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**Energy Savings by CHCP plants in the Hotel Sector**

# Combined Heat and Power Generation CHP

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# Combined Heat and Power Generation CHP

## 1 The concept of co-generation

Co-generation is the term universally applied to the simultaneous production of electricity and heat from one single fuel in a decentralised, and end-user-sized way. There are two main types of co-generation concepts: “Topping Cycle” plants, and “Bottoming Cycle” plants.

- In a topping-cycle plant the fuel is consumed by an engine or turbine, which is driving an alternator that generates the required electrical energy. Exhaust hot gas from combustion and heat from cooling systems is used to produce steam or hot water.
- In a bottoming cycle plant, a waste heat recovery boiler captures waste heat from a manufacturing heating process in heavy industries where very high temperature furnaces are used.

In principle, co-generation makes sense anywhere where electricity and heat are required. The layout depends on technical as well as economical issues.

**Combined heat and power plant,** often referred to in literature as **CHP**, is the name commonly used to an on-site electric generating plant serving the power and thermal needs of a given facility – manufacturing or processing plant, commercial or institutional complex – through application of the waste heat of electric generation. The CHP plant can be regarded as a boiler that produces both heat and electricity and can be incorporate into a site’s energy service.

## 2 Co-generation applications

Co-generation systems have been designed and built for many different applications.

**Large-scale systems** can be built for on-site plants, or off-site plants. Off-site plants need to be close enough to a steam customer or municipal steam loop to cover the cost of a steam pipeline. The plants may be owned and operated by industrial- or commercial facility owners, or a utility or non-utility generator.

District heating is a large-scale application of co-generation. In these applications steam, or hot water, and cold water are distributed in pipes. Many towns in northern Europe are well underway to cover more than 70% of their total heat demand by the use of district heating. It is used for more than 25% of all space heating in Germany, Denmark, Sweden and Finland.

Many cities, which have extensive district heating and cooling systems, have co-generation facilities. Some large co-generation facilities were built primarily to produce power.They produce only enough steam to meet the requirements for qualified facilities. For example, there are large plants that have large greenhouses as “steam hosts”. The greenhouses operate without losing money only because their steam is virtually free of charge.

Many utilities have formed subsidiaries to own and operate co-generation plants. These subsidiaries are successful due the operation and maintenance experiences that the utilities bring to them. Usually, they also have long-term sales contract lined up before the plant is built. One example is a de-salination multiflash plant that is owned and operates in Sicily by a subsidiary co-owned by an electric utility and a water utility. The former feed the power directly into the grid; the latter uses the steam to increase water production.

Large-scale co-generation systems can be classified according to the type of engine that they use:

- **Co-generation with steam turbines**
  If the average steam load is above 10 tonnes/hour, and where the potential for power generation is above 1.000 kWe, co-generation with steam turbines can be considered. Below this level, the additional capital investment required for the high pressure boiler and the turbines will not be justified.

- **Co-generation with gas turbine**
  They are widely used in size from 1.000 kWe continuous rating to 50 MWe. The heat content of the gas turbine exhaust stream is recovered in a waste heat recovery boiler. The exhaust gases produce direct sources of heat, high-pressure steam, low-pressure steam or hot water.

- **Co-generation with combined cycles gas turbine**
  They are used in those industrial plants where there is a considerable demand for electrical energy and a very small demand for heat. The gas turbines are used to generate electrical power in a topping co-generation cycle, and the high temperature exhaust stream’s thermal energy is recovered in a waste heat recovery boiler to produce high-pressure steam. This steam operates a steam turbine to increase the electrical power generation.

Co-generation systems are also available to **small-scale** users of electricity. Small-scale co-generation systems can be classified according to the type of engine or prime mover that they use.

**Reciprocating engine systems**

The most commonly applied in the 30-1 000 kWe size range. They are widely available as compact, fully packaged, skid-mounted units that are easy to install. Furthermore, each unit can readily be tailored to the customers' specific requirements and is assembled and tested by the supplier prior to installation.

Up to 90% of the engines waste heat is recovered in the form of hot water or low-pressure steam from the engines jacket cooling water and lubrication oil systems and from exhaust gases. This is achieved using a series of heat exchangers, and in the case where a demand for low-temperature water exists, condensing heat exchangers.

- **Gas turbines**

  Gas turbines are widely used in co-generation projects larger than 3-4 MWe where there is a demand for high-pressure steam. Systems are also available in the 100-600 kWe range, but the electrical efficiency achieved at this scale is reduced from 30% to around 25%. Despite this, overall efficiency is 80-90% with a high grade of heat recovery, which can be used for medium and high-pressure steam and for direct heating or drying applications.

- **Steam turbines**

  Steam turbines could be appropriate in cases where a site has a steam surplus compared to demand. There are several alternatives to the conventional use of co-generation systems for generating electricity and heat. For instance, instead of producing electricity, the shaft power can be used to drive compressors for air-conditioning chillers and industrial refrigeration plant or to supply compressed air. The recovered heat, instead of being used for water heating, can be used either for cooling purposes, via an absorption chiller, or for heating air for space- or dryer heating. It is also possible to combine a co-generation system with a heat pump to utilise a low temperature heat source in a highly efficient system.

- **Micro co-generation**

  These systems have also been developed for private residences. These home-sized co-generation packages have a capacity of up to 5 kWe. Both natural gas-fuelled and oil-fuelled systems exist. They are capable of providing most of the heating and electrical needs for a home.

# 3 Environmental considerations

Because co-generation systems often burn fossil fuel, they give rise to various products that are damaging to the environment. Industrial wastes, with a low calorific value and high moisture content, can also be burned in a co-generation plant, using fluidised bed burners. This helps companies to simplify their organisation of waste disposal, and eliminate most alternative waste disposal needs.

- **Carbon dioxide** is the most important product of the combustion process, well known for its contribution to the greenhouse effect and climatic change. However, where co-generation replaces the separate fossil fuel generation of electricity and heat, it reduces primary fuel consumption by approximately 35%. According to estimations, and in comparison to separate production of heat and electricity, the $CO_2$ savings from 1 MWh of CHP electricity production vary from 132 kg to 909 kg with a reasonable average of 500 kg saved $CO_2$ per MWh.

