GPG388

Good Practice Guide

Combined heat and power for buildings

Selecting, installing and operating CHP in buildings - a guide for building services engineers

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Contents

CHP GROUP CIBSE

chpa Combined Heat & Power Association energy efficiency for a better environment

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Overview

Introduction

Combined Heat and Power (CHP) is the on-site generation of electricity and the utilisation of the heat that is a by-product of the generation process. For a wide range of buildings, CHP can offer an economical method of providing heat and power which is less environmentally harmful than conventional methods. In these buildings, CHP is often the single biggest measure for reducing buildings-related carbon dioxide (CO_2) emissions and running costs. Where applicable, building designers, specifiers and operators should consider the option of CHP as an alternative means of supplying energy.

Where possible, buildings should be linked together through heat networks to form more significant energy demands that benefit from larger CHP e.g. community heating. If this is not possible, then consider supplying individual buildings using CHP. A brief option appraisal should always be carried out when replacing major plant or designing new systems to identify if CHP might be viable. If CHP begins to look like a leading option then a full feasibility study will need to be carried out. For detailed information, see CIBSE Applications Manual 12 (AM12).

The use of CHP has proved cost-effective in a variety of buildings. CHP capacity in buildings has doubled within the last decade and there are now over 1,000 installations providing around 400 MW_e (electrical output). Due to the smaller nature of the installations, only around 10% of total CHP capacity is in buildings and community heating but buildings constitute around 90% of the total number of CHP installations, the remainder being industrial. Small scale CHP is used as the prime source of heating and power in many hospitals, hotels and leisure centres, and examples are also found in universities, residential buildings and defence establishments. Large-scale CHP installations are being used with community heating schemes and on some multi-building sites such as major hospitals, prisons, airports and universities.

Under the Kyoto protocol, the UK government is committed to reducing greenhouse gas emissions to 12.5% below 1990 levels by the year 2010, and has set a more stringent internal target to reduce CO_2 emissions by 20% by 2010. The government has therefore set a target to encourage the installation of 10,000 MW_e of Good Quality CHP by 2010 which could produce around 20% of the Kyoto carbon savings target. The energy saving and environmental benefits of CHP are so clear and important that the government is actively encouraging the use of this technology through a number of key incentives available to schemes certified by the CHP Quality Assurance programme (CHPQA), see overleaf.

Purpose of this guide

This guide contains information on the design, selection, installation and operation of CHP in buildings. The guide will be of interest to building services engineers designing new buildings, refurbishing/upgrading existing buildings or in developing a site energy strategy. It may also be useful to building operators and energy managers intending to specify CHP or those running existing plant.

The guide explains what CHP is, discusses the available technologies and their application in buildings. It then focuses on project appraisal as the feasibility study underpins the future economics of the plant. A series of case studies is shown throughout the guide covering a range of technologies, applications and financing options.

Using CHP in a building can:
- Use fuel more efficiently
- reduce energy costs
- minimise environmental emissions
- improve security of electricity supply.

In the right application, CHP is the single biggest measure for reducing buildings related CO_2 emissions and running costs

Note: Throughout the guide reference is made to CHP schemes and units. For the purposes of the guide, a CHP scheme may consist of one or more CHP units. MW_e means electrical output of the CHP.

