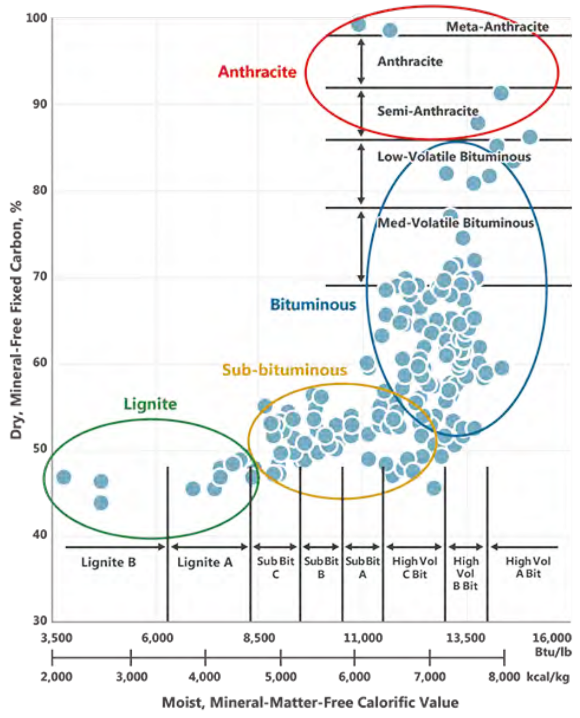


Once-through Boiler Fluid Path Diagram (Simplified)

In a drum boiler, to ensure reliability of the furnace area, a steam drum (an enormous tank) that continually supplies water to the furnace system is set up. On the other hand, a once-through boiler comprises a simpler structure that eliminates this steam drum.

Types of coal

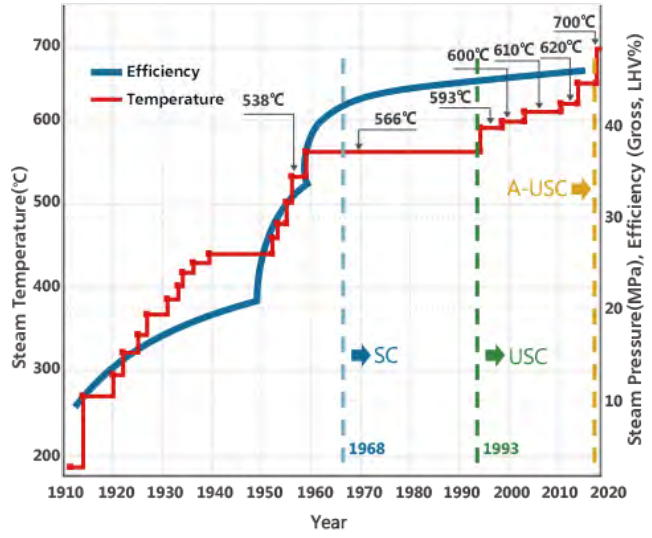
Various types of coal can be used, from anthracite with its high carbon content to bituminous coal, sub-bituminous coal and lignite (brown coal), an even younger coal. Power generating equipment needs to be optimized for these different types of coal. Mitsubishi Power is able to supply the optimum power generating equipment to match any variety of coal, from anthracite to lignite.



Once-through boilers

Overview

Once-through boilers are able to produce steam at higher pressures and temperatures than drum boilers. In steam power plants, raising steam conditions (pressure and temperature) can enable efficiency gains in power generation equipment, allowing an operator to reduce its fuel consumption and CO_2 emissions. Mitsubishi Power delivered its first supercritical pressure once-through boiler in 1968, and followed up in 1981 with delivery of the first supercritical variable pressure once-through boiler. In 1993, Mitsubishi Power sought to further improve steam conditions, culminating in the delivery of the first ultra-supercritical variable pressure once-through boiler. Mitsubishi Power boasts an extensive track record of both supercritical and ultra-supercritical variants and conditions to deliver highly reliable boilers.



2-pass boilers

2-pass boilers are designed to fire various kinds of fuel while delivering optimum conversion efficiency at lower emissions.

Performance advantages

• Low fuel consumption • Lower emissions (CO_2, Sox, NOx, dust, ash)
• Less auxiliary power consumption • High reliability

Fuel sources

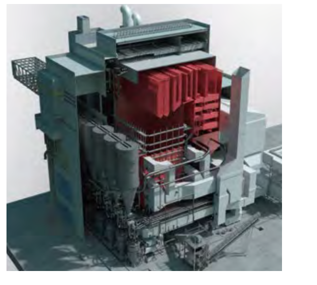
• Solid: Bituminous, sub-bituminous, lignite, anthracite coal, petroleum coke, biomass • Liquid: Heavy oil, vacuum residue, solvent de-asphalting pitch • Gas: Natural gas, petroleum gas, blast furnace gas, coke, oven gas, or other low BTU process waste gas streams

Technical advantages

< Furnaces >
• Optimized for specific types of fuel • Various burner system layouts for good combustion
< Burners >
• Low NOx and less unburned carbon • Advance combustion technology
< Pulverizers >
• Vertical mill for high classification performance at low power consumption • Highly durable and easy to maintain

Specifications

Output	~1,070 MW
Main steam flow rate	~3,210ton/hr
Steam temperature	~600/610°C
Steam pressure	~31MPa



Tower boilers

Tower boilers are designed to fire various kinds of fuel and are ideal for plants using highly erosive, high ash coal.

Performance advantages

• Proven technology and high reliability for combustion with lignite and low-heating-value coal

Fuel sources

• Lignite, sub-bituminous, bituminous, biomass

Technical advantages

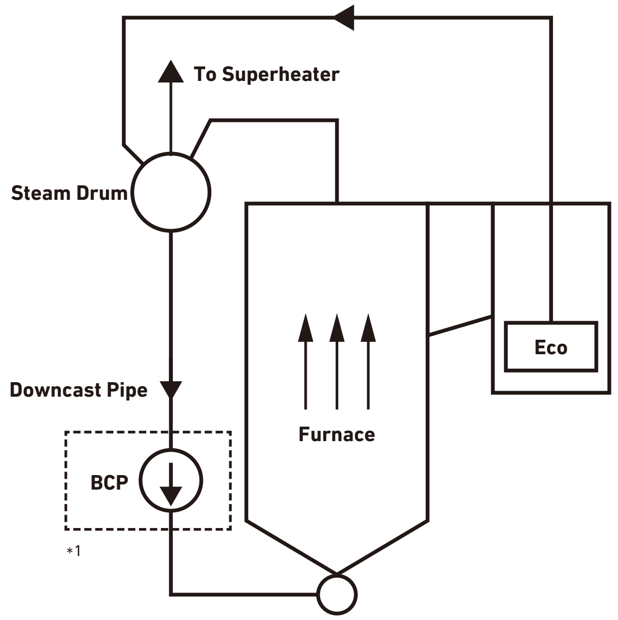
< Furnaces >
• Optimized to accommodate specific types of fuel
• Small footprint
< Burners >
• Low NOx and less unburned carbon • Advanced design based on experience with coal-fired power generation in Europe
< Pulverizers >
• Pulverization system for lignite and low-heating-value coal combustion • Vertical mill for high classification performance at low power consumption

Specifications

Output	~1,100 MW
Main steam flow rate	~2,939ton/hr
Steam temperature	~600/620°C
Steam pressure	~30.5MPa

Drum Boilers

In a drum boiler, the circulation of water is produced through the density difference of water in the downcast pipe and the water/steam mixture in the furnace water wall. In low-pressure boilers where this density difference is large, the circulating force is high and a high volume of circulation can be ensured. However, since it becomes difficult to sufficiently maintain circulation volume when the density difference between the two drops due to higher pressure, a pump is installed in the downcast pipe to supplement circulating force. The type that circulates water using only the density difference is known as a natural circulation boiler, while the type that includes an installed pump is known as a forced circulation boiler.



Forced Circulation Boiler Fluid Path Diagram (Simplified)

*1 BCP: Boiler Circulation Pump
Without BCP, it is Natural Circulation Boiler Fluid Path Diagram (Simplified)

Bubbling Fluidized Bed (BFB) Boilers

A bubbling fluidized bed (BFB) boiler is a boiler that can also handle fuels that are difficult to pulverize or less combustible. The fuel is introduced into a mixture of sand flowing at high temperatures, allowing the fuel to be efficiently combusted. Since Mitsubishi Power delivered its first commercial BFB boiler in 1984, it has established an impressive track record of deliveries. Customers can choose the optimum BFB boiler based on desired power generating output and the characteristics of the biomass to be used. In this way, Mitsubishi Power responses to a diverse range of customer needs.

Supports a wide variety of fuels
In BFB combustion, a material with a large thermal capacity such as sand is used as the flow medium. This allows for the stable combustion of a wide variety of fuels, from moisture-rich fuels to those with low combustibility. In addition to coal, our BFB boilers support a wide array of fuels from wood biomass such as waste wood and construction waste materials to industrial waste such as tires.

Stable emissions of foreign particles
At the bottom of the BFB, the bed drain extraction method is used based on the amount of foreign particles in the fuel. At the same time, the use of an appropriate furnace bottom shape and air nozzle shape ensures that foreign particles carried through the BFB are expelled outside the system in a stable manner, preventing poor flow associated with sedimentation inside the BFB.

Low environmental impact
As BFB combustion allows for sufficient combustion under lower temperatures up to around 900°C, the release of nitrogen oxides (NOx) and other pollutants can be reduced.

Chemical Recovery Boilers

A chemical recovery boiler is a type of biomass boiler that combusts black liquor produced as a by-product in the pulp manufacturing process at paper mills. Black liquor is a fuel derived from wood chips and is regarded as renewable. A chemical recovery boiler not only effectively uses the thermal energy gained by combusting black liquor, but also recovers sodium (carbonate) ingredients that are reused in the pulp manufacturing process, and thus plays an important role in a pulp manufacturing plant. Since it delivered the first such chemical recovery boiler in 1951, Mitsubishi Power has delivered more than a hundred units in over a half-century and continues to be one of the leading companies in the field.

High-pressure, high-temperature steam conditions
In 1983, Mitsubishi Power was first in the world to develop and deliver a high-pressure, high-temperature chemical recovery boiler that produced steam at 10 MPa and 500°C. Producing steam at higher pressures and temperatures helps to boost generating efficiency in turbine generating equipment. The highest steam conditions we have delivered to date are a steam pressure of 13.3 MPa and steam temperature of 515°C. Even today, these levels persist as the highest steam conditions for a chemical recovery boiler.

Corrosion protection
With a chemical recovery boiler, the furnace wall pipes and superheater tubes are exposed to a harsher corrosion environment compared with other fossil fuel-burning boilers. This harsh corrosion environment is due to the chlorine, potassium, sodium, and sulfur contained in the black liquor used as fuel. Our recovery boilers employ the following anti-corrosion measures to improve the reliability and durability of boiler equipment.

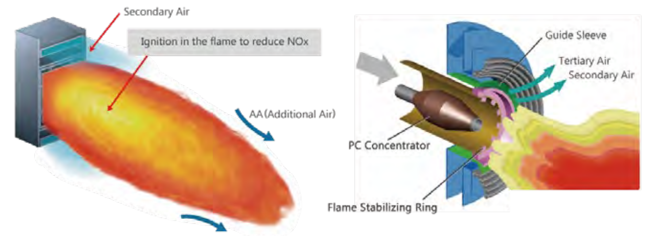
- Furnace wall pipes: Covering with overlaying of 25Cr steel
- Superheater tubes: Use of 25Cr steel tubing

Low NOx combustion
By employing a multi-stage air input method that adds fourth-stage air to the conventional primary, secondary and tertiary air, and eliminating localized regions of excessive air inside the furnace, low NOx combustion can be achieved.

Technical Information

Mitsubishi Power maintains proprietary boiler technologies designed to achieve high reliability and reduce environmental impact.

Low NOx burners
Mitsubishi Power offers low NOx burner technologies for solid, pulverized fuels by combustion method and different firing systems. For coal fired burners, PM burners are the jet burners which are used for the swirl combustion method in boilers with tangential or all-wall firing systems, while DS® and NR burners are circular swirl burners used for in boilers with the opposed firing method. The basic concepts for improving combustibility, however, are the same for PM, DS® and NR burners. By improving ignitibility in rich fuel flame areas and producing moderate combustion in moderate flame areas, the production formation of NOx emissions is reduced. Combustion air is added to the flame in subsequent stages in order to limit formation to its minimum. At the same time, an excellent burn out ratio is achieved. Mitsubishi Power also offers low NOx burners, both jet and swirl type, for boilers utilizing low rank coal (lignite).



PM Burner NR Burner

Combustion test facility
Mitsubishi Power maintains world-class combustion test facilities utilized to develop even more sophisticated combustion technologies that form the basis of boiler performance including lower nitrogen oxide (NOx) emissions, less unburnt fuel, and a reduced excess air ratio. We are particularly focused on enhancing the following two functions of our combustion test facilities to support cutting-edge technological development.

1. Functions to accurately recreate in-flame combustion phenomena in actual boilers
2. Functions to evaluate flow and combustion at high level of accuracy through precision measurement instrumentation

Combustion Test Facility (4t/h)

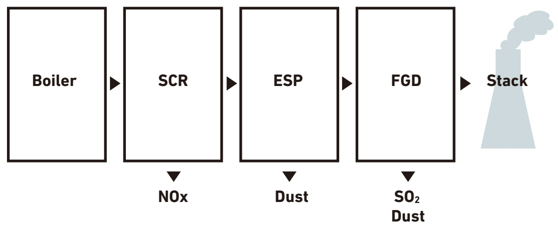
Air Quality Control Systems(AQCS)

Mitsubishi Power is the world's only AQCS solution provider able to develop its own technology for AQCS including SCR, FGD and ESP, and is capable of designing the total AQCS area to meet customers' commercial and environmental needs.

Mitsubishi Power advanced technologies help protect the environment

Mitsubishi Power is a world leader in air quality control systems (AQCS) including selective catalytic reduction (SCR), flue gas desulfurization (FGD), electrostatic precipitator (ESP) and more, offering a range of solutions to reduce emissions. Mitsubishi Power provides advanced technologies to key industries with reliable air quality control solutions and continues to research better ways of meeting our customers' evolving needs.

Total Solution

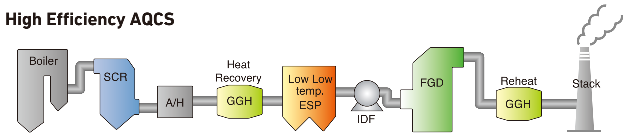


High-efficiency AQCS

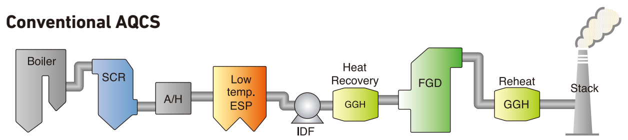
We have developed a new flue gas treatment system, consisting of the SCR, low low temperature ESP, FGD, and non-leakage gas-gas heater (GGH), which achieves effective treatment of flue gas so that it can control dust emissions within the scope of stringent regulations.

Furthermore, in urban areas where even stricter control is required, wet ESP can be installed downstream of the FGD. With a GGH installed upstream of the ESP, the dust removal efficiency of ESP can be improved markedly.

High Efficiency AQCS

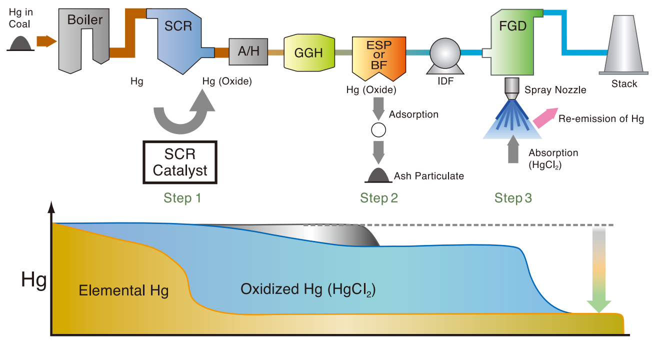


Conventional AQCS



Addressing the global demand for mercury control solutions

In addition to our NO_x, SO_2, SO_3 and particulate control technologies, Mitsubishi Power has developed mercury (Hg) control technologies that satisfy the global demand for managing multiple pollutants.