- **Sulphur dioxide** emissions vary directly with the sulphur content of the fuel. In the case of natural gas this is negligible, and condensing heat exchangers can be used to maximise heat recovery wherever appropriate. Diesel fuel and biogas, however, do contain sulphur and, where the sulphur content exceeds the limit set by the manufacturer, some form of fuel cleaning is necessary prior to use. Furthermore, the cost of installing a stainless steel heat exchanger and exhaust flue to counter the corrosive nature of the condensate usually precludes the use of condensing heat recovery systems with these fuels.

- **Oxides of nitrogen (NOx)** are produced by burning any fuel in air. The level of NOx emissions, however, is dependent on combustion conditions and particularly on temperature, pressure, combustion chamber geometry and the air/fuel mixture. However, modern co-generation engines typically achieve emissions levels of 140 g/GJ or less. Many of these engines are stoichiometric engines with a three-way catalytic converter to remove NOx, carbon monoxide and unburnt hydrocarbons. The NOx content of exhaust gases can also be reduced using selective catalytic reduction techniques based on ammonia or urea.

- **Carbon monoxide**, unburned hydrocarbons and particles are rarely a problem unless air/fuel ratios and combustion conditions are inadequately controlled.

- **Noise** can be seen as an environmental concern. The use of acoustic enclosures can easily reduce noise levels from their normal value of around 100 dB(a) at 1 m to 65-75 dB(a), well below the typical legislative limit of 85 dB(a).

# 4 The benefits of co-generation

The principal objective of any Combined Heat and Power installation is to save the owner and operator money. This is achieved by taking a comparatively low-cost fuel and converting into high value electricity. If the conversion can be done with a reasonable efficiency (23-37%), the value of the electrical output can be roughly equivalent to the cost of fuel. The heat to be recovered from engine cooling and exhaust gases can be 50%-70% of the fuel input. The value of this heat in the initial years can be considered as paying-off the capital and maintenance costs, and after this it will produce cash saving.

Also, CHP is one of the very few technologies that can offer a significant short or medium term contribution to the energy efficiency issue in the European Union and therefore can make a positive contribution to the environmental policies of the EU. In the White Paper “An Energy Policy for the European Union” (Brussels 15.10.97) the European Commission committed itself to present a strategy offering a coherent approach for the promotion of Combined Heat and Power (CHP) in the European Union. This initiative is to ensure the necessary co-operation between the Community, its Member States, utilities and consumers of electricity and heat to assist in dismantling barriers to the development of this environmentally friendly and energy saving concept.

CHP involves the simultaneous production of thermal and electric energy from the same primary fuel source and for a given application. This is achieved through one of a number of different electricity generation technologies in which heat is diverted partway through the electricity production process and used to satisfy thermal requirements. From a thermodynamic perspective, CHP offers efficiency advantages relative to the available alternatives.

The efficiency gains represented by CHP may be significant, but will vary depending upon the technology and fuel source employed and displaced by CHP systems. An efficient CHP plant can convert approximately 85-90% of the energy content of the fuel into useful energy. Although a small part of the heat will be lost before the heat reaches the consumers, the total efficiency will remain in the area of 80% or more. Conventional electric production systems typically convert 30-40%, with new combined-cycle gas turbine systems capable of up to 55%. In the case that heat generation plants will cover the heat demand with an efficiency of 90%, the total efficiency for the separate production of electricity and heat will be up to 70%.

Another opportunity that CHP offers, is the development of decentralised forms of electricity generation providing high efficiency and avoiding transmission losses.
In general terms, the potential benefits of co-generation include:

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### *National benefits*

- Fewer electricity shortages since co-generation by industrial and commercial facilities reduce the demand on the utility and make electricity available for distribution elsewhere.
- Co-generation plants with two or more engines are reliable electricity producers during peak demand periods.
- Primary fuel savings with higher total energy efficiencies in comparison to conventional thermal power plants.
- Enhanced efficiency of electric utility service, since co-generation plants are located near the end-user, and the centralised power plants generally have high transmission losses.
- The investment costs for gas engine driven co-generation systems are very attractive in comparison to conventional power plants. In combination with low electricity production costs, amortisation times of less than 5 years can be attained
- NOx emissions are 25% lower in comparison to electricity produced in coal-fired power plants and heat production in boilers.
- $CO_2$ emissions are 30-60% lower than those from conventional energy supply source.
- No sulphur emissions.
- Co-generation fuelled by biogas, sewage gas, landfill gas, etc. is $CO_2$-neutral and makes use of methane gas (CH4), which otherwise destroys ozone.

### *Propriety benefits*

- Reduced energy cost.
- Improves profit margin and give a competitive edge.
- Offers security against energy price fluctuations.
- More reliable power supply.
- Improved power supply quality.

In summary one can conclude that, when CHP is optimised it is an environmentally friendly energy production method, reducing fuel need and increasing competition in generation. For this reason it could be considered as a vehicle promoting liberalisation in the energy markets.

# 5 Co-generation in Europe

**Austria**
Co-generation is well known in Austria. The country occupies fourth place in its share of the electricity production produced by co-generation, largely because the utilities have been heavily involved in the technology. There are currently proposals to liberalise the electricity market.

**Belgium**
Although co-generation has due to historical reasons developed very little, things are slowly starting to change. Some of the most important should be to overcome future liberalisation of the energy market. Electrabel and SPE, the two main electricity utilities, have shown a growing interest in developing co-generation projects with customers.

**Czech Republic**
Co-generation, mainly in the form of district heating, is well known in the Czech Republic. There is good potential for further development due to the need to replace inefficient and environmentally unfriendly old technology with new technology. The transformation process from a centralised to a market economy is well advanced, but difficult steps remain in the energy sector. Natural gas is expected to become more widely available.

**Denmark**
Denmark is one of the countries where co-generation has developed the most, manly in the form of district heating. These have been very strong government support policy through tax incentives and subsidies. Industrial co-generation has developed much less. However it is in the industry sector where the largest future potential remains. The Danish government has announced its intention to continue to promote co-generation as a tool for environmental protection. While the government follows the EU Electricity Directive, it does not welcome liberalisation on environmental grounds.