Benefits of CHP

Overall energy costs can be reduced

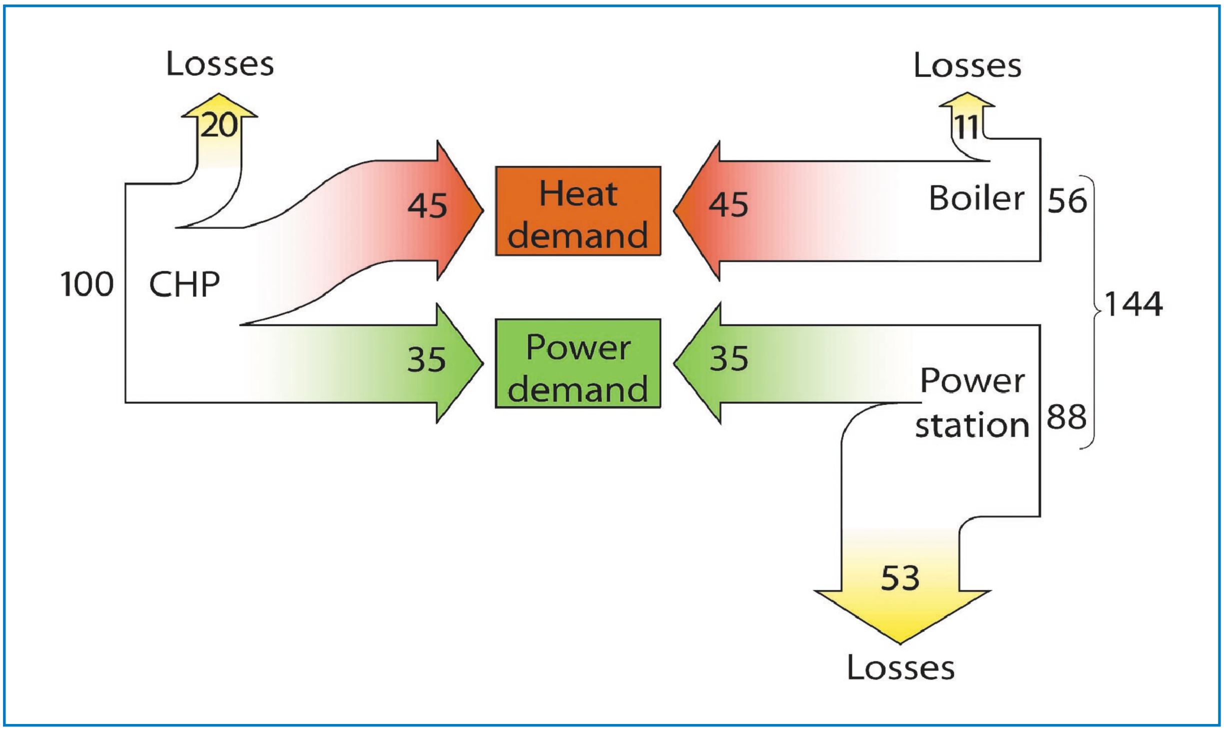
Electricity from traditional sources is a relatively high cost, high emission energy due to distribution losses and the poor efficiency of most power stations. Only around 40% of the energy used in electricity generation is delivered as electricity. Local CHP will generally achieve savings on electricity costs (including any sales to third parties) that should more than offset the increase in fossil fuel (usually gas) requirements and maintenance costs. In certain cases further savings from reduced maximum demand charges can also be made.

Environmental improvements

Each kWh of electricity supplied from the average fossil fuel power station results in the emission of over half a kg of CO_2 into the atmosphere. Typically, gas-fired boilers emit around one quarter of a kg of CO_2 per unit of heat generated. CHP has a lower carbon intensity of heat and power production than these separate sources and this can result in more than a 30% reduction in emissions of CO_2, thus helping to reduce the risk of global warming. It will also reduce the emission of SO_2, the major contributor to acid rain, and help to conserve the world's finite energy resources. The primary energy benifits can be clearly seen in the figure below.

Increased security of power supply

The CHP plant can be configured to continue to supply power should the grid fail. Conversely, the local electricity network can provide power when the CHP plant is out of operation.



Energy flow diagram - CHP vs. conventional

Benefits available to Good Quality CHP

The CHP Quality Assurance (CHPQA) programme specifies the threshold criteria for Good Quality CHP. CHP schemes that are certified under the programme qualify for a range of benefits:

Climate Change Levy exemption – the CCL, introduced in 2001, levies an additional cost on top of previous energy prices and affects almost all non domestic buildings. The CCL can often amount to around 10-15% of typical running costs. Fuel input to Good Quality CHP qualifies for exemption from CCL, which can often reduce payback periods by 1-2 years. Additionally, there is no levy on heat output and power output from GQCHP also qualifies for exemption from CCL.