Mercury control mechanisms

Step 1: Oxidation of gaseous mercury using SCR catalyst

Step 2: Absorption and neutralization of mercury on ash particles, captured by ESP or BF

Step 3: Control and absorption of mercury ($HgCl_2$) at wet FGD

Major mercury control methods and technologies

- Mercury Oxidation Catalyst: TRiple Action Catalyst (TRAC™)
  Mitsubishi Power's proprietary TRAC™ optimizes the oxidation of mercury and reduction of NOx, and achieves similar levels of SO_2 to SO_3 oxidation.
- Halogen injection
  Our halogen injection technology enhances mercury oxidation in the SCR. Mercury chloride is removed by the wet scrubbers.
- Technology to prevent re-emission of mercury in wet FGD
  Our Oxidation-Reduction Potential Control prevents the re-emission of mercury chloride in limestone-gypsum slurry in wet scrubbers.

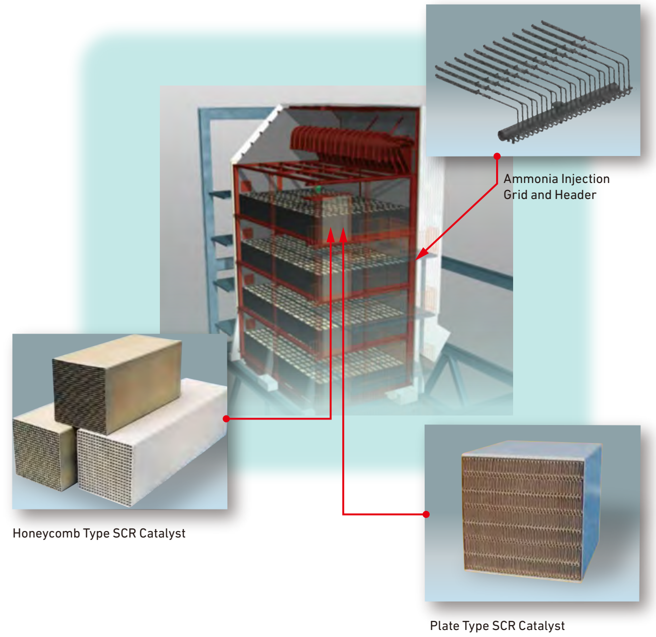
Selective Catalytic Reduction (SCR) System

Mitsubishi Power selective catalytic reduction (SCR) systems remove NOx from flue gas emitted by power plant boilers and other combustion sources to help prevent air pollution at the source. With more than 40 years of operational experience, supplying highly reliable SCR catalysts, Mitsubishi Power's advanced SCR systems provide efficient, reliable treatment of flue gases.

Special features

Here are some attributes that drive demand for Mitsubishi Power SCR systems:

- High NOx reduction meeting strict emission standards for various fossil fuels at the single-digit level of NOx concentration
- Integrated NOx reduction linked with boilers and HRSGs
- Optimization of catalysts according to the customers' requirements
- Multiple pollutant control including mercury and low sulfur trioxide
- High reliability
- Longer intervals of catalyst maintenance



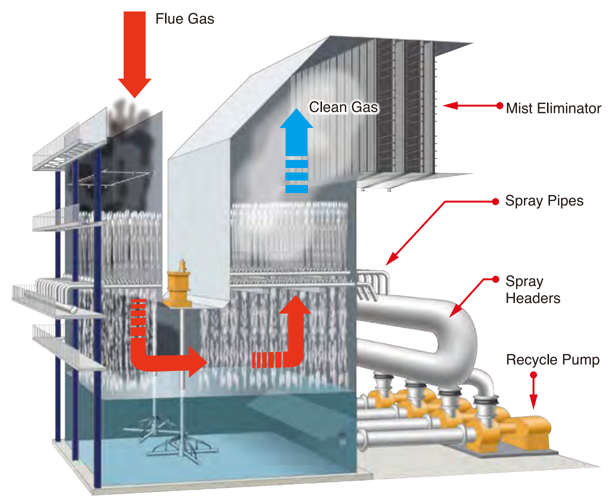
Flue Gas Desulfurization (FGD) Plant

Mitsubishi Power's flue gas desulfurization (FGD) plant removes sulfur dioxide (SO_2) from flue gas produced by boilers, furnaces, and other combustion sources, contributing to the effective prevention of air pollution. Our Seawater FGD and Wet Limestone-Gypsum FGD systems can both treat a wide range of SO_2 concentrations, for greater plant reliability and improved operational economics.

Market leading features

With over 300 FGD plants in operation worldwide, Mitsubishi Power has a leading share of the global market. Here's why:

- Excellent SO_2 removal efficiency meeting stringent emission standards for all kinds of fossil fuels
- Multiple pollutant control with associated environmental control equipment
- High reliability
- Savings on energy and utilities

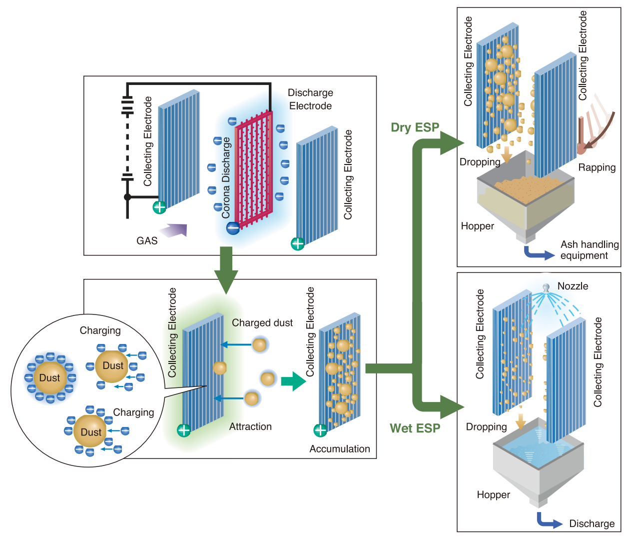


Electrostatic Precipitators (ESP)

Mitsubishi Power electrostatic precipitators (ESP) collect dust in the flue gas produced by boilers and other combustion sources to meet air pollution control and environmental standards at thermal power plants, steel plants, and various other industrial plants.

Basic principles of ESP

1. A high voltage is applied to the discharge electrode, generating a corona discharge that produces negative ions.
2. The electrically charged dust is accumulated on the collecting electrode by an electrical field.
3. The accumulated dust is removed by rapping hammer (dry ESP), scraping brush (dry ESP), or flushing water (wet ESP).



Dust collection performance and dust characteristics

Our accumulated know-how in evaluating characteristic assessments on various dust properties and flue gas conditions, together with extensive field experience, is reflected in the ESP design.

Services

Proposing services tailored to meet diverse customer needs

Solutions for Decarbonization

In order to reduce carbon dioxide emissions from steam power plants that use fossil fuels, Mitsubishi Power uses various fuel conversion technologies that allow conversion to carbon-neutral plant-derived biomass fuels, ammonia fuels that do not emit carbon dioxide when burned, and waste co-firing depending on customer needs.

In addition, we are developing technologies that allow sustainable and stable power plant facilities to achieve net-zero carbon dioxide emissions through automatic optimal operation tuning using AI for various fuels including biomass, upgrading to high-efficiency turbines with high-performance blades and advanced sealing technologies, and technologies to absorb and fix carbon dioxide.

Decarbonization

Fuel conversion

- Biomass co-firing/100% biomass firing
- Ammonia co-firing/100% ammonia firing

Efficiency improvement

- Efficiency improvement of turbine

CCS/CCUS*

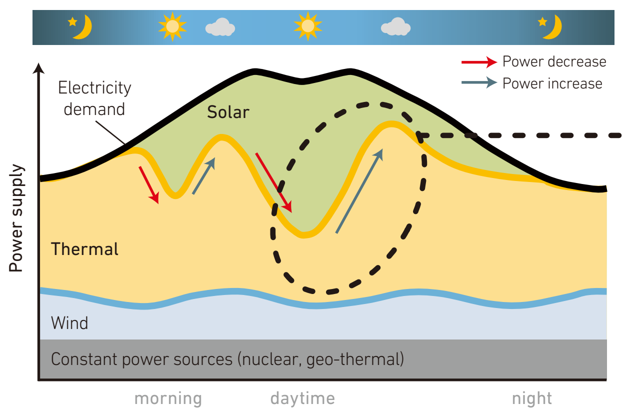
- CCS: Carbon dioxide Capture and Storage
  CCUS: Carbon dioxide Capture, Utilization and Storage

Example of Biomass Plant Denmark/Avedore #1/250MWe

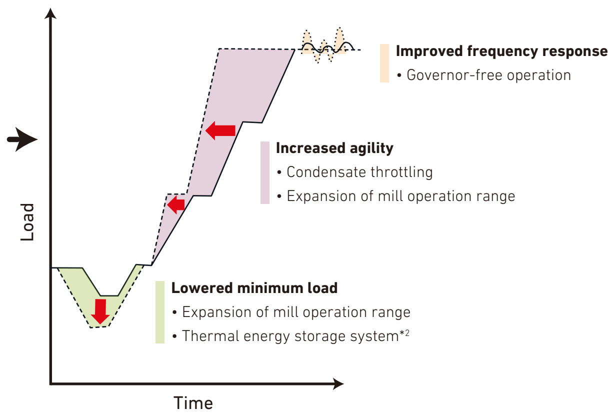
Solutions for the Spread of Renewable Energy

As interest in climate change increases, renewable energy sources such as solar and wind power are becoming more popular and widespread. Since the amount of power generated by these renewable energies is greatly affected by the season and weather, steam power is required to bridge the gap between fluctuations of renewable energies and electricity demand.
To achieve this, it is necessary to respond to rapid load changes and move away from conventional base-load operation.
Based on technology and experience accumulated over many years, Mitsubishi Power provides various steam power solutions that take the characteristics of plant systems and equipment into account and supports improving operation flexibility of existing plants in line with the spread of renewable energy.

Image of Daily Electricity Supply and Demand*1



Thermal Power Operation



*1 Source: Edited from "Japan's Energy (2019 Edition)" published by Agency for Natural Resources and Energy
*2 A system that recovers boiler heat output during extremely low-load plant operation by using a heat accumulator and uses it when the load rises to reduce heat losses associated with start-up and shutdown

Solutions for Maintenance Efficiency

Shortening outages and retrofit construction periods

Mitsubishi Power is working to shorten outages and construction periods in order to reduce construction costs for our customers.

• Outages

We provide equipment modifications to shorten outages. For example, an advanced work platform inside the boiler can be utilized for easy access to suspended tubes.

• Application of 3D measurement technology

3D models are created using CAD based on the 3D measurement results of existing parts such as the outer casing. Small clearances that may cause interference are detected with existing 3D models of the inner casings, and necessary adjustments are made in advance to enable quick construction work. In addition, based on the 3D measurement results and stress analysis, construction periods are shortened by simulating the work conditions before actual construction.

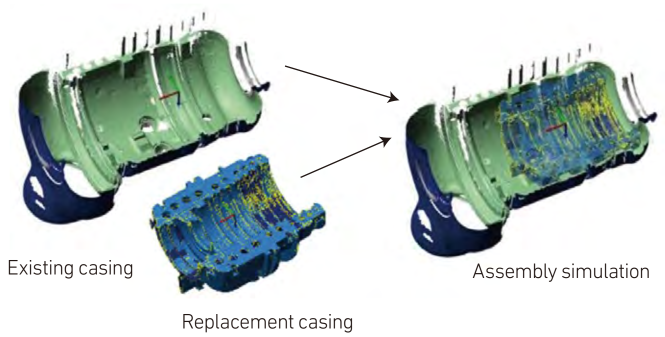
Special Inspection Technology

Mitsubishi Power is developing special inspection technologies that help shorten outage periods.
These include: drone inspection technology that eliminates the need for scaffolding, pencil ECT*3 that can efficiently detect surface defects even with a large number of tubes without scale removal, and post-welding inspection technology (RT alternate UT) that does not require a controlled area like radiation inspection.
Boiler soundness can be confirmed by using a 3D laser to measure mill wear amount, and by using the inner UT and inner ECT that use special sensors to inspect wear inside tubes.
*3 ECT: Eddy Current Test

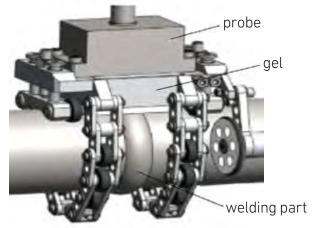
Remote Services

Our experts can provide remote support for outages and construction work using advanced digital tools.

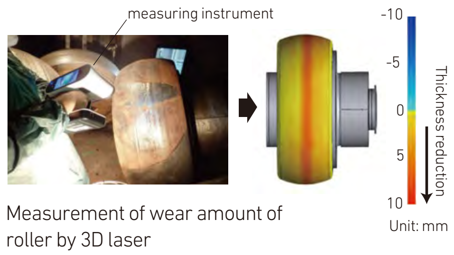
Example of 3D interface check of casing replacement



Pencil UT



RT alternate UT



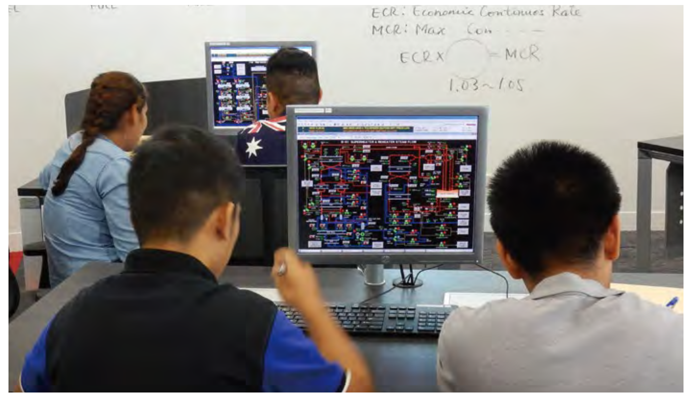
Measurement of wear amount of roller by 3D laser

Inner UT

Training Services

Mitsubishi Power provides customized training under the supervision of our experts to meet customer needs.
We support the training of your engineers and operators through technical training using actual steam turbines used in power plants, plant operation simulation training, and classroom lectures.

Maintenance training at the Steam Turbine Technical Training Center



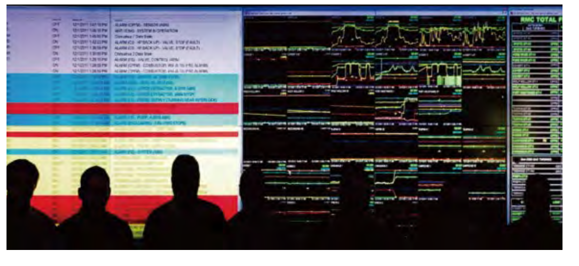
Operation Training

TOMONI™, a suite of intelligent solutions use advanced analytics and are driven by customer collaboration to deliver powerful financial and environmental advantages including decarbonization.

TOMONI, a Japanese word meaning "together with," reflects the emphasis Mitsubishi Power places on collaborating with customers to solve their unique challenges. Mitsubishi Power works together with customers, partners and society to deploy solutions that support the decarbonization of energy and deliver reliable power everywhere.

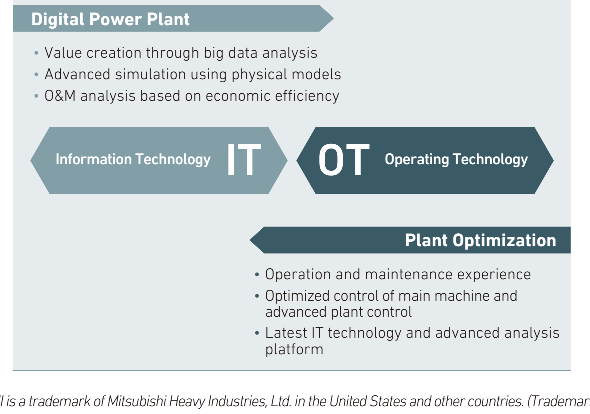
Features of TOMONI

- TOMONI is composed of three solution categories: O&M Optimization, Performance Improvement, and Flexible Operation based on Data Foundation & Enablers. The combination of these categories allows us to deliver optimal solutions.
- From utility to industry power plant, TOMONI is applicable to a wide variety of power plants.
- TOMONI is able to customize for a variety systems such as cloud and edge computing as well as customer's existing platforms.