**Finland**
As in Denmark and the Netherlands, co-generation supplies a very high share of electricity production. Contrary to the two other countries, this has not been the result of a supportive government policy, but through the natural economic advantages of CHP in a cold climate. Co-generation will continue to develop, although less fast and lifting a number of remaining obstacles would help.

**France**
France has currently the lowest share of production by co-generation in the EU. In spite of this, the share has doubled in a relatively short period from 1% to 2%. Developing further capacity is a difficult task since high nuclear capacity makes

further development of electricity production less necessary and the electricity market is controlled by a monopoly.

**Hungary**
There is already much co-generation in Hungary in the form of district heating. There is a considerable potential for further development due to the future need of new capacity and to modernise existing district heating networks. Under the current arrangements, large CHP plants will have better prospects than small- and medium sized plants. There is discrimination against decentralised production. Steps towards a market economy have been taken quickly, but more difficult steps, such as energy price liberalisation, remain to be achieved.

**Germany**
Co-generation in Germany is relatively well developed, but due a number of remaining barriers, its full potential is still a long way from being realised. Liberalisation will probably lift most of the existing barriers, but it may also lower electricity prices. Decentralised co-generation based on natural gas has the largest future market potential. There is currently a government proposal to liberalise the gas and electricity markets in a single step process.

**Greece**
Co-generation in Greece has developed very little, but there are brighter outlooks for the future. The main barriers, related to the electricity industry structure, will be overcome, and piped natural gas is becoming available. Liberalisation of the electricity market will take place, but more slowly than in the rest of Europe.

**Ireland**
Co-generation is not very developed in Ireland, and it remains one of the countries where it has developed the last. However, the introduction of certain incentives for energy efficiency has led to the construction of a number of new plants. Liberalisation will take place slowly, since Ireland obtained an extension of one year for the Electricity Directive.

**Italy**
Until recently, co-generation enjoyed a favourable environment in Italy, which produced a strong development in relatively few years. The trend has recently been reversed, and new rules now apply to the sector. At the moment, the situation is very uncertain. There are already plans to liberalise and restructure the electricity industry, but they are subject to change.

**Luxembourg**
In a relatively short period of time, co-generation has become a well-known technology in Luxembourg, demonstrating the impact which government measures can have.

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**The Netherlands**
Co-generation has developed very successfully in the Netherlands trough a combination of interlinked and favourable factors such as natural gas availability, favourable government policy and strong environmental concerns. The amount of electricity produced by CHP has grown from 9% of the total generated power in 1980, up to 18% in 1993. Future prospects remain good. The government plans to reach a capacity 8.000 MWe (40% of the total capacity) by the year 2000, and the target appears achievable. There is a proposal to liberalise the electricity market in three steps. The first step was taken in 1998.

**Poland**
As in the other two eastern European countries, there is a lot of co-generation in the form of district heating in Poland. Future prospects are good, since new capacity is needed and some existing plants have to be replaced or upgraded. Coal will remain the main fuel. Some steps have been taken to reform energy prices so that they reflect the real costs of production.

**Portugal**
In spite of the, until recently, lack of natural gas, co-generation is reasonably well developed in Portugal. The arrival of natural gas, and energy market liberalisation, are likely to present good prospects, but at the same time electricity prices have decreased, providing less incentive. The structure of the electricity market is unique in Europe, with the co-existence of a liberalised and a centralise sector.

**Spain**
Co-generation has developed very fast in Spain due the development of a favourable legal framework. However, this legal framework is currently changing, and the energy market is going to be liberalised. However, as the proposals stand at present, this future liberalised framework places co-generation at a competitive disadvantage with the utilities. Another important barrier is the discriminatory price of natural gas. With the removal of uncertainty and barriers, the potential for further development is good.

**Sweden**
Although co-generation is currently not well developed in Sweden, the current situation is very interesting. The government has taken the decision to phase out nuclear capacity – which represents almost half of the electricity production. Alternative forms of energy will need to be found to replace the nuclear production, and strong environmental concerns are likely to work in favour of co-generation. The government has announced continuing support for certain forms of CHP (generated from non-fossil fuels) and for the replacement of electricity in district heating networks. The Swedish electricity market is already liberalised.

**UK**

Co-generation represents a small share in the total production of electricity in the UK, but most of the growth has occurred in the last years and has been very rapid since the process of liberalisation is completed. However, electricity prices will continue to remain low, which will act as a disincentive.

# 6 Design of CHP and factors influencing the viability of co-generation installations

In spite of its benefits, co-generation may not be profitably applied in every commercial and industrial installation. Several factors need to be evaluated before co-generation projects can be started. The factors influencing the feasibility of a co-generation application are:

- Minimum size - to take advantage of economies of scale.
- High initial costs.
- Operating and maintenance costs
- Careful design and optimisation of the balance between power generation and process heat requirements.
- The possibility of selling surplus power to national electric utility.

The design elements to be considered are:

- Heat load profile, requirement temperatures
- Electricity load profile, self generated power, how much is used and exported
- Financial feasibility
- Control strategy
- Electrical connections
- Environmental impact.

# 7 Co-generation system equipment

A co-generation plant generally consists of the following main components:

- Prime mover
- Alternator
- Electric and thermal equipment
- Heat recovery system
- Hydraulic interconnection to the end user
- System controls which ensure efficient and safe operation

The most important component in a co-generation system is the prime mover, which converts fuel energy to shaft energy. The conversion devices most frequently used are reciprocating engines, combustion gas turbines, expansion turbines and boiler-steam turbine combinations. Reciprocating engines, which convert fuel energy to shaft power for electricity or mechanical drives. These include spark-ignition and compression-ignition internal combustion engines. Turbines which convert chemical energy to shaft power for electricity or mechanical drives. These include steam and gas turbine. Nevertheless steam turbines are not used in hotels because of their high cost and complexity.