Enhanced Capital Allowances (ECAs) - provide a tax incentive to encourage the purchase of energy efficient technologies as defined on the energy efficiency technology list (www.eca.gov.uk). This covers a wide range of technologies including Good Quality CHP. The ECA permits businesses to offset 100% of the capital cost of these technologies against tax in the first year, instead of having to spread the tax write-off over, say, 10 years. This can save around 7-8% of the capital cost over the plant life time.

Exception from Business Rating – where business rates apply, Good Quality CHP can bring reductions in the amount paid.

CHPQA certification can also be used as a way of demonstrating regulatory compliance:

The Building Regulations - Part L (2002) in England and Wales now sets minimum efficiencies (based on maximum carbon intensities) for heating systems at full load and 30% load, based on the overall output of the system. Where CHP is included, then special adjustments can be made to take into account the benefit of the on-site electricity generation in reducing emissions from power stations. Certification through CHPQA is a way of demonstrating that the heat and power efficiencies of the CHP have been estimated in a satisfactory way for the purposes of compliance.

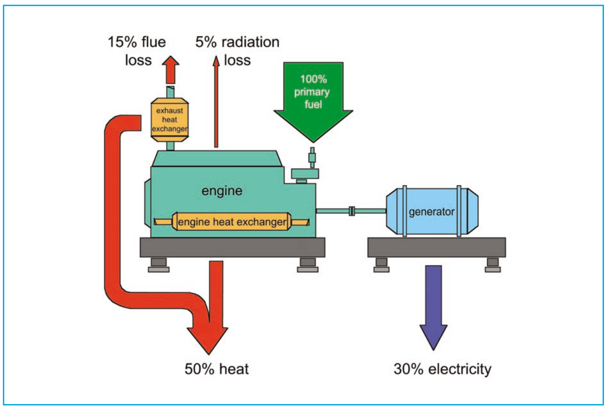
What is CHP?

Combined heat and power is the generation of thermal and electrical energy in a single process. In this way, optimum use can be made of the energy available from the fuel. CHP installations can convert up to 90% of the energy in the fuel into electrical power and useful heat. This compares very favourably with conventional power generation which has a delivered energy efficiency of around 30-45%.

CHP installations can run on natural gas, bio-gas or diesel (gas oil). Reliability of CHP is generally good with availability factors of over 90% being common. The energy balance of a typical CHP plant is shown below.

The range of CHP available for buildings is:

- Micro CHP (up to 5 kW_e)
- Small scale (below 2 MW_e)
  - Spark Ignition engines
  - Micro-turbines (30-100 kW_e)
  - Small scale gas turbines (typically 500kW_e)
- Large scale (above 2 MW_e)
  - Large reciprocating engines
  - Large gas Turbines



Energy balance for a typical gas engine

The high efficiencies achieved are much greater than conventional power stations, reducing the amount of primary energy required to satisfy a given heat and electrical load. Site energy cost can be reduced significantly using CHP. The delivered energy consumed on a site will increase due to CHP but overall primary energy consumption and CO_2 emissions will decrease.

As a rule of thumb, CHP plant must operate for about 5,000 hours per year or about 14–16 hours per day to be economic, although this depends on the application. Usually, shorter paybacks, e.g. around 5 years, can only be achieved where there is a significant year round demand for heating and hot water, e.g. in hospitals, hotels or swimming pools.

Micro CHP - there are a small number of examples of micro CHP serving small groups of dwellings and small commercial applications, typically providing around 5 kW_e output and 10-15 kW heat. Smaller units of around 1 kW_e based on Stirling engines are planned for the market.