Intelligent solutions

Combining the latest AI technology with our extensive experience and knowledge in technology, R&D, design manufacture and maintenance of power generation equipment has enabled us to achieve optimal operations that meet the needs of our customers.



TOMONI Solutions: Functions and examples

O&M OPTIMIZATION	• Trouble management and prevention support • Predictive maintenance by understanding remaining life
FLEXIBLE OPERATION	• Efficiency improvement by optimized control
PERFORMANCE IMPROVEMENT	• Response to fuel and load changes
DATA FOUNDATION & ENABLERS	• PI system construction support • Cyber security support

TOMONI™

Notes: TOMONI is a trademark of Mitsubishi Heavy Industries, Ltd. in the United States and other countries. (Trademark registration has been applied for)

Solutions for Performance and Reliability Optimization

Mitsubishi Power provides maintenance services to improve performance and reliability by combining customers' operation data with design data and plant information supported by our extensive technology and design experience.

■ Performance improvement
- Predicting performance degradation status through operation data analyses
- Proposing recommended actions for the next outage by analyzing performance degradation

■ Reliability improvement and stable operation
- Predicting remaining life and functional deterioration of crucial parts
- Proposing parts replacement and modification to improve reliability

Boiler Smart Inspections

In addition to outage planning, there are issues such as human resource development and the transfer of skills from experts to the next generation.

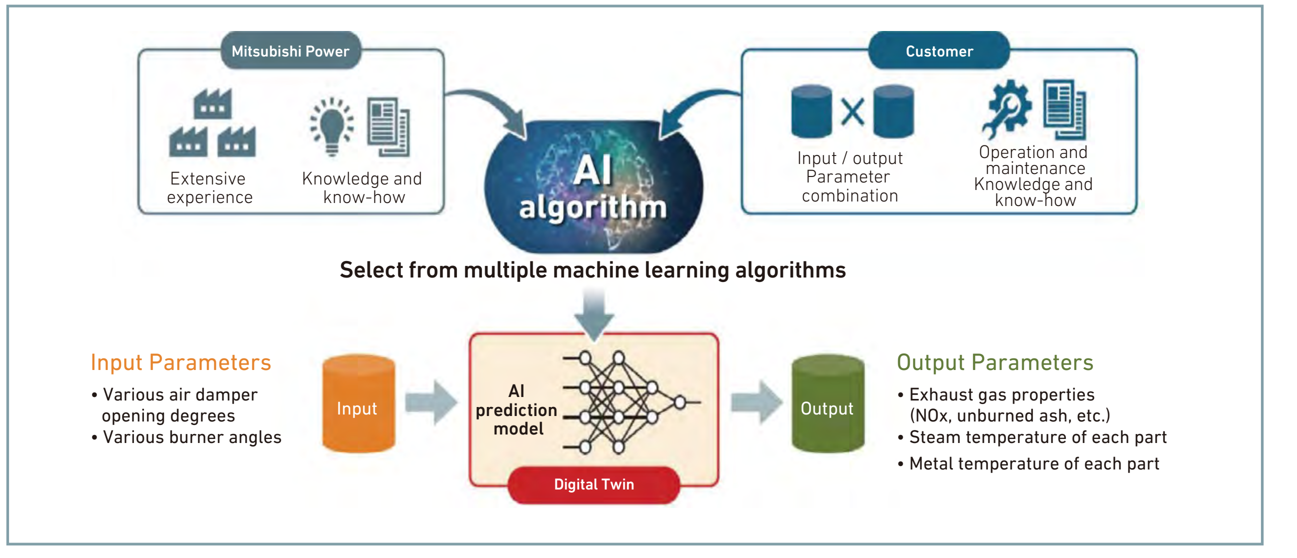
In this service, we support our customers search maintenance records utilizing digital technology, human resource development, and outage planning.

Mitsubishi Power also encourages dialogue with our experts to help solve a wide range of equipment issues.

Solutions for Optimizing Operations using AI

Customers' needs for operation are changing and diversifying, such as high-efficiency operation and carbon-neutral fuel firing.

Mitsubishi Power can provide optimized operation solutions utilizing AI without having to dispatch experienced engineers.



Solutions for Operation and Maintenance

Mitsubishi Power provides solutions to various operation and maintenance issues based on our extensive technology, design and manufacturing knowledge.

Remote monitoring and operation support

Our TOMONI HUBs (Analytics and Performance Center) monitor the entire steam power plant 24 hours a day, 365 days a year. Our operation and maintenance experts provide full support throughout the plant life cycle.

Using our cutting-edge digital technology, intelligent solutions TOMONI, Mitsubishi Power meets customer needs by providing comprehensive solutions that ensure high availability and efficiency by not only monitoring operation data parameters but also diagnosing signs of anomalies utilizing AI.

Mitsubishi Power provides Long Term Service Agreements* utilizing remote monitoring data and outage records to assist with general plant optimization such as scheduling planned outages for long term and stable operation.

• Mitsubishi Power can offer tailored services depending on customer needs, including spare parts supply, turnkey outages, dispatch of technical advisors, and more.

TOMONI HUB in Nagasaki Shipyard & Machinery Works

TOMONI HUB in Alabang, Philippines

7. COGENERATION

Syllabus

Cogeneration: Definition, Need, Application, Advantages, Classification, Saving potentials

7.1 Need for Cogeneration

Thermal power plants are a major source of electricity supply in India. The conventional method of power generation and supply to the customer is wasteful in the sense that only about a third of the primary energy fed into the power plant is actually made available to the user in the form of electricity (Figure 7.1). In conventional power plant, efficiency is only 35% and remaining 65% of energy is lost. The major source of loss in the conversion process is the heat rejected to the surrounding water or air due to the inherent constraints of the different thermodynamic cycles employed in power generation. Also further losses of around 10–15% are associated with the transmission and distribution of electricity in the electrical grid.

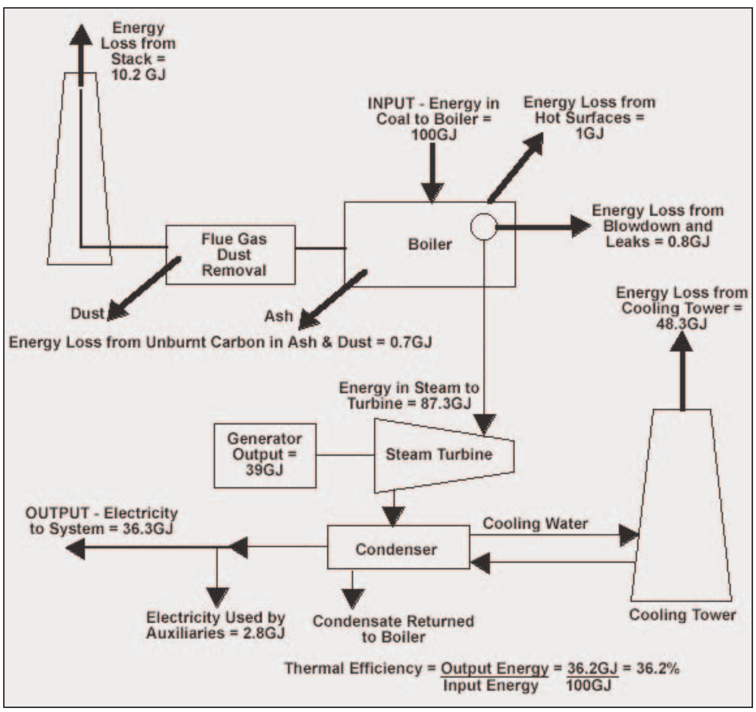


Figure 7.1 BALANCE IN TYPICAL COAL FIRED POWER STATION For an Input Energy of 100 Giga Joules (GJ)

7.2 Principle of Cogeneration

Cogeneration or Combined Heat and Power (CHP) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used either to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling.

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.

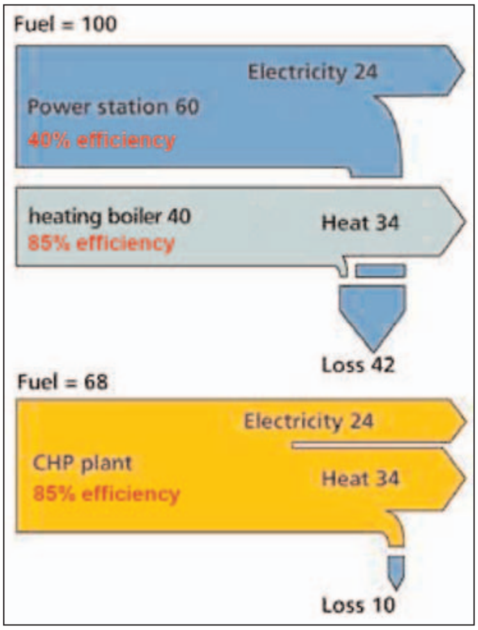


Figure 7.2 Cogeneration Advantage

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 CO_2 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.

7.3 Technical Options for Cogeneration

Cogeneration technologies that have been widely commercialized include extraction/back pressure steam turbines, gas turbine with heat recovery boiler (with or without bottoming steam turbine) and reciprocating engines with heat recovery boiler.

7.3.1 Steam Turbine Cogeneration systems

The two types of steam turbines most widely used are the backpressure and the extraction-Another variation of the steam turbine topping cycle 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 emand for electricity is greater than one MW up to a few hundreds of MW. Due to the system inertia, their operation is not suitable for sites with intermittent energy demand.

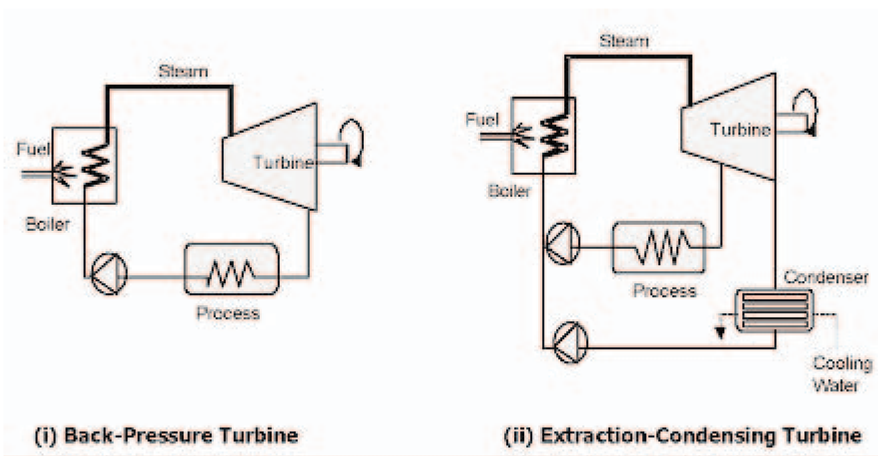


Figure 7.3 Schematic Diagrams of Steam Turbine Cogeneration Systems

7.3.2 Gasturbine Cogeneration Systems

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. Furthermore, the gestation period for developing a project is shorter and the equipment can be delivered in a modular manner. 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.

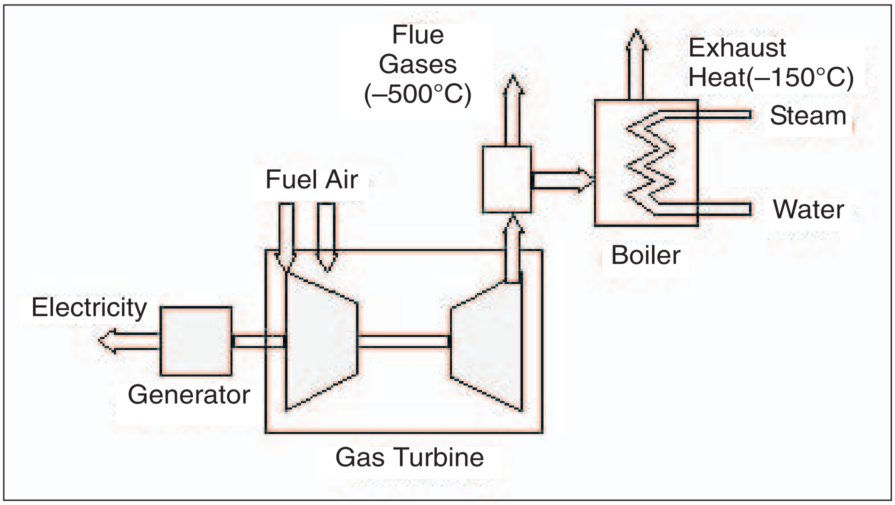


Figure 7.4 Schematic Diagram of Gas Turbine Cogeneration

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.

7.3.3 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 7.5). 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.

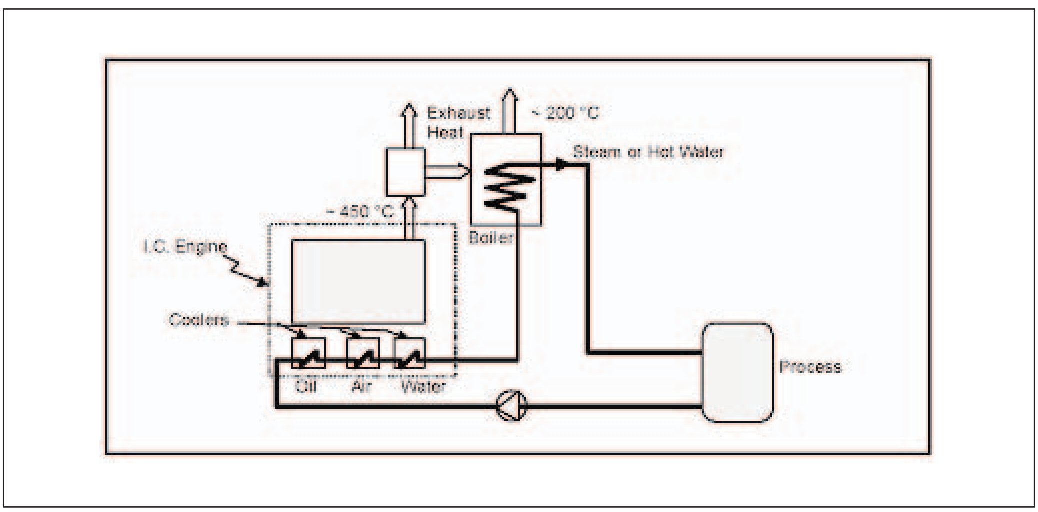


Figure 7.5 Schematic Diagram of Reciprocating Engine Cogeneration

Though diesel has been the most common fuel in the past, the prime movers can also operate with heavy fuel oil or natural gas. These machines are ideal for intermittent operation and their performance is not as sensitive to the changes in ambient temperatures as the gas turbines. Though the initial investment on these machines is low, their operating and maintenance costs are high due to high wear and tear.

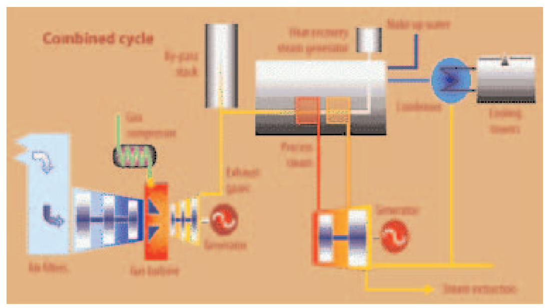
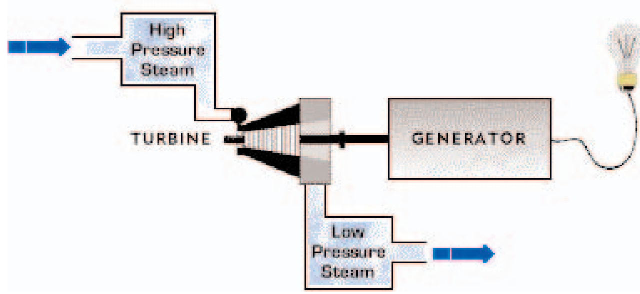
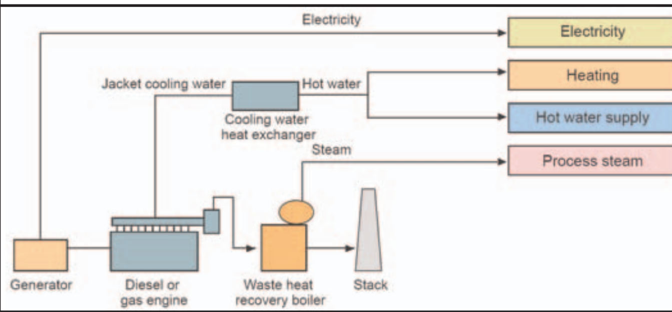
7.4 Classification of Cogeneration Systems

Cogeneration systems are normally classified according to the sequence of energy use and the operating schemes adopted.