Different prime movers provide different amounts of electric power relative to the thermal energy rejected and in selecting a suitable configuration system, the thermal-to-electric ratio is used to select the most appropriate prime mover.

Electrical generators (alternators), which convert mechanical shaft power to electric power are available in a wide range of sizes, speeds, and control options. These include induction and synchronous generators.

The criteria influencing the selection of alternative current (AC) generators for co-generation system are:

- Machine efficiency at various loads
- Electrical load requirements
- Phase balance capabilities
- Equipment cost
- Motor starting current requirements

Waste heat recovery systems is the component, which convert part of the rejected heat into useful heat. A variety of waste heat recovery equipment is available, depending on the quality and type of vast heat to be utilised. These equipment can range from exchangers recovering heat from hot cooling water to sophisticated recovery boilers generating steam or absorption chillers generating cooling from gas turbine exhaust.

## 7.1 The prime mover

Various types of engines exist. Below is a short description of some alternatives.

### 7.1.1 Combustion gas turbines

A simple cycle gas turbine includes a compressor that pumps compressed air into a combustion chamber. Fuel in gaseous or liquid-spray form is also injected into this chamber, and combustion takes place there. The combustion products pass from the chamber through the nozzles to the turbine wheel. The spinning wheel in turn

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drives the compressor and the external load, such as an electrical generator. Natural gas is an ideal fuel for these turbines. Light distillate oils also provide satisfactory service. Biomass combustion on fluidised bed can also be utilised. The thermal efficiency of a gas turbine depends mainly on the pressure ratio, the turbine inlet temperature, and the parasitic losses. The efficiency of the simple-cycle gas turbine is limited by the need for continuous operation at high temperature in the combustion chamber and early turbine stages. A small, simple-cycle gas turbine may have a relatively low thermodynamic efficiency, comparable to a conventional gasoline engine.

At present turbine inlet temperatures are limited to 850-950°C, giving overall efficiencies approaching 30%, with some industrial gas turbine operating below 20%, and almost all of its losses are in the aghast flue, which has temperature typically in the range of 400 to 540 °C.

Advances in heat-resistant material, protective coatings, and cooling arrangements have made possible large units with simple-cycle efficiencies of 34 percent or higher. The efficiency of gas-turbine cycles can be enhanced by the use of auxiliary equipment such as intercoolers, regenerators and re-heaters. However, these devices are expensive, and economic considerations usually preclude their use. Nevertheless, the efficiency of larger modern gas turbines continues to increase as new technology allows higher turbine inlet temperatures and pressure ratios. Heavy-duty gas turbines are operating with a firing temperature as high as 1100°C at base load, with pressure ratios of up to 12, and with thermal efficiencies of up to 36 %. Newer units derived from aircraft technology can operate at pressure steam ratio as high as 30:1 and reach efficiencies of as high as 40 percent.

### 7.1.2 CHP with gas turbine prime mover

When the CHP sets have to interface with a large steam system, then a steam turbine or a gas turbine is usually used.

The principal advantages of the gas turbine are its compact size, being an internal combustion engine it need no boiler and condenser, and the fact that the pressures achieved are much lower than those of the steam turbine cycle.

The gas turbine can be specially designed for CHP applications or can be a modified aero-engine or military power unit.

The gas turbine has the following advantages over internal combustion engine drives:

- Small size and low to medium thermal to electric ratio.
- Ability to burn a variety of fuels.
- Clean dry exhaust and hence ability to meet stringent pollution standards.

- High reliability and easy maintenance.
- Immediate power availability, no warm-up period required.
- No cooling water requirement
- Lubrication oil not contaminated by products of combustion.

The recovery in a waste heat recovery boiler of the considerable heat remaining in the gas turbine exhaust, can significantly improve the gas turbine's overall efficiency. The turbine output follows the thermal load. By varying the steam requirement, the pressure in the circuit changes and a pressure control valve varies the fuel rate incoming in combustion chamber.

Recoverable heat is obtained from the turbine manufactures, but can be estimated by: $\mathbf{Q=C_pM(T_1-T_2)}$

Where:

Q = Recoverable Heat (kW/h)
M = Exhaust Mass Flow (Kg/h)
$C_p$ = Specific Heat
$T_1$ = Exhaust Gas Stack Temperature °C
$T_2$ = Exhaust Gas Exit Temperature °C

The potential heat recoverable from turbine exhaust gas is approximately 10 kW/kg/sec per degree C temperature drop in the exhaust gas.

A typical heat balance for gas turbine with standard small and medium sized units is:

| | Small Units | Medium Units |
|---|---|---|
| Electricity | 21% | 29% |
| Exhaust gas (recoverable to 150°C) | 53% | 46% |
| Exhaust gas (not recoverable) | 21% | 20% |
| Losses | 5% | 5% |

Owing to their low electric efficiency, these industrial gas turbines find their match with significant steam loads at medium to high pressure. When a gas turbine is operated at part load, less fuel is consumed, but the turbine's efficiency drops. As a result, a smaller proportion of the input fuel energy is converted to electrical energy, and a greater proportion is exhausted as waste heat. Even if all the waste heat could be used to meet thermal load, the cost of electricity generation goes up.
**The conclusion** is that for high operating efficiencies, the gas turbine must see not only large steam loads but also steady steam loads. As a result, co-generation gas turbines are more applicable to steady process loads. Because operating the gas

turbine at part load in not economical, the system should be sized to meet the maximum demand for steam that can be sustained at a steady level (base steam load).

Owing to that the exhaust gas contain a substantial quantity of unburned oxygen (15%) all installations can be equipped with supplementary firing, which might even be of considerable advantage for the co-generation process because it offers a much greater design and operating flexibility than available with waste heat utilisation alone.

The production of steam or thermal energy can be controlled independently of the electrical power output because the gas turbine assumes control of the power output and the auxiliary firing handless control of the steam or heat generation. Turbines with waste heat boilers can be considered when thermal–to-electric ratios are in the range 1,2:1 to as high as 4.1.