Small scale CHP - is most commonly retrofitted to existing building installations although CHP can prove to be even more beneficial in new buildings. Small-scale plant has electrical outputs of up to about 2 MW_e, and usually comes as packaged plant, often based on gas-fired reciprocating engines, with all components assembled ready for connection to a building's central heating and electrical distribution systems. Small gas turbines and micro-turbines are also available within this size band.

Example of a small scale gas engine installation

Large scale CHP – generally above about 2 MW_e, is designed specifically for each application. Larger multi-building installations (e.g. hospitals, universities) and community heating use either gas turbines or large reciprocating engines, fuelled by gas or oil. Gas turbines are favoured when high grade heat is required for steam raising. However, large gas turbines are more complex to maintain, have lower electrical efficiencies (up to the size range covered by this guide) and have a poorer efficiency at part load than engine based CHP. Community heating with CHP is a particularly efficient means of supplying large portfolios of domestic and/or commercial properties; see GPG234 (Guide to Community Heating and CHP) for details.

Overall, savings are achieved because the value of the electricity and heat produced by CHP is greater than the cost of operating i.e. the fuel consumed and the plant maintenance. In particular, the value of a unit of electricity can be up to five times that of a unit of heat. In order to maximise savings from the initial capital investment, running hours (and equivalent full load running hours) should be as long as possible.

When to consider using CHP

The best time to consider CHP in existing buildings is when the heating plant is being replaced, as the CHP can be more easily integrated with the new heating system. To achieve the greatest potential from CHP, it should always be considered at an early stage when:

- Designing a new building
- Installing new boiler plant
- Replacing/refurbishing existing plant
- Reviewing electricity supply
- Reviewing standby electrical generation capacity or plant
- Considering energy efficiency in general.

CHP should be considered right at the start of a project, when a full option appraisal should be carried out.

CHP - Key facts

- It is on-site electricity generation with heat recovery
- Typically around 70% efficient
- Best sites have a year round heat demand
- In general, CHP is economic if it runs for more than 5,000 hours/year
- An independent feasibility study is essential, based on reliable demand profiles
- CHP should always be the lead 'boiler'
- Economics improve if used as standby generation
- Sizing somewhat above the base heat load usually provides the best economics
- Oversizing CHP can lead to excessive heat dumping which destroys the economics.

Example of a gas turbine installation with waste heat boiler

CHP Technologies

Reciprocating Engines

Most small-scale CHP installations are based on packaged units, with a spark ignition gas reciprocating engine as prime mover. The engine is used to drive an electrical generator, usually synchronous, with heat being recovered from the exhaust and cooling systems. They are often used in modular arrangements alongside boiler plant.

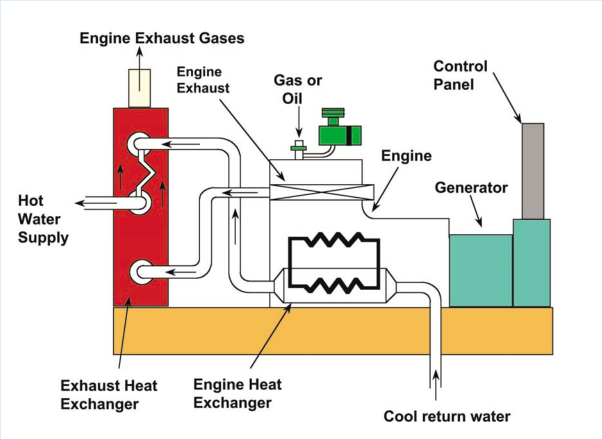
Packaged reciprocating engine CHP units are typically in the range of 50 kW_e to 800 kW_e output. They are run on gas and have a heat to power ratio of typically around 1.5:1. Larger custom built engines are available for bigger schemes and these typically have higher electrical efficiencies, e.g. 35%+ based on Gross Calorific Value, with heat to power ratios around 1:1. Many units can modulate down to 50% of full load electrical output and their part load efficiency is generally good.