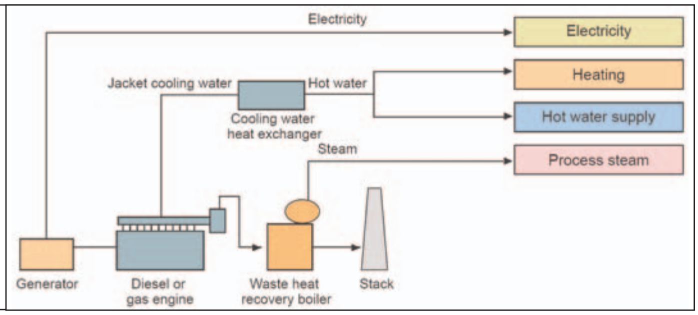
A cogeneration system can be classified as either a topping or a bottoming cycle on the basis of the sequence of energy use. In a topping cycle, the fuel supplied is used to first produce power and then thermal energy, which is the by-product of the cycle and is used to satisfy process heat or other 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.

<table>
<tr><th colspan="2">TABLE 7.1 TYPES OF TOPPING CYCLES</th></tr>
<tr><td>A gas turbine or diesel engine producing electrical or mechanical power followed by a heat recovery boiler to create steam to drive a secondary steam turbine. This is called a combined-cycle topping system.</td><td>
</td></tr>
<tr><td>The second type of system burns fuel (any type) to produce high-pressure steam that then passes through a steam turbine to produce power with the exhaust provides low-pressure process steam. This is a steam-turbine topping system.</td><td>
</td></tr>
<tr><td>A third type employs heat recovery from an engine exhaust and/or jacket cooling system flowing to a heat recovery boiler, where it is converted to process steam / hot water for further use.</td><td>
</td></tr>
</table>

The fourth type is a gas-turbine topping system. A natural gas turbine drives a generator. The exhaust gas goes to a heat recovery boiler that makes process steam and process heat



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 Figure 7.6 illustrates the bottoming cycle where fuel is burnt in a furnace to produce synthetic rutile. The waste gases coming out of the furnace is utilized in a boiler to generate steam, which drives the turbine to produce electricity.

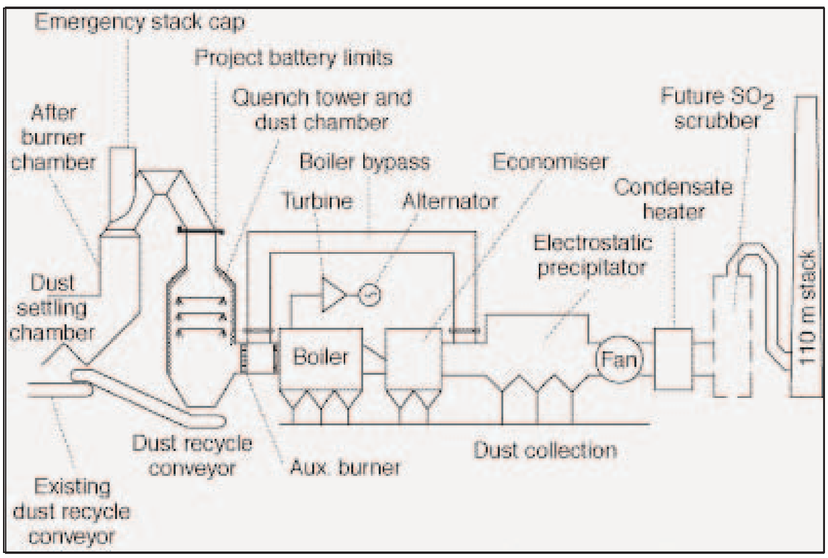


Figure 7.6 Bottoming Cycle

7.5 Factors Influencing Cogeneration Choice

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

7.5.1 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 neighbouring customers.

7.5.2 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.

7.5.3 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 neighbouring facilities.

7.5.4 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.

7.6 Important Technical Parameters for Cogeneration

While selecting cogeneration systems, one should consider some important technical parameters that assist in defining the type and operating scheme of different alternative cogeneration systems to be selected.

7.6.1 Heat-to-Power Ratio

Heat-to-power ratio is one of the most important technical parameters influencing the selection of the type of cogeneration system. The heat-to-power ratio of a facility should match with the characteristics of the cogeneration system to be installed.

It is defined as the ratio of thermal energy to electricity required by the energy consuming facility. Though it can be expressed in different units such as Btu/kWh, kCal/kWh, lb./hr/kW, etc., here it is presented on the basis of the same energy unit (kW).

Basic heat-to-power ratios of the different cogeneration systems are shown in Table 7.2 along with some technical parameters. The steam turbine cogeneration system can offer a large range of heat-to-power ratios.

TABLE 7.2 HEAT-TO-POWER RATIOS AND OTHER PARAMETERS OF COGENERATION SYSTEMS

Cogeneration System	Heat-to-power ratio (kW_{th}/kW_e)	Power output (as percent of fuel input)	Overall efficiency per cent
Back-pressure steam turbine	4.0-14.3	14-28	84-92
Extraction-condensing steam turbine	2.0-10.0	22-40	60-80
Gas turbine	1.3-2.0	24-35	70-85
Combined cycle	1.0-1.7	34-40	69-83
Reciprocating engine	1.1-2.5	33-53	75-85

Cogeneration uses a single process to generate both electricity and usable heat or cooling. The proportions of heat and power needed (heat: power ratio) vary from site to site, so the type of plant must be selected carefully and appropriate operating schemes must be established to match demands as closely as possible. The plant may therefore be set up to supply part or all of the site heat and electricity loads, or an excess of either may be exported if a suitable customer is available. The following Table 7.3 shows typical heat: power ratios for certain energy intensive industries:

TABLE 7.3 TYPICAL HEAT: POWER RATIOS FOR CERTAIN ENERGY INTENSIVE INDUSTRIES

Industry	Minimum	Maximum	Average
Breweries	1.1	4.5	3.1
Pharmaceuticals	1.5	2.5	2.0
Fertilizer	0.8	3.0	2.0
Food	0.8	2.5	1.2
Paper	1.5	2.5	1.9

Cogeneration is likely to be most attractive under the following circumstances:

(a) The demand for both steam and power is balanced i.e. consistent with the range of steam: power output ratios that can be obtained from a suitable cogeneration plant.

(b) A single plant or group of plants has sufficient demand for steam and power to permit economies of scale to be achieved.

(c) Peaks and troughs in demand can be managed or, in the case of electricity, adequate backup supplies can be obtained from the utility company.

The ratio of heat to power required by a site may vary during different times of the day and seasons of the year. Importing power from the grid can make up a shortfall in electrical output from the cogeneration unit and firing standby boilers can satisfy additional heat demand.

Many large cogeneration units utilize supplementary or boost firing of the exhaust gases in order to modify the heat: power ratio of the system to match site loads.

7.6.2 Quality of Thermal Energy Needed

The quality of thermal energy required (temperature and pressure) also determines the type of cogeneration system. For a sugar mill needing thermal energy at about 120°C, a topping cycle cogeneration system can meet the heat demand. On the other hand, for a cement plant requiring thermal energy at about 1450°C, a bottoming cycle cogeneration system can meet both high quality thermal energy and electricity demands of the plant.

7.6.3 Load Patterns

The heat and power demand patterns of the user affect the selection (type and size) of the cogeneration system. For instance, the load patterns of two energy consuming facilities shown in Figure 7.7 would lead to two different sizes, possibly types also, of cogeneration systems.

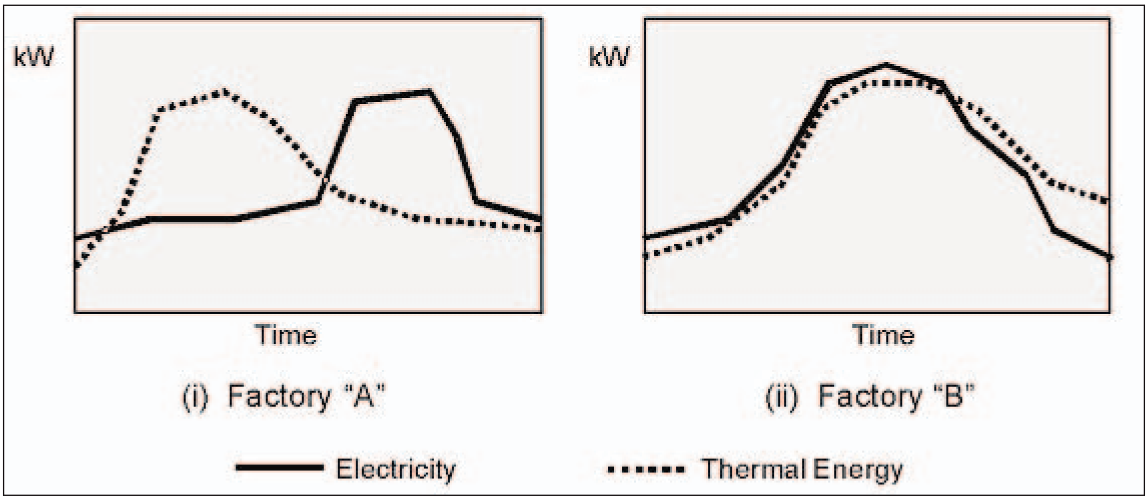


Figure 7.7 Different Heat and Power Demand Patterns in two Factories

7.6.4 Fuels Available

Depending on the availability of fuels, some potential cogeneration systems may have to be rejected. The availability of cheap fuels or waste products that can be used as fuels at a site is one of the major factors in the technical consideration because it determines the competitiveness of the cogeneration system.

A rice mill needs mechanical power for milling and heat for paddy drying. If a cogeneration system were considered, the steam turbine system would be the first priority because it can use the rice husk as the fuel, which is available as waste product from the mill.

7.6.5 System Reliability

Some energy consuming facilities require very reliable power and/or heat; for instance, a pulp and paper industry cannot operate with a prolonged unavailability of process steam. In such instances, the cogeneration system to be installed must be modular, i.e. it should consist of more than one unit so that shut down of a specific unit cannot seriously affect the energy supply.

7.6.6 Grid Dependent System Versus Independent System

A grid-dependent system has access to the grid to buy or sell electricity. The grid-independent system is also known as a "stand-alone" system that meets all the energy demands of the site. It is obvious that for the same energy consuming facility, the technical configuration of the cogeneration system designed as a grid dependent system would be different from that of a stand-alone system.

7.6.7 Retrofit Versus New Installation

If the cogeneration system is installed as a retrofit, the system must be designed so that the existing energy conversion systems, such as boilers, can still be used. In such a circumstance, the options for cogeneration system would depend on whether the system is a retrofit or a new installation.

7.6.8 Electricity Buy-back

The technical consideration of cogeneration system must take into account whether the local regulations permit electric utilities to buy electricity from the cogenerators or not. The size and type of cogeneration system could be significantly different if one were to allow the export of electricity to the grid.

7.6.9 Local Environmental Regulation

The local environmental regulations can limit the choice of fuels to be used for the proposed cogeneration systems. If the local environmental regulations are stringent, some available fuels cannot be considered because of the high treatment cost of the polluted exhaust gas and in some cases, the fuel itself.

7.7 Prime Movers for Cogeneration

7.7.1 Steam Turbine

Steam turbines (Figure 7.8) are the most commonly employed prime movers for cogeneration applications In the steam turbine, the incoming high pressure steam is expanded to a lower pressure level, converting the thermal energy of high pressure steam to kinetic energy through nozzles and then to mechanical power through rotating blades.

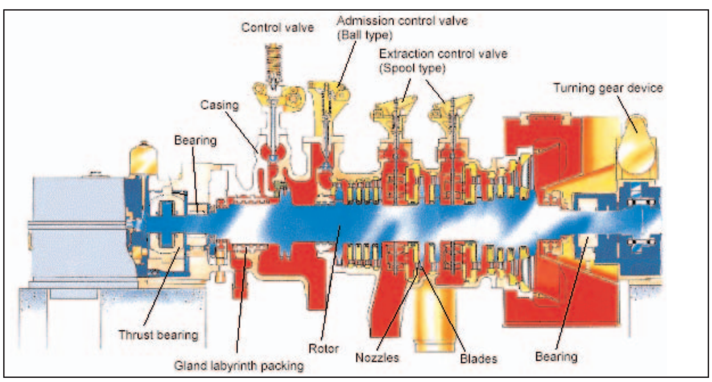


Figure 7.8 Steam Turbine

Back Pressure turbine: In this type steam enters the turbine chamber at High Pressure and expands to Low or Medium Pressure. Enthalpy difference is used for generating power / work.

Depending on the pressure (or temperature) levels at which process steam is required, backpressure steam turbines can have different configurations as shown in Figure 7.9.

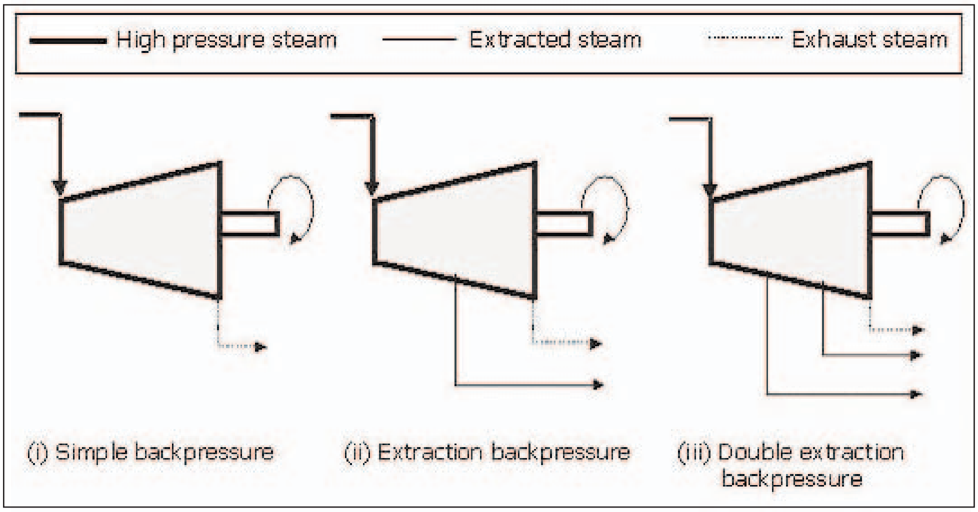


Figure 7.9 Different Configurations for Back Pressure Steam Turbines

In extraction and double extraction backpressure turbines, some amount of steam is extracted from the turbine after being expanded to a certain pressure level. The extracted steam meets the heat demands at pressure levels higher than the exhaust pressure of the steam turbine.

The efficiency of a backpressure steam turbine cogeneration system is the highest. In cases where 100 per cent backpressure exhaust steam is used, the only inefficiencies are gear drive and electric generator losses, and the inefficiency of steam generation. Therefore, with an efficient boiler, the overall thermal efficiency of the system could reach as much as 90 per cent.

Extraction Condensing turbine: In this type, steam entering at High / Medium Pressure is extracted at an intermediate pressure in the turbine for process use while the remaining steam continues to expand and condenses in a surface condenser and work is done till it reaches the Condensing pressure.(vacuum).

In Extraction cum Condensing steam turbine as shown in Figure 7.10, high Pressure steam enters the turbine and passes out from the turbine chamber in stages. In a two stage extraction cum condensing turbine MP steam and LP steam pass out to meet the process needs. Balance quantity condenses in the surface condenser. The Energy difference is used for generating Power. This configuration meets the heat-power requirement

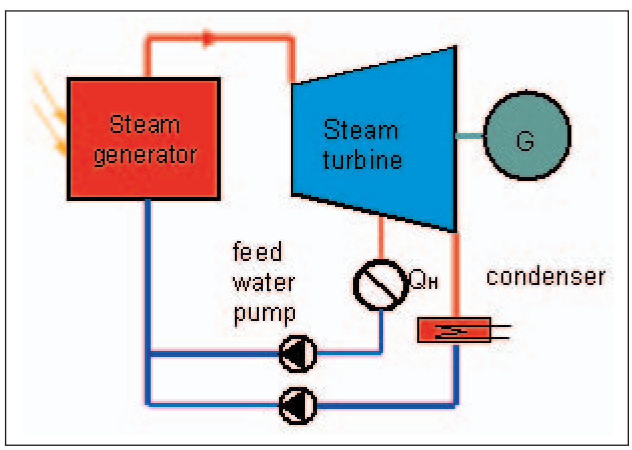


Figure 7.10 Extraction Condensing Turbine

of the process.