In a combined-cycle power plant the exhaust is used to raise steam for an associated steam turbine. The combined output is about 50% greater than that of the gas turbine alone. Combined cycles with thermal efficiency of 52 percent and higher are being used. Heavy-duty gas turbines in both simple and combined cycles have become important for large-scale generation of electricity. Unity ratings in excess of 200 MW are available. The combined-cycle output can exceed 300 MW.

**The Micro Turbines** are compact power generation systems providing electrical power up to 30kW. In addition to producing electricity, the Micro Turbine produces usable exhaust heat. The oxygen-rich exhaust can be used directly without any "cleaning" thanks to the very low levels of NOx (less than 9 parts per million), and CO.

Typical micro turbines performance are:

| | |
|---|---|
| Efficiency | 26% |
| Heat rate | 35% |
| Exhaust gas temperature | 270°C |
| Velocity | 96.000 RPM |

### 7.1.3 Reciprocating engines

Reciprocating engines are the most common type of prime mover used for the production of shaft power. They are used extensively in industrial and commercial applications to provide shaft power either to operate an alternator for the production of electricity, or to operate rotating equipment such as centrifugal compressors, pumps, and blowers. These engines use all types of gaseous and liquid fuels.

Reciprocating engines have several advantages over the gas turbines when a substantial mechanical output is required. In general their shaft efficiency is greater than that of the turbine, ranging from 30 percent to 40 percent, depending on engine size and configuration, and their cost is less.

Unlike gas turbine, the per unit fuel consumption of a reciprocating engine does not increase at lower loads, making it more desirable for part electric load operation.

On the debit side, the ancillary systems required for reciprocating engine tend to be more complex particularly in view of the water-cooling required, and oil consumption can be considerable.

Reciprocating engines include the following types:

- Spark ignition Otto cycle engines, which can use natural gas, liquefied petroleum gas and other gaseous volatile liquid fuels
- Compression ignition diesel cycle engines, whit can be fuelled by a wide range of petroleum products

Reciprocating engines may be either **naturally aspirated** or **turbo-charged**. Turbo-charges (combustion air compressors driven by an exhaust gas turbine) increase the amount of air delivered to the combustion chamber and hence, allow from a given engine, increasing mechanical efficiency.

Spark ignition Otto cycle engines usually use turbo-charged, intercooled industrial engines. These are commonly derived from standard diesel engine blocks and are normally fitted with spark ignition systems. The main fuel used is natural gas, although diesel, LPG, propane and biogas can also be used. Most engines operate at 1500 rpm, and turbo-charging boost power output by about 40%.

The combustion engines produce heat as a by-product of combustion. As a general rule, 20% to 40% of the energy input into an engine must be removed by the cooling system. The four basic systems used to reject this heat are the aftercooler, oil cooler, fuel cooler, and jacket water circuits. Each of these systems has specific requirements that must be met to provide a well designed cooling system.

The combustion engine heat balance help to understand how much heat is being rejected through each of the cooling circuits:

***Total Heat Input = Work Output + Total Exhaust Heat + Radiation + Jacket Water + Oil Cooler + Aftercooler***

- **Work output** is the total power developed.
- **Total exhaust heat** is the total heat available in the exhaust when it is cooled from the stack temperature down to standard conditions of 25°C.
- **Radiation** is the amount of heat loss from the engine surface into the engine room or surrounding ambient.
- **Jacket water** heat is the total amount of heat picked up by the engine cooling system. The **aftercooler and oil cooler** heat is usually included in this figure unless otherwise specified.
- Radiator cooling is the most common and reliable method used to cool engines. Radiators normally have top tanks for filling, expansion, and deteriorating of engine coolant. A heat exchanger is sometimes preferred to cool the engine when ventilation air is limited, or when excessive static head on the engine must be avoided. The most common type of heat exchanger is the shell and tube type.

***Spark ignition Otto cycle engines***

This gas engine is a very popular prime mover and is available in all sizes from 6 kW to 13,5 MW. However the range of smaller sizes is economically very attractive, especially because of low maintenance costs and simple installation.

In the smaller-sized equipment, no other prime mover is available that can match the gas engine's continuous operation power output costs. Although very reliable diesel engines are available in the smaller range, the cost of fuel is higher, and gas engines remain the preferred base-load machines wherever gas is available.

Heat can be reclaimed from the engine jacked cooling system, lubricating system and the exhaust.

While exact figures vary with engine design and load, the approximate distribution of input gas fuel energy for an engine operating at optimum design rating is as follows:

- Shaft power 33%
- Rejected in cooling water 30%
- Rejected in exhaust 30%
- Convection and radiation loss 7%

The final exit temperature limits the actual heat recovery from the engine, which must be high enough to avoid condensation (generally around 150°C).

While jacked water temperature approach 88°C, a separate circuit aftercooling remove the aftercooler from the jacked water circuit and provides aftercooler cooling from an independent source. The separate circuit provides much cooler water, allowing the air charge temperature to be further reduced, and improve engine performance.

The separate circuit aftercooling is necessary in all turbocharged engines and high temperature jacked water systems used in heat recovery applications. A closed cooling circuit, i.e. heat exchanger or radiator, is preferred to control water quality. Cooling water temperature less than 54°C is required.

***Compression ignition diesel cycle engines***

Besides a spark-ignition gas engine, a gas-diesel (dual fuel) or a diesel engine can be used as drives. However, their main disadvantage is the considerably higher emissions.

They are available as naturally aspirated engines, engines with exhaust gas turbocharger or with exhaust gas turbocharger and charge air cooler.

A wide range of petroleum products can fuel compression ignition diesel cycle engines. Dual fuel diesel engines can also be used. Dual fuel is an engine that runs on the diesel cycle, using a small amount of diesel fuel as the igniter when using natural gas as the main fuel. This result in simultaneous combustion of atomised liquid fuel and gas, and the engine has similar economy and emission characteristics to the pure natural gas engine.

Although very reliable diesel engines are available in the smaller range, the cost is very high and gas engines are the preferred base-load machines wherever gas is available.