The heat from the jacket cooling water can be recovered to provide low temperature hot water (LTHW) at up to 95°C or sometimes Medium Temperature Hot Water (MTHW) from larger, specially modified engines. Heat can be recovered from the exhaust, as well as the engine cooling systems. The exhaust system typically provides gases at around 600°C. The heat in these gases can be used to provide LTHW or to raise steam using the exhaust gas heat exchanger.

Around 50% of the energy content of the fuel can be recovered by these heat recovery systems. A further 10% can be recovered as low grade heat from the exhaust gases on gas-fired plant by using a condensing heat exchanger. Overall efficiencies can be up to 90% when condensing.

Synchronous generators are nearly always used for modern CHP units because they can act as standby generators, do not require power factor correction and can modulate output power over a wide range.

CHP engine



Example of a small scale gas engine

Case Study - Large scale engine

In February 1995 a 1,030 kW_e reciprocating engine CHP scheme was commissioned at York University. This provides 60% of the campus electrical demands and 20% of the annual heat requirement, including all heating and hot water needs from June to October. Heat is provided at up to 127˚C from the reciprocating engine. Installation was straightforward and initial operating experience showed over 97% availability at an average load factor of 85%. The initial capital cost of £520,000 was paid back in around 3.5 years with subsequent years' savings going directly towards running the university. The CHP unit saves around 14% of the overall annual energy bill.

York University

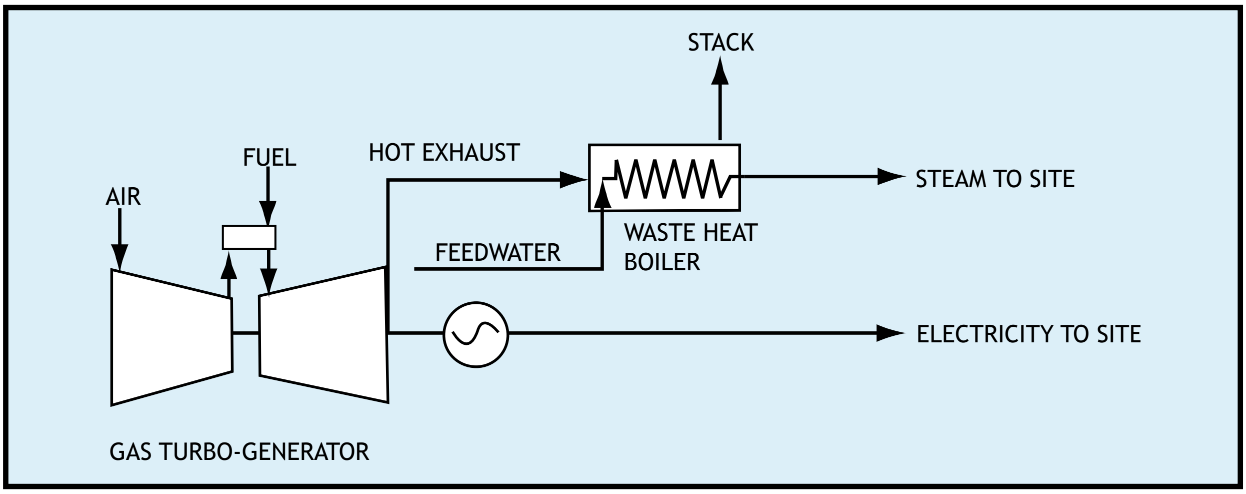
- Various campus buildings
- 1030 kW_e engine
- Installed in 1995
- Finance option: Capital purchase
- Cost savings £150,000 per year
- Simple payback - 4 years.

Gas turbines

The gas turbine has been widely used as a prime mover for large-scale CHP. They are generally industrial scale plant, typically above 1 MW_e, running on gas or light oil with a higher temperature heat output than most engines. Although part load efficiency is not as high as engine based systems they have been used in large multi-building sites e.g. hospitals and universities. For more information refer to GIR083 - The Managers Guide to Custom Built CHP.