The extraction condensing turbines have higher power to heat ratio in comparison with back-pressure turbines. Although condensing systems need more auxiliary equipment such as the condenser and cooling towers, better matching of electrical power and heat demand can be obtained where electricity demand is much higher than the steam demand and the load patterns are highly fluctuating.

The overall thermal efficiency of an extraction condensing turbine cogeneration system is lower than that of back pressure turbine system, basically because the exhaust heat cannot be utilized (it is normally lost in the cooling water circuit). However, extraction condensing cogeneration systems have higher electricity generation efficiencies

7.7.2 Gas Turbine

The fuel is burnt in a pressurized combustion chamber using combustion air supplied by a compressor that is integral with the gas turbine. In conventional Gas turbine (Figure 7.11), gases enter the turbine at a temperature range of 900 to 1000°C and leave at 400 to 500°C. The very hot pressurized gases are used to turn a series of turbine blades, and the shaft on which they are mounted, to produce mechanical energy. Residual energy in the form of a high flow of hot exhaust gases can be used to meet, wholly or partly, the thermal (steam) demand of the site. Waste gases are exhausted from the turbine at 450°C to 550°C, making the gas turbine particularly suitable for high-grade heat supply.

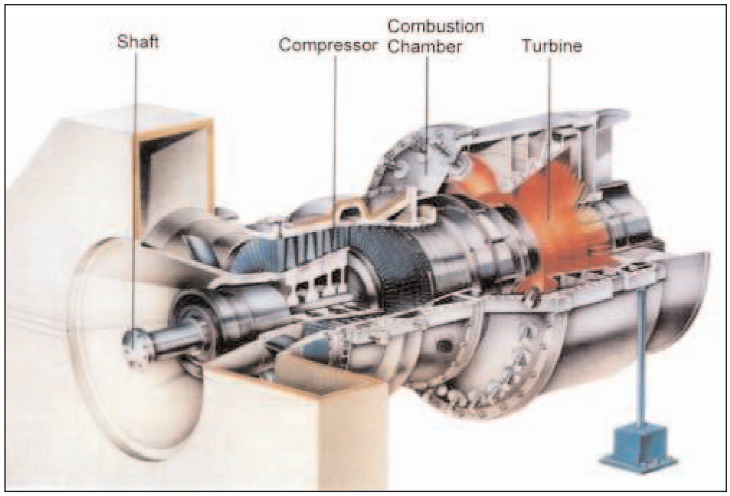


Figure 7.11 Gas Turbine

The available mechanical energy can be applied in the following ways:

- to produce electricity with a generator (most applications);
- to drive pumps, compressors, blowers, etc.

A gas turbine operates under exacting conditions of high speed and high temperature. The hot gases supplied to it must therefore be clean (i.e. free of particulates which would erode the blades) and must contain not more than minimal amounts of contaminants, which would cause corrosion under operating conditions. High-premium fuels are therefore most often used, particularly natural gas. Distillate oils such as gas oil are also suitable, and sets capable of using both are often installed to take advantage of cheaper interruptible gas tariffs. LPGs and Naphtha are also suitable, LPG being a possible fuel in either gaseous or liquid form.

Gas Turbine Efficiency

Turbine Efficiency is the ratio of actual work output of the turbine to the net input energy supplied in the form of fuel. For stand alone Gas Turbines, without any heat recovery system the efficiency will be as low as 35 to 40%. This is attributed to the blade efficiency of the rotor, leakage through clearance spaces, friction, irreversible turbulence etc.

Since Exhaust gas from the Gas Turbine is high, it is possible to recover energy from the hot gas by a Heat Recovery Steam Generator and use the steam for process.

Net Turbine Efficiency

Above efficiency figures did not include the energy consumed by air compressors, fuel pump and other auxiliaries. Air compressor alone consumes about 50 to 60% of energy generated by the turbine. Hence net turbine efficiency, which is the actual energy output available will be less than what has been calculated. In most Gas Turbine plants, air compressor is an integral part of Turbine plant.

7.7.3 Reciprocating Engine Systems

This system provides process heat or steam from engine exhaust. The engine jacket cooling water heat exchanger and lube oil cooler may also be used to provide hot water or hot air. There are, however, limited applications for this.

As these engines can use only fuels like HSD, distillate, residual oils, natural gas, LPG etc. and as they are not economically better than steam/gas turbine, their use is not widespread for co-generation. One more reason for this is the engine maintenance requirement.

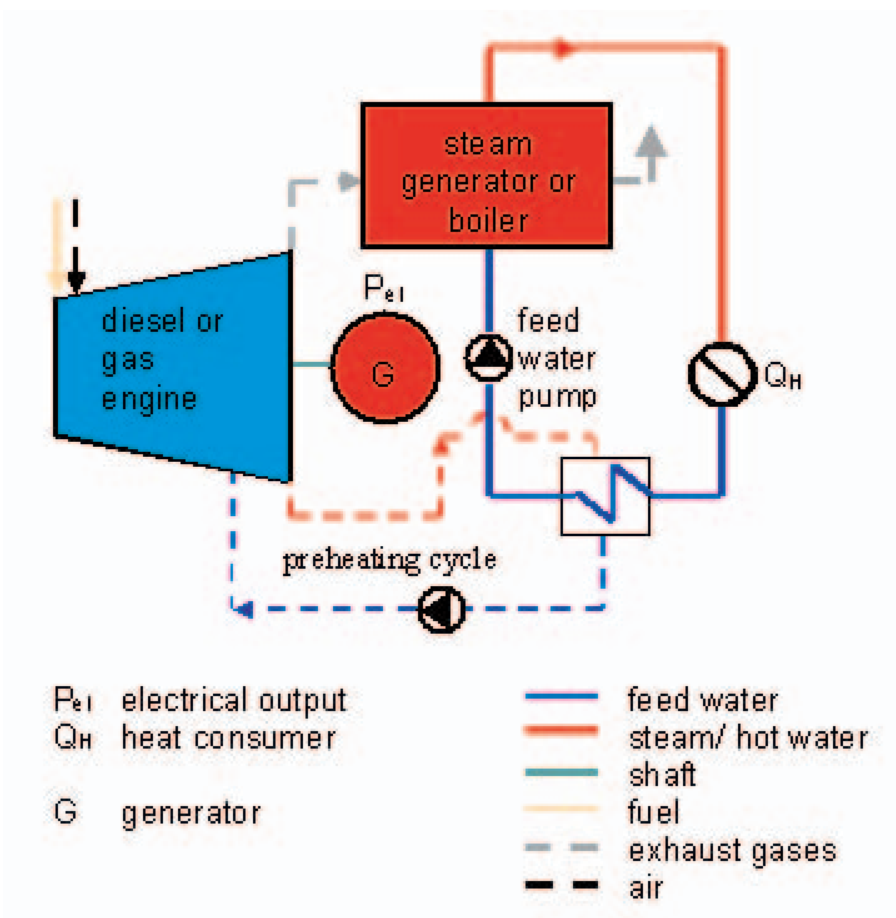


Figure 7.12

7.8 Typical Cogeneration Performance Parameters

The following Table 7.4 gives typical Cogeneration Performance Parameters for different Cogeneration Packages giving heat rate, overall efficiencies etc.

TABLE 7.4 TYPICAL COGENERATION PERFORMANCE PARAMETERS

Prime Mover in Cogen. Package	Nominal Range (Electrical)	Electrical Generation Heat Rate (kCal / kWh	Efficiencies, %		
			Electrical Conversion	Thermal Recovery	Overall Cogeneration
Smaller Reciprocating Engines	10–500 kW	2650–6300	20–32	50	74–82
Larger Reciprocating Engines	500–3000 kW	2400–3275	26–36	50	76–86
Diesel Engines	10–3000 kW	2770–3775	23–38	50	73–88
Smaller Gas Turbines	800–10000 kW	2770–3525	24–31	50	74–81
Larger Gas Turbines	10–20 MW	2770–3275	26–31	50	78–81
Steam Turbines	10–100 MW	2520–5040	17–34	–	–

Note: Adapted from Cogeneration Handbook California Energy Commission, 1982

7.9 Relative Merits of Cogeneration Systems

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

TABLE7.5 ADVANTAGES AND DISADVANTAGES OF VARIOUS COGENERATION SYSTEMS

Variant	Advantages	Disadvantages
Back pressure	– High fuel efficiency rating	– Little flexibility in design and operation
Steam turbine & fuel firing in boiler	– Simple plant – Well-suited to low quality fuels	– More capital investment – Low fuel efficiency rating – High cooling water demand – More impact on environment High civil const. cost due to complicated foundations
Gas turbine with waste heat recovery boiler	– Good fuel efficiency – Simple plant – Low civil const. Cost – Less delivery period	– Moderate part load efficiency – Limited suitability for low quality fuels

	– Less impact on environment – High flexibility in operation	
Combined gas & steam turbine with waste heat recovery boiler	– Optimum fuel efficiency rating – Low relative capital cost – Less gestation period – Quick start up & stoppage – Less impact on environment – High flexibility in operation	– Average to moderate part-load efficiency – Limited suitability for low quality fuels
Diesel Engine & waste heat recovery Boiler & cooling water heat exchanger	– Low civil const. Cost due to block foundations & least no. of auxiliaries – High Power efficiency – Better suitability as stand by power source	– Low overall efficiency – Limited suitability for low quality fuels – Availability of low temperature steam – Highly maintenance prone.

7.10 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 /cm_2.
Steam enthalpy	:	676.44 kCal / Kg.
Fuel used	:	Natural gas
Calorific value – LCV	:	9500 kCal/ sm_3
Price of gas	:	Rs 3000 /1000 sm_3
Capital investment for total co-generation plant	:	Rs. 1300 Lakhs

Cost Estimation of Power & Steam From Cogeneration Plant

1. Estimated power generation from Cogeneration plant at 90% Plant Load Factor (PLF)	:	PLF × Plant Capacity × no. of operation hours (90/100)×4000×8000 288.00 × 10^5 kWh per annum
2. Heat input to generate above units	:	Units (kWh) × heat rate 288 x 10^5 × 3049.77 878333.76 × 10^5 kCal
3. Natural gas quantity required per annum	:	Heat input / Calorific value (LCV) of natural gas
	:	878333.76 x 10^5 / 9500

4. Cost of fuel per annum	:	92.46×105 sm_3 Annual gas consumption. × Price $92.46 \times 10^5 \times$ Rs.3000./1000 sm_3 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 cost with demand & energy charges	:	Rs. 3.00/kWh
Capital investment for 10 TPH, 8.5 kg/sq.cm.200)°C Natural gas fired fire tube boiler & all auxiliaries	:	Rs. 80.00 lakh

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 $=541152 \times 10^5$ kCals
(ii) Heat Input required to generate 10 TPH steam per annum @ 90% efficiency	:	Heat output/boiler efficiency $541152 \times 10^5/0.90$
Heat Input	:	601280×10^5 kCal per annum
(iii) Natural Gas Quantity	:	Heat Input/Calorific

		value (LCV) of natural gas $601280 \times 10^5/9500$ 63.29×10^5 sm_3 per annum
(iv) Cost of fuel per annum	:	Annual gas consumption × price $63.29 \times 10^5 \times 3000$ $/1000\ sm_3$ 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.

QUESTIONS	
1.	Explain what do you mean by cogeneration.
2.	Explain how cogeneration is advantageous over conventional power plant.
3.	What is meant by wheeling?
4.	What is meant by combined cycle cogeneration?
5.	Explain the term topping cycles with examples.
6.	Explain the term bottoming cycles with examples.
7.	Explain the term heat-to-power ratio.
8.	Explain with diagrams cogeneration systems using the back pressure turbine, extraction-condensing turbine and double extraction back pressure turbine.
9.	The efficiency of which of the following is the highest (a) condensing (b) back pressure (c) extraction condensing (d) double extraction condensing
10.	Explain the principle of operation of a steam turbine.
11.	Explain the principle of operation of a gas turbine.
12.	What are the common fuels used in gas turbines?
13.	Clean fuels are used in gas turbines because (a) the operate at high speed and high temperature (b) pollution act requires it (c) combustion would be affected (d) they are inexpensive
14.	The system efficiencies of gas turbine units are (a) 35 to 40% (b) 85 to 90% (c) 75 to 80% (d) 55 to 60%
15.	A heat recovery steam generator is used with (a) gas turbines (b) stem turbines (c) back pressure turbines (d) condensing turbines
16.	List the circumstances under which cogeneration will become attractive.
17.	What are the sources of waste heat in a diesel engine?
18.	Explain how you will go about an energy audit of a steam turbine based fully back pressure cogeneration system.

REFERENCES

1. Cogeneration – Training Material by NIFES, UK.
2. Energy Cogeneration handbook Criteria for Central Plant Desing by George Polimeros, Industrial Press Inc, N.Y.

www.cogen.org
www.unescap.org/enrd/energy/co-gen/
http://www.cogen.org/Downloadables/Projects/EDUCOGEN_Cogen_Guide.pdf.

How Refrigerators Work

from HOW STUFF WORKS

Introduction to How Refrigerators Work

In the kitchen of nearly every home in America there is a refrigerator. Every 15 minutes or so you hear the motor turn on, and it magically keeps things cold. Without refrigeration, we'd be throwing out our leftovers instead of saving them for another meal.

The refrigerator is one of those miracles of modern living that totally changes life. Prior to refrigeration, the only way to preserve meat was to salt it, and iced beverages in the summer were a real luxury.

In this article, you'll find out how your refrigerator performs its magic.

The Purpose of Refrigeration

The fundamental reason for having a refrigerator is to keep food cold. Cold temperatures help food stay fresh longer. The basic idea behind refrigeration is to slow down the activity of bacteria (which all food contains) so that it takes longer for the bacteria to spoil the food.

For example, bacteria will spoil milk in two or three hours if the milk is left out on the kitchen counter at room temperature. However, by reducing the temperature of the milk, it will stay fresh for a week or two -- the cold temperature inside the refrigerator decreases the activity of the bacteria that much. By freezing the milk you can stop the bacteria altogether, and the milk can last for months (until effects like freezer burn begin to spoil the milk in non-bacterial ways).

Refrigeration and freezing are two of the most common forms of food preservation used today.

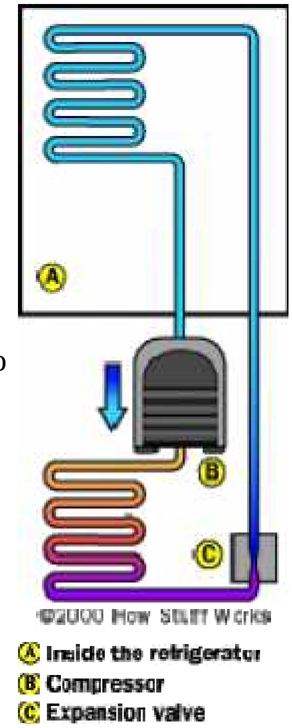
Parts of a Refrigerator

The basic idea behind a refrigerator is very simple: It uses the evaporation of a liquid to absorb heat. You probably know that when you put water on your skin it makes you feel cool. As the water evaporates, it absorbs heat, creating that cool feeling. Rubbing alcohol feels even cooler because it evaporates at a lower temperature. The liquid, or refrigerant, used in a refrigerator evaporates at an extremely low temperature, so it can create freezing temperatures inside the refrigerator. If you place your refrigerator's refrigerant on your skin (definitely NOT a good idea), it will freeze your skin as it evaporates.

There are five basic parts to any refrigerator (or air-conditioning system):

- **Compressor**
- **Heat-exchanging pipes** - serpentine or coiled set of pipes outside the unit
- **Expansion valve**
- **Heat-exchanging pipes** - serpentine or coiled set of pipes inside the unit
- **Refrigerant** - liquid that evaporates inside the refrigerator to create the cold temperatures.