Diesel engines provide economical shaft power in sizes from about 560 kW to 37 MW where the engines high specific power output and low noise level ensure soft, quiet operation, low fuel consumption, long service life, and minimum maintenance. The approximate distribution of fuel input energy for a diesel engine operating at optimum design rating is as follows:

- Shaft power 42%
- Rejected in cooling water 24%
- Rejected in exhaust 20% (recoverable)
- Rejected in exhaust 9% (non recoverable)
- Convection and radiation loss 5%

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### 7.1.4 Heat Recovery from reciprocating engines

The heat rejected by the jacked water can be totally recovered, and 50-70% of the exhaust energy is economically recoverable. Jacked heat recovery design best suited for any installation depends on many considerations, technical as well as economical. The main function of any design is to cool the engine. The engine must be cooled even when heat demand is low, but power is still required.

Heat recovery of a standard engine may amount to nothing more than utilising heat transferred from the engine radiator. This air is usually 38-65°C. The recovered heat is quite suitable for space heating. The system cost is minimal and overall efficiency will increase to approximately 60%.

More versatile jacked heat recovery methods are grouped into:

- Standard temperature, up to 99°C outlet temperature.
- High temperature, up to 127°C outlet temperature.
- In both cases the engines are generally designed to operate with a jacked water temperature differential of less than 10°C.

High temperature systems are further divided in to:

- Solid water system
- Water and steam system
- Ebullient steam system

***Exhaust Heat Recovery***
Shell and tubes heat exchangers recover about half the engine exhaust heat.
Recoverable heat can be estimated by: $\mathbf{Q=C_pM(T_1-T_2)}$

Where:
Q = Recoverable Heat (kW/h)
M = Exhaust Mass Flow (Kg/h)
$C_p$ = Specific Heat
Diesel Engines – 0,300 kW/kg per °C
Gas Engines – 0,325 kW/kg per °C
$T_1$ = Exhaust Gas Stack Temperature °C
$T_2$ = Exhaust Gas Exit Temperature °C

Exhaust exit temperature above 150°C discourage condensation in ducting. To avoid too expensive and large heat exchangers, the minimum drop temperature usually utilised between primary and secondary circuits is 25°C.

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### *Jacked Water Standard Temperature Heat Recovery*

A versatile method of recover heat from a standard temperature system uses a heat exchanger to transfer rejected engine heat to a secondary circuit, usually process water. The aftercooler and oil cooler heat rejection is usually included. There are many advantages inherent with this design; the standard engine jacket water pump, thermostatic configuration, and water bypass line are retained. The engine system is independent from the load process loop, which allows operation with antifreeze and coolant conditioner. This alleviates concern for problems associated with using process water to cool the engine. To reduce the temperature drop, plate heat exchangers are generally used.

When normal process load is insufficient to absorb enough heat, load balancing thermostatic valve limits jacked water inlet temperature by directing coolant though a secondary cooling source. The secondary cooling device must be incorporated in the engine loop and may be either a heat exchanger or a radiator.

An exhaust heat recovery device may be included in the system in series, parallel, or as a separate water or steam circuit.

### *Jacket Water High Temperature Heat Recovery*

To ensure proper cooling in all types of high temperature systems, the engine oil cooler and aftercooler require a cooling water circuit separate from the engine jacket water. A thermostat in the oil system bypasses the oil cooler to control lubricating oil minimum temperature and prevents overcooling.

While exact figures vary with engine and load, the approximate heat balance data and natural gas engine operating at optimum design rating is given by:

| | |
|---|---|
| Fuel consumption (natural gas) MJ/BkW-hr* | 10,37 |
| Engine efficiency, % | 34,7 |
| Electrical efficiency, % | 33 |
| Heat rejected to jacket (127°C), % | 22,5 |
| Heat rejected to lube oil, % | 6,4 |
| Heat rejected to aftercooler, % | 3,8 |
| Heat rejected to exhaust (LHV to 25°C), % | 27 |
| Heat rejected to exhaust (120°C), % | 20 |
| Heat rejected to exhaust (150°C) % | 18 |
| Heat rejected to atmosphere, % | 5,7 |
| Exhaust stack Temperature, °C | 430 |
| Exhaust mass, kg/BkW-hr | 5,95 |
| Total efficiency, % | 83,7 |
| Thermal to electric ratio | 1.54/1 |

**= BkW is the engine power in kW.*

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***High Temperature Solid Water Heat Recovery***

This system functions similar to a standard temperature water system except that elevated jacket water temperatures 99°-127°C are used.

A pressure cap or static head must be provided in the engine coolant circuit to assure a pressure of 27,6-34,5 kPa above the pressure at witch steam forms. For 127°C water, the pressure at the engine should be approximately 172 kPa.

A load balancing thermostatic valve is used to direct coolant through a secondary cooling source to limit and control jacket water outlet temperature. In the system the boiler water is pumped through the jacket water heat exchanger, and the exhaust heat recovery device in series where it is heated to the desired temperature. To control the exit temperature, the exhaust recovery device can be bypassed using two pneumatic valves.

***High Temperature Water-Steam Recovery***

The high temperature water-steam system provides solid water to cool the engine, but then flashes it to steam to be used for loads requiring low pressure steam (97 kPa). A circulation pump forces water through the cylinder to block the steam separator. In the steam separator, some of the water flashes to steam and the water return to the engine.

The relief valve pressure of 103 kPa is set by boiler codes qualifying low pressure steam. Pressure in the separator is controlled by the pressure control valve. Once pressure builds to 96,5 kPa, the control valve will allow steam to flow. The actual steam pressure in the load line is a function of load requirements. If the load is not consuming steam, the pressure in the steam line will increase. Then the excess steam valve will open to transfer engine heat to the waste cooling device. Again, owing to the high temperature, separate circuits must remove the aftercooler and the heat rejected to lubricating oil.

***Ebullient Cooling System***

The ebullient system utilises heat of vaporisation to remove heat from the engine. Steam is not collected within the engine, but moves through the water passages along with high temperature water by a change in coolant density as it gains heat. Therefore, no jacket water pump is used.

The water/steam mixture flows to a steam separator located above the engine. A temperature differential between engine-water-in and engine-water out is usually 1,1°-1,7°C. Correct flow require careful design of pipes and lines.

Because the critical design requirements, ebullient systems are losing favour to positive flow systems that incorporate a high temperature pump that forces steam flow through the engine.

### *Lubricating Oil Heat Recovery*

When recovering heat from engine using high temperature cooling systems, it may be worthwhile to utilise heat reject to lubricating oil. This heat can be applied to preheated boiler feed water, domestic hot water, or other low temperature requirements. Heat removed by lubricating oil from engines operating above 100°C is always rejected to a cooling medium other than the jacked water. Heat rejection to the oil is approximately 0,14 kW/kWe for gas engines, 0,21Btu/kWe for diesel engines.

## 7.2 Heat recovery Systems

There are different types of heat recovery systems available. Below is a description of some alternatives.

### *Waste heat boilers*

In a direct fired boiler the primary objective is to produce steam or hot water by using heat produced within the boiler by the combustion of a solid, liquid or gaseous fuel. A waste heat boiler, does not posses its own combustion system, but is supplied with hot gases from reaction taking place elsewhere.

The use of waste heat in exhaust gas streams to generate steam compared to gas-to-gas heat recover gives the following advantages:

- It is one of the most compact types of heat recovery unit.
- Installations are in most instances lower on capital cost than other heat recovery systems of comparable duty
- Waste heat boilers can in general withstand high temperature exhausts without incurring problems of materials selection and life.
- Response rate is high, and adjusting operation pressure on the steam side may conveniently vary the duty.
- Precise control of gas and water flow rates is not demanded.
- In the gas turbine a waste heat boiler as a supplementary firing capability can be provided. This releases the particular process for which the steam is being raised from its dependence on the performance of the gas turbine, and also allows boiler efficiency to be raised.

### *Heat exchangers*

Shell and tubes heat exchangers (S&THE) are used to recover waste heat from such sources as steam condensate, hot water and hot gases.

Inside the exchanger, the waste heat is recovered by the transfer of heat to some liquid at a lower temperature –heat exchangers are single or multiple-pass type. This refers to the flow in the raw water circuit of the exchanger. In the two-pass exchanger, water flows twice through the exchangers.

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Shell and tubes heat exchangers are available in three basic configurations:

- liquid to liquid
- steam to liquid
- gas to liquid

Plate heat exchangers (PHE) are popular in a wide range of industries, in particular the food processing industries. The primary and secondary liquid flows are separated by a thin metallic membrane, which is corrugated to achieve maximum heat transfer by creating turbulence. Each plate is provided with a gasket that effectively seals in the fluid being heated or cooled. A complete installation involves a number of these plates, suspended on a frame, and compressed against a fixed rigid end plate by a moveable plate at the other end of the heat exchanger.

A comparison between heat transfer surfaces, and the drops through plate heat exchangers, and shell and tubes, shows the significant reductions in surface possible and the lower pressure drop obtained with plat units in a liquid to liquid system.

To avoid too expensive and large heat exchangers, the minimum drop temperature usually utilised between primary and secondary circuits is 8°C.

# 8 Fuels

All of the co-generation prime mover technologies discussed above can operate on a variety of fuels. The choice of fuel type will depend on the size of installation, engine speed (in the case of diesel engines), fuel conditioning capability, and availability of fuels.

The customary used primary fuel for co-generation is natural gas. Fuel oil (distillate and residual) and synthesis gas (coal or biomass) will also provide satisfactory service, and can be used on gas turbine engines as an alternative to natural gas.

The type of fuel used in diesel engines depends on engine speed and, to some extent, on engine design. As engine speed increased, higher grades of fuel are required to operate them.

Fuel normally recommended for diesel generator sets is furnace oil or diesel fuel. Crude oil, in some cases, is a practical and economical fuel for diesel engines. Kerosene type fuels may be used as a diesel engine fuel, provided that it meets the acceptable limits.

Gas engines can be configured to accommodate a wide variety of fuels.

The use of **biomass in CHP** can be examined as a factor in increasing the penetration of this environmentally friendly option. Biomass fuels include a wide range of material such as field crops, forest residues, and food and fibres processing wastes. While the characteristics of these materials vary, they all consist of cellulose, water and mineral matter. The moisture and ash contents are the most highly variable parameters, being strongly influenced by storage and handling practices. The key parameters influencing combustion system performance (in addiction to physical factors that effect handling) are higher heating value, proximate and ultimate analyses, and ash characteristics.

The use of biomass to generate power is a cost-effective way to reduce carbon dioxide emissions and the use of non-renewable resources. During combustion, both biomass and traditional fossil fuels release $CO_2$ previously derived from the atmosphere. Fossil fuels derived their $CO_2$ from the atmosphere millions of years ago, and only the recent surge of use has resulted in the current high atmospheric levels of $CO_2$. Biomass recycles $CO_2$, at a more rapid pace, ensuring that the balance of $CO_2$ in the atmosphere is not disturbed. A net reduction of $CO_2$ emissions may be achieved if biomass fuel is substituted for fossil fuels. Additionally, biomass is a cheap, abundant and renewable form of fuel energy. World production is estimated at 146 billion metric tons a year, mostly wild plant growth. Some farm crops and trees can produce up to 20 metric tons per acre of biomass a year. Types of algae and grasses may produce 50 metric tons per year. Dried biomass has a heating value of 11.000-18,500 kJ/kg. with virtually no ash or sulphur produced during combustion.

Biomass conversion may be conducted on two broad pathways: **chemical decomposition** and **biological digestion.**

Biogases from biological digestion, from landfill sites, from the chemical industry and pyrolysis gas of municipal waste or wood have become an interesting financial and environmental option for operators throughout the world.

Combustion is widely used on various scales to convert biomass energy to heat and/or electricity with the help of a steam cycle (stoves, boilers, and power plants). Production of heat, power and (process) steam by means of combustion is applied for a wide variety of fuels, and from very small scale (for domestic heating) up to a scale in the range of 100 MWe. Co-combustion of biomass in (large and efficient) coal fired power plants is an especially attractive option as well because of the high conversion efficiency of these plants. It is a proven technology, although further improvements in performance are still possible.