The basic mechanism of a refrigerator works like this:



1. The compressor compresses the refrigerant gas. This raises the refrigerant's pressure and temperature (**B**), so the heat-exchanging coils outside the refrigerator allow the refrigerant to dissipate the heat of pressurization (**B to C**).
2. As it cools, the refrigerant condenses into liquid form and flows through the expansion valve (**C**).
3. When it flows through the expansion valve, the liquid refrigerant is allowed to move from a high-pressure zone to a low-pressure zone, so it expands and evaporates (**A**). In evaporating, it absorbs heat, making it cold.
4. The coils inside the refrigerator allow the refrigerant to absorb heat, making the inside of the refrigerator cold. The cycle then repeats.

This is a fairly standard -- and somewhat unsatisfying -- explanation of how a refrigerator works. So let's look at refrigeration using several real-world examples to understand what is truly happening.

Understanding Refrigeration

To understand what is happening inside your refrigerator, it is helpful to understand refrigerants

Experiments

These experiments can help you understand the properties of gases and their role in refrigeration.

Experiment 1

You will need:

- A pot of water
- A thermometer that can measure up to at least 250 degrees F
- A stove

Put the pot of water on the stove, stick the thermometer in it and turn on the burner. You will see (if you are at sea level) that the temperature of the water rises until it hits 212°F. At that point, it will start boiling, but will remain at 212°F -- this is the boiling point of water at sea level. If you live in the mountains, where the air pressure is lower than it is at sea level, the boiling point will be lower -- perhaps between 190 and 200°F. This is why many foods have "high-altitude cooking directions" printed on the box. You have to cook foods longer at high altitudes.

Experiment 2

You will need:

- An oven-safe glass bowl
- A thermometer that can measure up to at least 450°F
- An oven

Put the thermometer in your container of water, put the container in the oven and turn it to 400°F.

As the oven heats up, the temperature of the water will again rise until it hits 212°F, and then start boiling. The water's temperature will stay at 212°F even though it is completely surrounded by an environment that is at 400°F. If you let all of the water boil away (and if the thermometer has the range to handle it), as soon as the water is gone the temperature of the thermometer will shoot up to 400°F.

a little better. Here are two experiments that help you see what is happening.
The second experiment is extremely interesting if you think about it in the following way: Imagine some creature that is able to live happily in an oven at 400 degrees Fahrenheit. This creature thinks 400°F is just great -- the perfect temperature (just like humans think that 70 F is just great). If the creature is hanging out in an oven at 400°F, and there is a cup of water in the oven boiling away at 212°F, how is the creature going to feel about that water? It is going to think that the boiling water is REALLY cold. After all, the boiling water is 188 degrees colder than the 400°F that this creature thinks is comfortable. That's a big temperature difference!

(This is exactly what is happening when we humans deal with liquid nitrogen. We feel comfortable at 70 F. Liquid nitrogen boils at -320 F. So if you had a pot of liquid nitrogen sitting on the kitchen table, its temperature would be -320 F, and it would be boiling away -- to you, of course, it would feel incredibly cold.)

Modern refrigerators use a regenerating cycle to reuse the same refrigerant over and over again. You can get an idea of how this works by again imagining our oven creature and his cup of water. He could create a regenerating cycle by taking the following four steps:

1. The air temperature in the oven is 400 degrees F. The water in the cup boils away, remaining at 212°F but producing a lot of 400°F steam. Let's say the creature collects this steam in a big bag.
2. Once all the water boils away, he pressurizes the steam into a steel container. In the process of pressurizing it, its temperature rises to 800°F and it remains steam. So now the steel container is "hot" to the creature because it contains 800°F steam.
3. The steel container dissipates its excess heat to the air in the oven, and it eventually falls back to 400°F. In the process, the high-pressure steam in the container condenses into pressurized water (just like the butane in a lighter -- see sidebar).
4. At this point, the creature releases the water from the steel pressurized container into a pot, and it immediately begins to boil, its temperature dropping to 212°F.

Butane Lighters

If you go to the local store and buy a disposable butane lighter with a clear case (so that you can see the liquid butane inside), what you are seeing is liquid butane stored in a high-pressure container. Butane boils at 31 degrees F at normal atmospheric pressure (14.7 PSI). By keeping butane pressurized in a container, it remains liquid at room temperature. If you took a cup of butane and put it on your kitchen counter, it would boil, and the temperature of the boiling liquid would be 31°F.
The boiling point of butane, by the way, also explains why butane lighters don't work very well on cold winter days. If it is 10 degrees Fahrenheit outside, the butane is well below its boiling point, so it cannot vaporize. Keeping the lighter warm in your pocket is what allows it to work in the winter.

By repeating these four steps, the creature now has a way of reusing the same water over and over again to provide refrigeration.

Now let's take a look at how these four steps apply to your refrigerator.

The Refrigeration Cycle

The refrigerator in your kitchen uses a cycle that is similar to the one described in the previous section. But in your refrigerator, the cycle is continuous. This is what happens to keep the refrigerator cool:

1. The compressor compresses the refrigerant gas. The compressed gas heats up as it is pressurized.
2. The coils on the back of the refrigerator let the hot refrigerant gas dissipate its heat. The refrigerant gas condenses into liquid at high pressure.
3. The high-pressure liquid flows through the expansion valve.

You can think of the expansion valve as a small hole. On one side of the hole is high-pressure refrigerant liquid. On the other side of the hole is a low-pressure area (because the compressor is sucking gas out of that side).

4. The liquid immediately boils and vaporizes, its temperature dropping to about -25°F. This makes the inside of the refrigerator cold.
5. The cold refrigerant gas is sucked up by the compressor, and the cycle repeats.

By the way, if you have ever turned your car off on a hot summer day when you have had the air conditioner running, you may have heard a hissing noise under the hood. That noise is the sound of high-pressure liquid refrigerant flowing through the expansion valve.

You may have heard of refrigerants know as CFCs (chlorofluorocarbons), originally developed by Du Pont in the 1930s as a non-toxic gas for use in refrigeration and air conditioning and sold as Freon® . In the 1970's we began to notice a thinning of the ozone layer high in the atmosphere. It is this layer that absorbs much of the ultraviolet radiation coming from the sun. Ultraviolet radiation causes sunburn and skin cancer. The cause of the thinning was determined to be the Freon® that had come from leaking or discarded refrigerators and air conditioners. Freon® breaks down ozone into oxygen gas. The reaction is shown below.

$$2O_3(g) \xrightarrow{\text{freon}} 3O_2(g)$$

As of the 1990s, all new refrigerators and air conditioners use refrigerants that are less harmful to the ozone layer. Use of highly purified liquified propane gas as a refrigerant is gaining favor, especially in systems originally designed for Freon®. Yes, the same liquid used in barbeque grills. As such, it is designated as R-290 and is marketed under the trade name Duracool®. Although propane is flammable, in home and automotive systems it is present in quantities small enough to not pose an undue fire hazard if a system should develop a leak. Moreover, propane is nontoxic.

AIR CONDITIONING

- Air conditioning is the process of giving comfort to the occupant in a particular space irrespective of any external climatic conditions
- Air conditioning systems are broadly classified into

➢ **Comfort Air conditioning**

- It is the process of giving comfort atmosphere to majority of the occupant
- It is subdivided into

❑ Summer A/C

❑ Winter A/C

❑ Year – round A/c

➢ **Industrial Air conditioning**

- It provides air at required temperature and humidity to perform a specific industrial process successful
- Design conditions are not based on human comfort but purely on the requirement of industrial process

ROOM AIR CONDITIONER

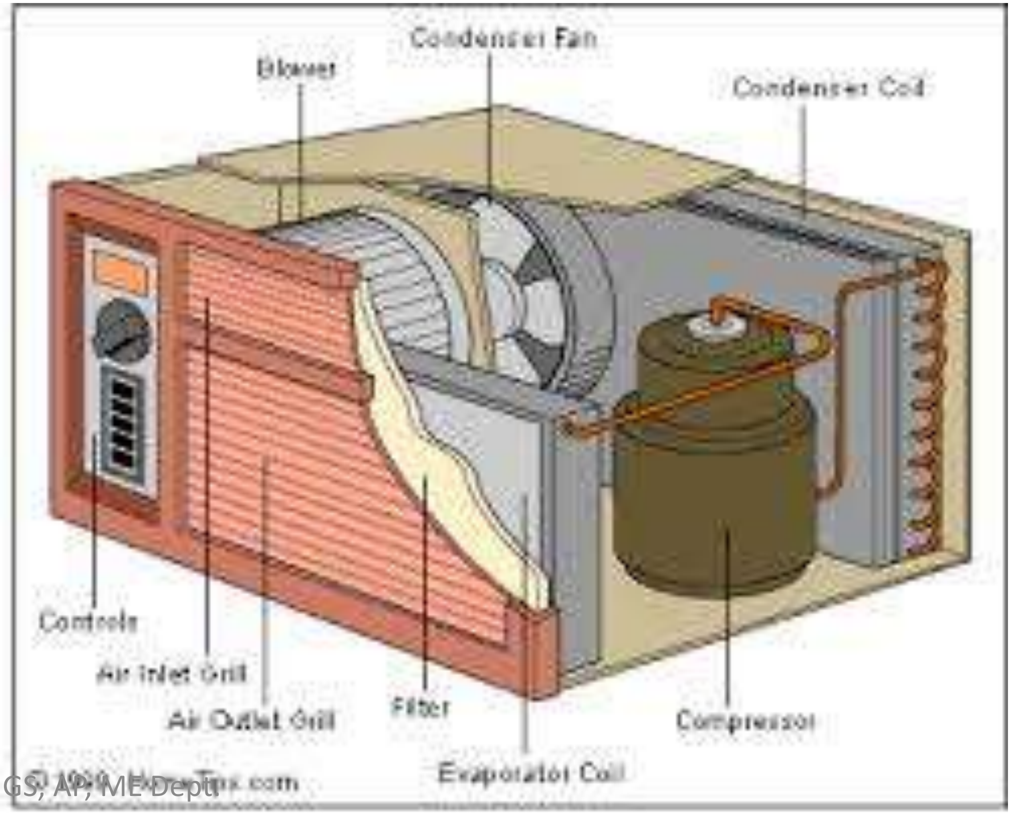
- Also called Window air conditioner
- It is the simplest form of an air conditioning system
- Usually mounted on windows or walls.
- It is a single unit that is assembled in a casing where all the components are located.
- This unit has a double shaft fan motor with fans mounted on both sides of the motor.
- One at the evaporator side and the other at the condenser side.
- Evaporator side will face the room and the condenser side face outside
- The front panel is the one that is seen by the user from inside the room where it is installed and has a user interfaced control be it electronically or mechanically.
- The front panel has adjustable horizontal and vertical(some models) louvers where the direction of air flow are adjustable to suit the comfort of the users.

- **Indoor Side Components**

- The indoor parts of a window air conditioner include:
- **Cooling Coil** with a air filter mounted on it. The cooling coil is where the heat exchange happen between the refrigerant in the system and the air in the room.
- **Fan Blower** is a centrifugal evaporator blower to discharge the cool air to the room.
- **Capillary Tube** is used as an expansion device.
- **Operation Panel** is used to control the temperature and speed of the blower fan. A thermostat is used to sense the return air temperature and another one to monitor the temperature of the coil.
- **Filter Drier** is used to remove the moisture from the refrigerant.
- **Drain Pan** is used to contain the water that condensate from the cooling coil and is discharged out to the outdoor by gravity.

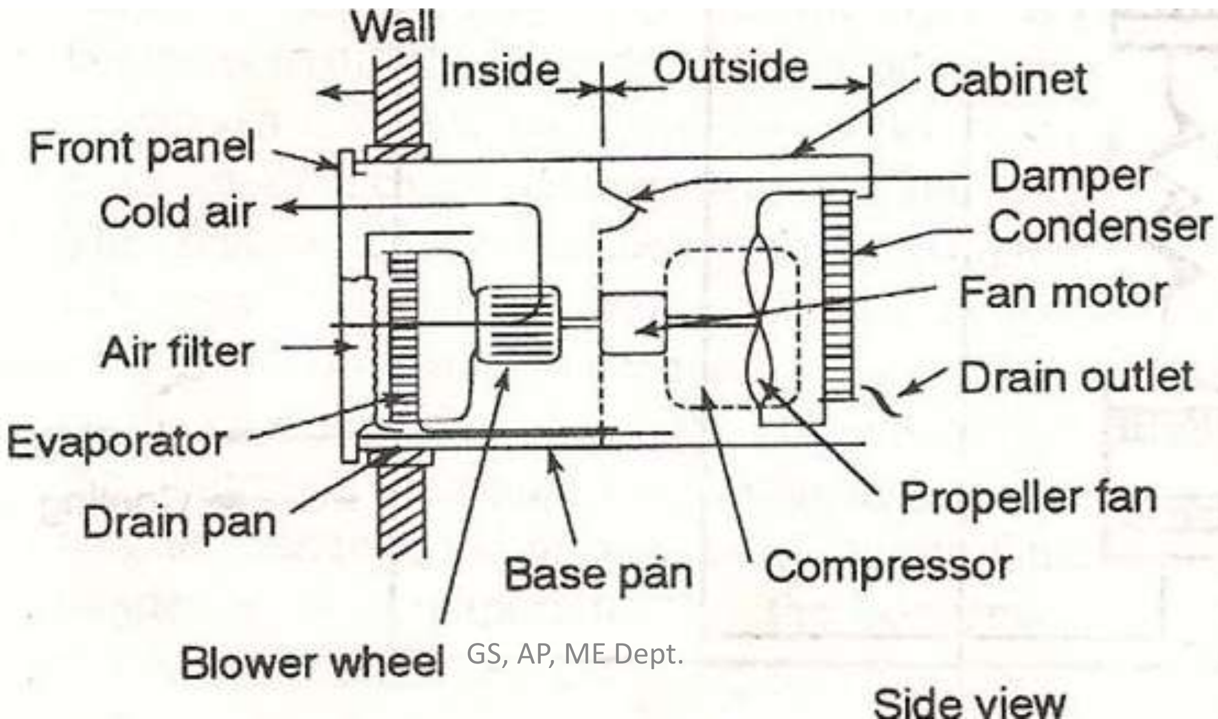
➢ Outdoor Side Components

- The outdoor side parts include:
- **Compressor** is used to compress the refrigerant.
- **Condenser Coil** is used to reject heat from the refrigeration to the outside air.
- **Propeller Fan** is used in air-cooled condenser to help move the air molecules over the surface of the condensing coil.
- **Fan Motor**



- **Operations**

- Once the room temperature has been achieved, the compressor cuts off.
- The evaporator blower fan will suck the air from the room to be conditioned through the air filter and the cooling coil. Air that has been conditioned is then discharge to deliver the cool and dehumidified air back to the room. This air mixes with the room air to bring down the temperature and humidity level.
- The introduction of fresh air from outside the room is done through the damper which is then mixed with the return air from the room before passing it over the air filter and the cooling coil.
- The air filter which is mounted in front of the evaporator acts as a filter to keep the cooling coil clean to obtain good heat-transfer from the coil.



Split Air Conditioner

- also known as split units.
- There are basically 2 casings that are mounted one at the indoor and the other at the outdoor.
- Compared to the window units, it is less noisy
- piping connects the two units.

➢ Indoor Unit

- The indoor unit is installed inside the room to be air conditioned.
- It can be mounted on the ceiling, wall or simply as a console unit on the floor. It consists of the following parts:

❑ **Evaporator Coil** is where the heat exchange is done with the room. It consists of fins and tubes.

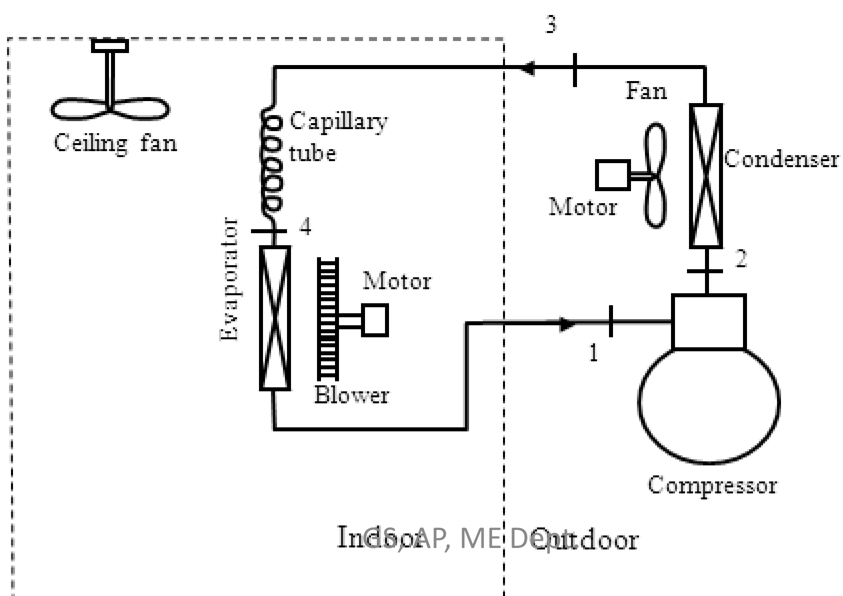
❑ **Control Panel** is where user control the functions of the air conditioner.

- Displays at the panel may indicate the mode of operation, timer, on/off status, fan speed and other special functions.

❑ **Air Filter** is located in front of the evaporator coil to trap any dust or particles before going into the evaporator.

- ❑ **Supply and Return Air Grills** are where the air enters and discharge from the indoor unit.
- ❑ **Fan Blower** together with its motor are used to control the fan speed of the unit.
- ❑ **Capillary Tube** is used as an expansion device where the flow of the refrigerant depends on the tube internal diameter, shape and its length.

- This tube is usually used in smaller units.
- Larger units use thermostatic expansion valve which has a controlling valve to control in greater precision the flow of the refrigerant.



- **The outdoor unit**
- is installed outside the building and consists of the following parts:
- **Compressor** is the main component of the system and is used to compress the refrigerant.
- **Condenser Coil** is used to reject heat from the refrigerant to the outside air.
- **Condenser Fan** is used in air-cooled condenser to help move the air molecules over the surface of the condensing coil, hence rejecting the heat from the indoor to the space outside the building.
- **Condenser Motor** The motor usually has two to three speeds. Smaller unit may only have 1 speed of control and turns on/off simultaneously with the compressor.

Packaged Air Conditioner

- Package air conditioner is a bigger version of the window air conditioner.
- it has a higher cooling or heating capacity
- is usually able to cool an entire house or a commercial building.
- The nominal capacities ranges from 3 tonne to 15 tonne.
- These units are used commonly in places like restaurants, telephone exchanges, homes, small halls, etc.

- The conditioned air are transferred to the space to be conditioned through ducting
- Duct works are usually hidden in the ceiling and wall of the building.
- The unit is placed outside the house, a special room in a building or even on top of a roof.
- This unit is factory assembled and skilled technicians are needed to install this type of unit.
- All the components are assembled inside a single housing/casing
- Depending on the type of the cooling system used in these systems, the packaged air conditioners are divided into two types:

➢ **ones with water cooled condenser and**

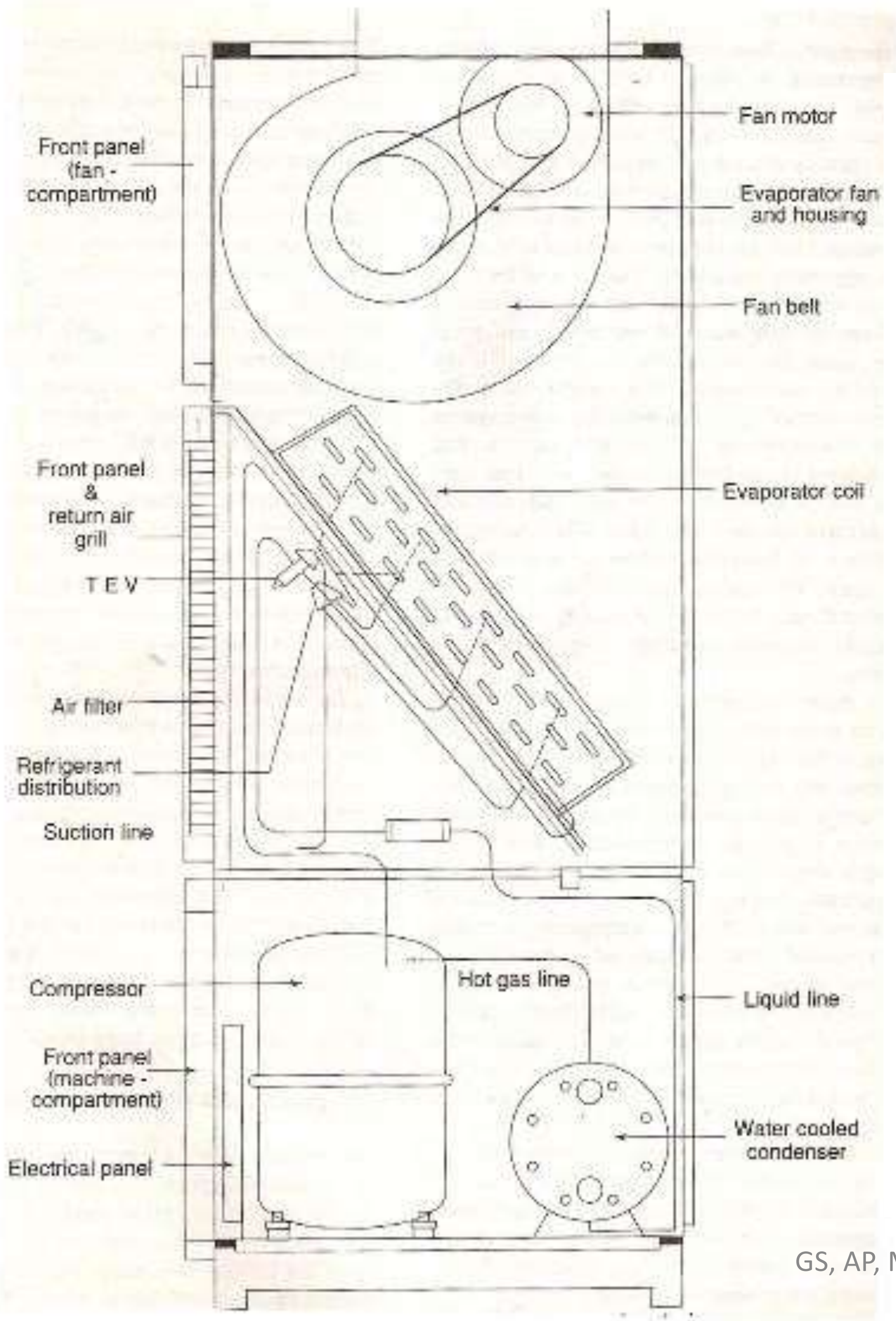
➢ **the ones with air cooled condensers.**

➢ Components

- **Compressor** usually hermetic or semi-hermetic type for operation on 380/400 Volts 3 Phase is used.
- **Water-cooled or Air-cooled condenser.**
- **Electrical Panel.**
- **Thermostatic Expansion Valve.**
- **Air Filter.**
- **Front Panel & Return Air Grill.**
- **Evaporator Coil.**
- **Evaporator Fan And Housing.**
- **Heating and Humidifying Components** may be included in the unit.
- **Dehumidification unit** if needed for cooling mode during summer

Packaged Air Conditioners with Water Cooled Condenser

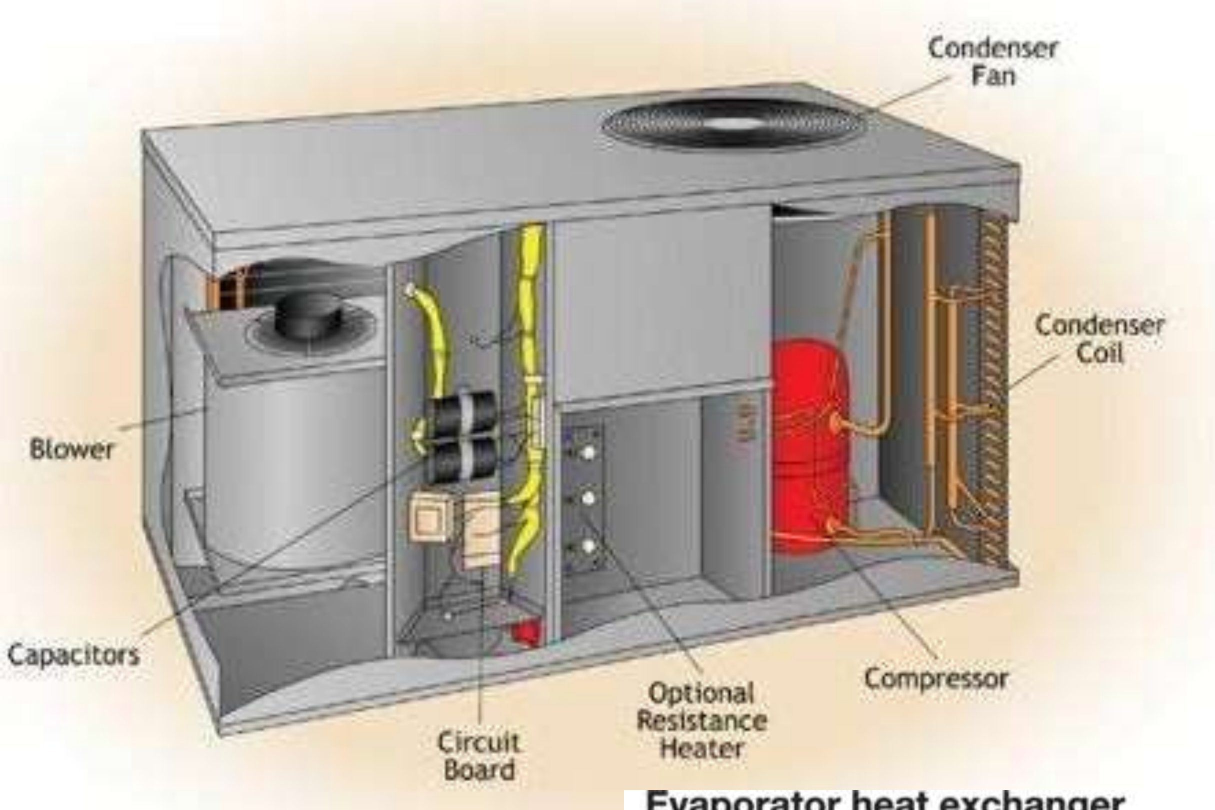
- In these the condenser is cooled by the water.
- The condenser is of shell and tube type
- refrigerant flows along the tube and water flows along the shell.
- The shell and tube type of condenser is compact in shape
- it is enclosed in a single casing along with the compressor, expansion valve, and the air handling unit including the evaporator coil.
- This whole packaged air conditioning unit externally looks like a box with the control panel located externally.
- In these systems, the compressor is located at the bottom along with the condenser.
- Above these components the evaporator or the cooling coil is located.
- The air handling unit comprising of the centrifugal blower and the air filter is located above the cooling coil.
- The centrifugal blower has the capacity to handle large volume of air required for cooling a number of rooms.
- From the top of the package air conditioners the duct comes out that extends to the various rooms that are to be cooled.

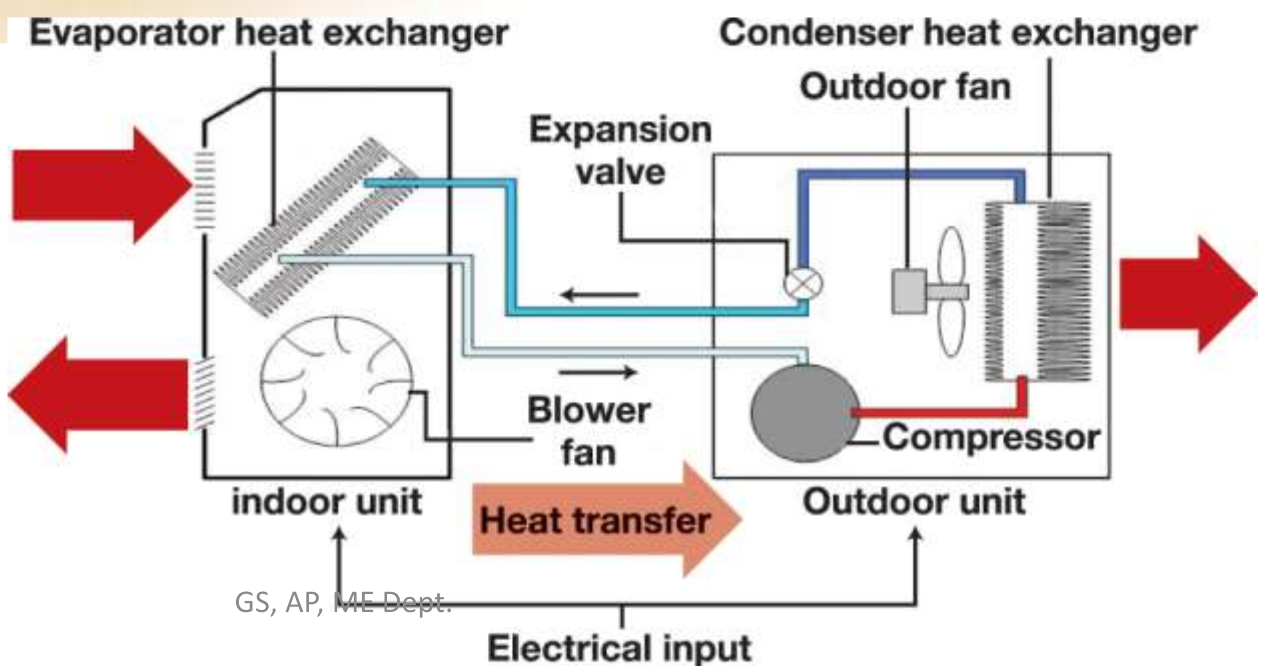

Fan motor
Front panel
(fan -
compartment)
Evaporator fan
and housing
Fan belt
Front panel
&
return air
grill
Evaporator coil
T E V
Air filter
Refrigerant
distribution
Suction line
Compressor
Hot gas line
Liquid line
Front panel
(machine -
compartment)
Water cooled
condenser
Electrical panel


YONAN

➢Packaged Air Conditioners with Air Cooled Condensers

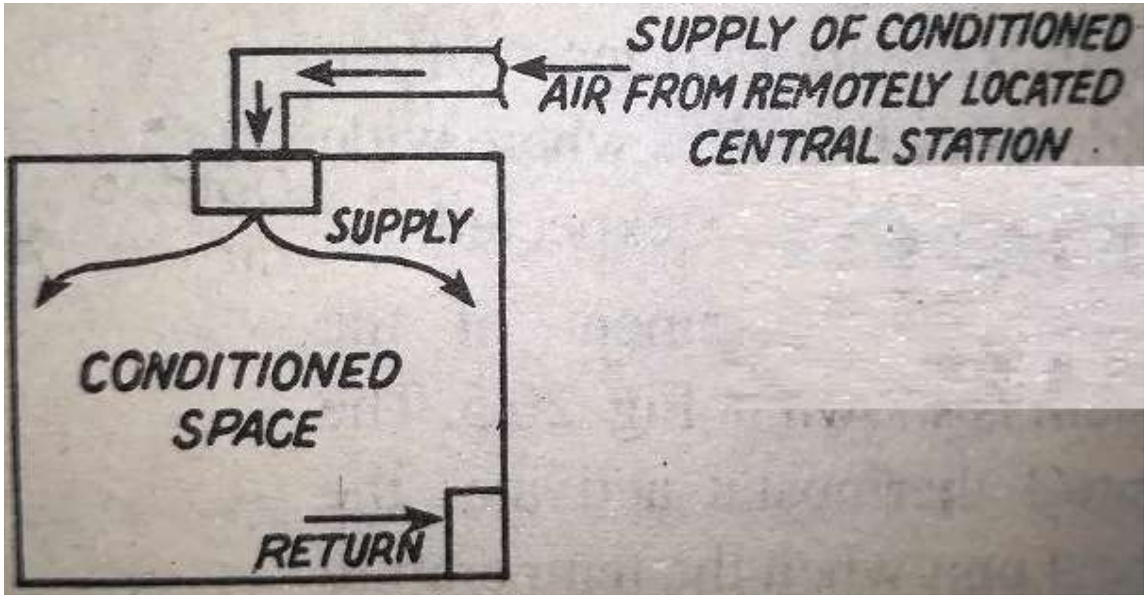
- In this the condenser is cooled by the atmospheric air.
- There is an outdoor unit that comprises of compressor, condenser and in some cases the expansion valve.
- The outdoor unit can be kept on the terrace or any other open place where the free flow of the atmospheric air is available.
- The fan located inside this unit sucks the outside air and blows it over the condenser coil cooling it in the process.
- The condenser coil is made up of several turns of the copper tubing and it is finned externally.
- The packaged ACs with the air cooled condensers are used more commonly than the ones with water cooled condensers since air is freely available it is difficult maintain continuous flow of the water.
- The cooling unit comprising of the expansion valve, evaporator, the air handling blower and the filter are located on the floor or hanged to the ceiling.
- The ducts coming from the cooling unit are connected to the


Condenser Fan
Condenser Coil
Blower
Capacitors
Circuit Board
Optional Resistance Heater
Compressor


Evaporator heat exchanger
Condenser heat exchanger
Outdoor fan
Expansion valve
Blower fan
Compressor
indoor unit
Heat transfer
Outdoor unit
Electrical input

ALL AIR SYSTEM

- Air conditioning system can also be classified according to the type of fluid used either for heating or cooling the space.
- The classifications are:-
- Direct expansion system
- All – water system
- All – air system
- Combined system
- Heat pump systems



- In all air system, the air is conditioned with the help of an air conditioning plant which is located at a remote area.
- Duct works are used to connect the plant and the space to be conditioned.
- The conditioned air is sent through the ducts and distributed into the air conditioned space through inlets.
- This type can be adopted both for comfort and industrial a/c
- It can be applied in buildings requiring individual control of conditioning and also for office buildings, restaurants, hospitals, stores which require multiple (zone) conditioning
- When load in the space changes, the required property of the air should change.
- Various methods are used in this system to maintain the air property within the desired limit when load changes.