Net electrical efficiencies for biomass combustion power plants range from 20 to 40%. The higher efficiencies are obtained with systems over 100 MWe or when the biomass is co-combusted in coal-fired power plants.

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The figure below show the cost ratios compared to conventional fuel cost of various bioenergy systems. Performance ranges of the bioenergy systems cause ranges. Fossil fuel prices are kept constant. Calculations are made with 5% discount rate.

| Option | Biofuel production cost (based on 1991 crop prices in EU and USA). | Possible future biofuel production cost (based on world market/ lowest 1991 crop prices) |
|---|---|---|
| Ethanol production from wheat in EU (replaces petrol) | 4.7 - 5.9 | 2.9 - 3.5 |
| Ethanol production from beet in EU (replaces petrol) | 5 - 5.7 | 4.2 - 4.5 |
| RME production in EU (replaces diesel) | 5.5 - 7.8 | .8 - 3.3 |
| Methanol production from wood (replaces petrol) | N.A. | 1.9 - 2.2 |
| Electricity production from wood (replaces grid electricity) | 1.3 - 1.9 | 0.8 - 1.1 |

# 9 The co-generation in hotels

## 9.1 Energy efficiency considerations

Advances in technology are making it possible to use co-generation for small-scale local energy production units across the commercial, industrial and public sectors. This has opened a world of opportunity for using CHP plants in small commercial and even single-home installations.

The hotel industry is equipped with energy intensive equipment and lighting. Air conditioning, heating, ventilation, refrigeration, motors, cooking, laundry, cleaning and office equipment are purchased and used in most hotel operations. Minimising energy expenses without diminishing guest satisfaction is the goal of any hotel manager in creating an energy management system. The importance of saving energy is further underlined by the fact that, after staff, it makes up the largest proportion of hotel running cost.

In its simplest forms co-generation has a proper place in the energy management efforts of the hospitality industry.

Potential benefits of hotel co-generation is discussed below.

## 9.2 Costs savings and Environmental benefits

Increased competitiveness created by cheaper energy prices is one of the driving forces behind the increased use of co-generation in business today.

Co-generation has a very high-energy efficiency. This optimises the use of fossil fuels and reduces the production of $CO_2$. Gas-fired co-generation schemes eliminate $SO_2$ emissions; they allow $NO_x$ to be controlled to meet environmental legislation. These give a genuine reason to promote environmental credentials for a greener image.

## 9.3 Secure supply of energy

A secure supply of electricity and heat are critical for both commercial and safety reasons. The impact of any temporary loss of main electricity can be minimised by using emergency engine-generator sets to supply essential site loads.

But, the emergency engine-generator sets represent a large capital investment and they can be substituted by co-generation plant sized to meet the electrical demands of the essential operating equipment required to protect and keep the property operating. This maintains safety and can avoid disappointed customers and lost business.

## 9.4 System design

Co-generation is a well-established and technically mature technology but it involves a substantial investment and the right decisions must be made when designing a system that meets the hotel specific needs.

Each prospective application of the use of on-site generation with heat recovery must be thoroughly studied and analysed on its own merits. Critical factors such as the availability of fuels and potential environmental impacts will be also considerate in order to screen the options.

Large co-generation plants in hotels are possible and most cost effective when installed in new or refurbished building or while large part of the energy system is at the end of its nominal life and must be replaced. Generally speaking, in the other cases co-generation rests remunerative when covers only a small part of energetic needs of hotel.

There are several configurations for connecting the co-generation system to the existing heating and electrical systems. Most systems are connected in parallel with existing heating systems, although series connection may be selected for new installations, particularly when co-generation supplies a large proportion of the heat load. Electrical connection is normally to the low-voltage system, although units rated at more than 500 kWe and with a high load factor may be linked to the high voltage system and export power back to the grid during periods of low on-site demand. Most co-generation systems use synchronous generators. These, although connected to the public electricity supply, operate independently of the grid and can therefore continue to supply power in the event of grid failure.

In any case co-generation requires centralised energy systems as centralised domestic hot water and steam distribution, fan coils units and air conditioning units with chilled and/or hot water coming from a central system.

The basic co-generation configuration useful in hotels, consists of a topping cycle unit set were electricity is produced first and the thermal energy exhausted is captured for further use.

Off all the types of industrial topping-cycle systems available today, only two have been commercially ready and applicable to the specific requirements of hotels:

- Reciprocating engine driving a compressor or with an electrical generator and a heat recovery system for medium-sized and large hotels.
- Combustion turbine with a generator and a recovery boiler for very large building complexes.

The CHP plant should be sized correctly in order to maximise the hours it runs and hence the savings achieved.

Prime mover equipment options that can match the site's electrical and thermal energy requirements will be selected on the basis of the ratio of thermal-to-electric output, the potential to produce power and heat and the quality of thermal load.

In comparison to gas turbines, CHP with reciprocating engines indicate higher electrical efficiency and considerably lower investment costs. Turbines can be more economically used in applications with a large constant high value heat requirement of over 110°C or in a large multi-Megawatt installations. For each of the options selected, a preliminary technical feasibility study will be done to determine configuration, size of the equipment and fuel requirements of co-generation system.

Generally speaking, in the hotel the thermal output at full load should amount to about 30% to 50% of the maximum yearly heat requirement. Experience has shown than the co-generation modules can cover about 50% to 70% of yearly heat requirement. Boilers supply the rest for peak load periods.

The "Electric Load Duration Curve" can be used in determining how much purchased power can be displaced by a base-load co-generation system, how much supplemental power must be purchased, and how much excess power is available to be sold to the utility.

If the export of electricity is impossible or economically non convenient, then the system must be used in such a manner that there will not be the problem of selling surplus electricity to the local utility and the CHP installation must be designed to meet electrical load.

The essential first step in the design is the clear identification of the heating loads. It could be the entire load supplied by a central boiler plant, or it could be more suitable to have the CHP dedicated to only part of the load. Thus applications could range from meeting the hotel’s total base heating load, through to dedicated uses, such as preheating feed water, heating domestic water, heating special areas remote from central plant as swimming pool area, etc.