- Various method to maintain the air property within the desired limit used are

➢ **Volume control**

- Here variable load is taken care of by varying the volume of conditioned air supplied to the room

➢ **By pass control**

- Here the total quantity of air passing through air conditioner is varied and total quantity of air supplied to room is maintained constant

➢ **Reheat control**

- Use reheat coils for controlling the air property

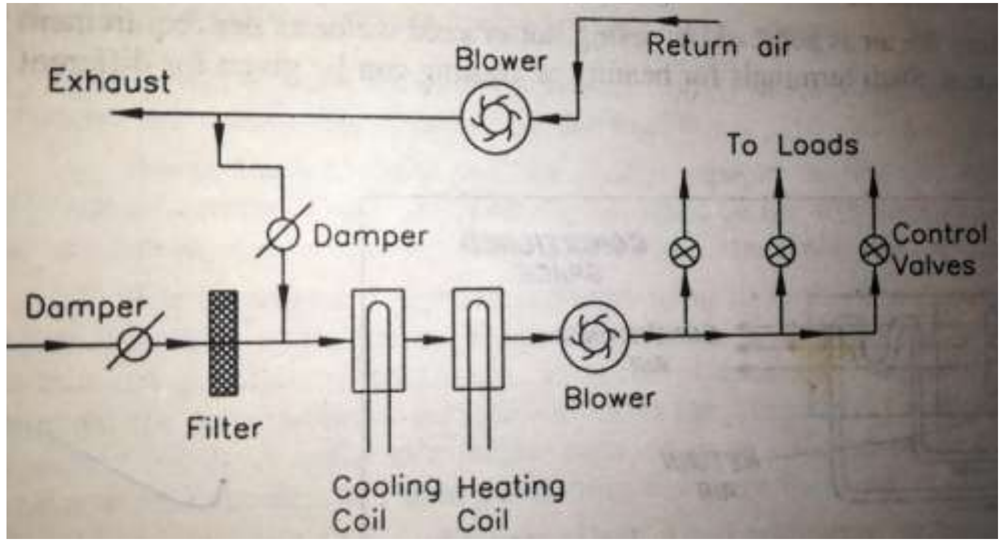
➢ **Dual duct system**

- two ducts are used one for cooled air and other for warm air

➢ **Multizone system**

- Use single duct and mixing of air is performed according to the load demand in room

➢ Volume control

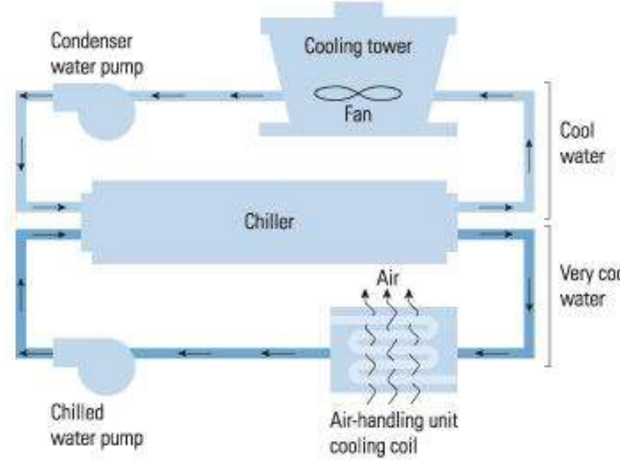


- Also called all-air-variable-volume control
- When load demand varies the volume of cooled air supplied to each room is varied via control valves
- Advantages are low initial and operating cost
- Needs only single duct
- Generally used in schools, hotels, offices, apartments etc.
- Since the volume of air supplied is reduced with a reduction in load, the refrigeration and fan power follow closely the actual air-conditioning load of the building
- This system is virtually self balanced.

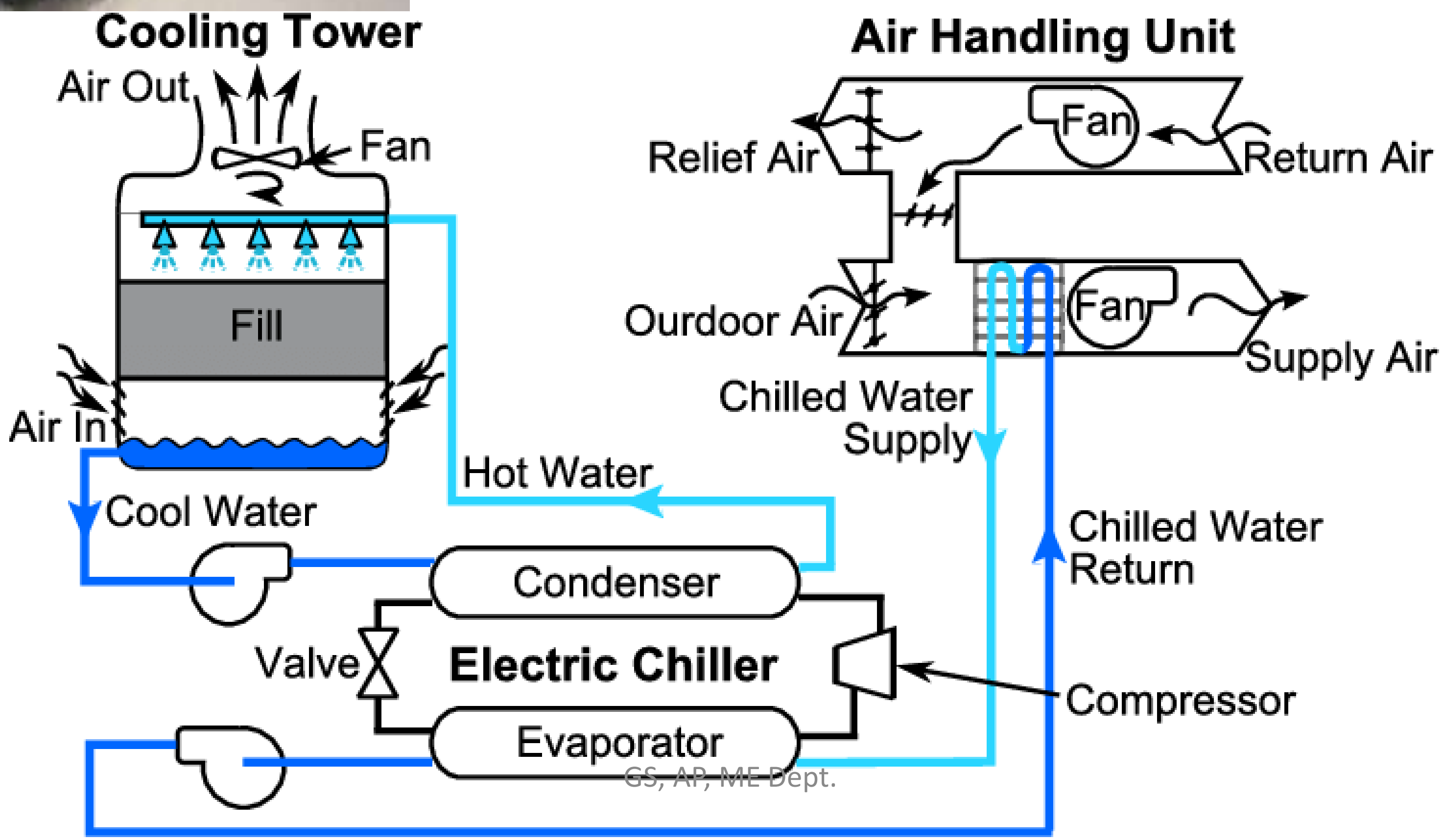
Chilled Water Air Conditioning

- They are commonly used in applications that need large cooling capacity such as hypermarket, industrial process and commercial air conditioning such as offices and factories.
- As its name suggest, this system makes use of water as its secondary refrigerant.
- Chiller is used to remove heat from the water which is then circulated through other components to absorb heat from the space.
- Water is non-corrosive, has specific heat value, fluid, non-toxic and is cheap.
- This makes it an excellent choice compared to other secondary refrigerants such as sodium chloride brines, propylene glycols, ethylene, methanol or glycerin.
- Main advantages are its cost-effectiveness and no hazard of having refrigerant piped all over the house.

- The chiller is the section of the system where an exchange of heat occurred between the water that goes to the building and the evaporator.
- The water leaves the chilled water evaporator at 7°C.
- This chilled-water is then circulated through the entire building by the use of a pump.
- The chilled water is piped into fan coil units which consist of fins & fans with large surface area that absorbed heat from the space through the air-heat exchange process.
- Each fan coil unit has its own thermostat that regulate the amount of cooling needed.
- The chilled water got heated up and returns to the chiller
- The water pumped back to the chiller evaporator get cooled back to 7°C before being circulated back to all the fan coil units.
- This process is repeated.



Chilled Water Air Conditioning System with a Cooling Tower



COMMERCIAL APPLICATIONS OF A/C

- Require separate consideration than industrial a/c
- Prime importance is human comfort
- Degree of comfort varies according to application area

- ❑ **Air conditioning of restaurants,**
- ❑ **Air conditioning of hospitals,**
- ❑ **Air conditioning of retail outlets,**
- ❑ **Air conditioning of computer center,**
- ❑ **Air conditioning of cinema theatre, and**
- ❑ **Air conditioning of other place of amusement**

Air Conditioning of Restaurants

- Some of the usual problems encountered for comfort air conditioning of restaurant are:-
- Extremely variable load
  - High peak occurs from 1pm to 8pm
- High sensible and latent heat gain
  - From gas, steam, electric appliances etc.
- High concentration of odour
  - From body, food, smoke etc.
  - It requires adequate ventilation with proper exhaust facilities
- Localized high sensible and latent heat gains
  - From dinner club, dancing areas etc
- Heavy infiltration of air
  - Through doors
  - Usage of door increases during rush hours

Good restaurant have the following features

- Full capacity to handle the peak load with outdoor air in sufficient quantity
- Proper air distribution system
- Higher air motion in dancing areas
- Care should be taken against beams and columns(they may cause blocking)
- Use perforated ceiling
- Use ceiling diffusers
- Use Side wall outlets
- Air should be exhausted at ceiling for the removal of smoke and odor

- Conventional HVAC systems just have a central control system, so it’s impossible to individually adjust their performance.
- restaurant air conditioning requires highly personalized control of specific spaces, like kitchens.
- There should be a Central Controller and easy to use Management System that can be used to monitor and tailor the conditions in a wide variety of key areas around the restaurant, such as dining rooms.
- It should create a fresh and pleasant atmosphere for diners with a draught-free air distribution
- it is essential that one takes into consideration the room shape, seating arrangements before deciding on the location of the air conditioning unit/s.

- **wall-mounted units** are usually the cheapest option it's still important to place them correctly for maximum comfort and effect.

- They should be placed as centrally as possible on a wall to ensure that the airflow can cover the whole room.

- **Ceiling mounted 'cassette' units** are and excellent solution for restaurants.

- They are a little more costly than wall units, however, they are almost entirely hidden within a suspended ceiling and are therefore more discreet and aesthetically pleasing in a restaurant environment

- **Ducted air conditioning systems** are ideal for restaurants and cafes that are looking for an 'invisible' air conditioner.

- They are usually the most expensive option; however, they are also the most aesthetically pleasing as the duct-work and internal units are hidden entirely within a suspended ceiling with only small grilles remaining visible.

Air Conditioning of Cinema Theatre

- the main load in this areas are occupants and outdoor air
- Capacity required at day is more compared to night
- Outdoor air required per person is 0.15 cu. m
- If air is provided through ventilation, then per person the ventilated air requirement is 0.5 cu. m
- Common design condition at cinema theatre is 26 deg C DBT and 55% RH
- The required capacity of air conditioning plant is one tonn per 15 persons.
- Normally pre cooling is used in theatres
- The system should take care of the rapid rise and fall of the load, as the theatre may get filled and emptied within a short time
- Pre cooling helps to absorb a portion of the peak heat load and this reduces the equipment size requirement

- Air distribution is achieved by overhead diffusers
- The audience demands modern ambient standards: perfect comfort control, the right temperature, optimum relative humidity and calibrated air re-circulation.
- All of these aspects are ensured by the choice of a systems solution that optimizes the use of energy.
- During a show that lasts two or more hours, the spectator must not feel too warm nor too cold.
- There must be no air currents, and unpleasant odours must be reduced to the extent possible.
- Noise from adjacent rooms or from outdoors must be reduced to a minimum
- Based on the external environmental conditions and crowd levels in the auditorium, the units operate at reduced load for the majority of the time.


Packaged unit for auditoriums


CLIVET
CLIVET

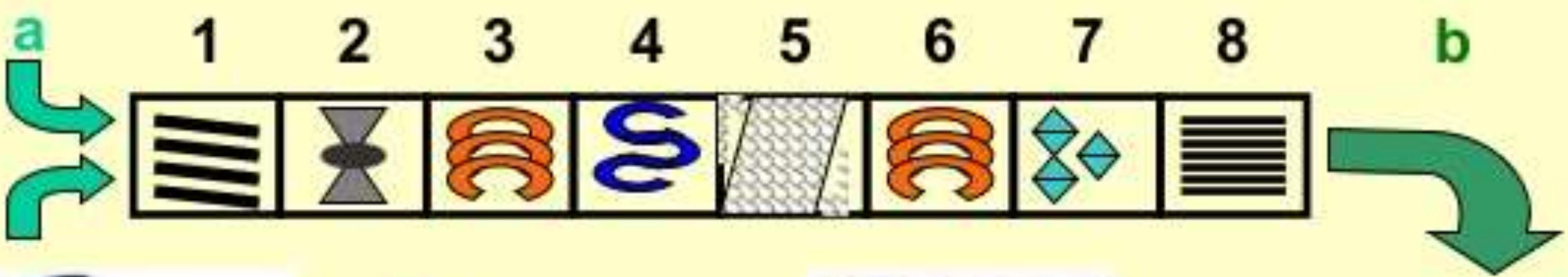
•in the evening, in spring, autumn and winter it is often possible to exploit the freecooling.

•With only the cost of the energy absorbed by the fans, the unit cools the room, and leaves the compressors in standby mode, with substantial energy savings

•The correct removal of impurities present in the air is fundamental to maintain the desired comfort.

•For this reason a second high efficient filtering stage, usually a pocket filter, is often employed on the air to be introduced into the environment.

Theatre Air Conditioning



- a Air intake
- 1 Coarse filters
- 2 Fan
- 3 Heaters
- 4 Condensers
- 5 Filters
- 6 Heaters
- 7 Humidifiers
- 8 Attenuators
- b Filtered, humidified (conditioned) air