Gas turbines utilise pressurised combustion gases from fuel burned in one or more combustion chambers to turn a series of bladed fan wheels. This rotates the shaft on which they are mounted, driving the generator. The same or a separate power turbine is used to drive a compressor delivering air at high pressure to the combustion chamber to burn the fuel.

Combustion gases are delivered to the power turbine at a temperature between 900°C to 1200°C and exhausted from it at 450°C to 550°C. This exhaust is the source of heat energy for the site and makes the gas turbine particularly suited to high grade heat supply. The usable heat to power ratio ranges from 1.5:1 to 3:1 depending upon the characteristics of the particular gas turbine. The gas turbine ingests more air than its fuel combustion needs (excess air). Therefore, the exhaust gases contain large amounts of oxygen surplus to fuel combustion needs which can burn extra fuel. Such supplementary firing can raise the overall heat to power ratio to around 5:1. This offers valuable flexibility to serve variable heat loads.



Advantages

- Potential operational flexibility in heat to power ratio
- High reliability permitting long-term unattended operation
- High grade heat provided
- Constant high speed enabling close frequency control of electrical output
- High power to weight ratio
- No cooling water required.

Disadvantages

- Limited number of unit sizes within the output range
- Lower electrical efficiency than reciprocating engines
- If gas fired, requires high pressure supply or in-house boosters
- High noise levels
- Poor efficiency at low loadings.

Case Study - Gas turbines

Queens Medical Centre is a 1,400 bed acute/teaching hospital in Nottingham. A 4.9 MW_e gas tubine was installed in 1998 under a contract energy management agreement. The CHP unit drives a 12 tonne per hour waste heat boiler to provide steam heating and cooling. Powergen Plc are responsible for the operation of the CHP and boiler house in partnership with the Trust whose staff provide the first line management and operations.

Queens Medical Centre, Nottingham

- University Hospital NHS Trust
- 1,400 beds
- Large acute/teaching hospital
- 4.9 MW_e gas turbine
- Installed 1998
- Energy service contract (Powergen Plc)
- Cost saving £350,000 per year.

Micro turbines

Gas turbines are now available in much smaller sizes than previously. They have been commonly available down to 500 kW_e for a number of years but the recent introduction of even smaller packaged micro-turbine technology as small as 30 kW_e presents a whole new option to the designer. These units have comparable capital costs to those of reciprocating engine CHP with claimed lower maintenance costs as there are less moving parts. However, micro turbines have slightly lower electrical efficiency than reciprocating engines (around 25%) even when using a recuperator to pre-heat inlet air. Without a recuperator power efficiencies are generally too low to meet the threshold power efficiency criterion for Good Quality CHP. Overall efficiencies are comparable to reciprocating engines. Integrated packages are also available with micro-turbines and absorption cooling combined to provide heating, cooling and power.

Case study - micro turbines

Southbury Leisure Centre is a new building in the London Borough of Enfield. It includes a 25 metre swimming pool, sports hall, fitness studio, gymnasium 2 full size synthetic pitches, a café and children's play area. A micro turbine CHP unit using natural gas provides 80 kW_e of electrical and 150 kW thermal energy. All of the electricity is used on the Southbury site, and the heat provides space heating in the complex and heat for the swimming pool, supplemented by a conventional boiler at peak times. Installing a micro turbine at Southbury Leisure Centre shows that Enfield Council is among the front-runners of environmentally conscious local authorities helping the UK meet its emission reduction targets.

Southbury Leisure Centre, Enfield

- London Borough of Enfield
- Leisure centre
- 80 kW_e micro turbine
- Installed 2002
- Cost savings - £12,000 per year (projected)
- Simple payback - 6 years (projected).

Fuel Cells

A fuel cell is an electrochemical device that combines hydrogen fuel and oxygen from the air to produce electricity, heat and water. Fuel cells operate without combustion, so they are virtually pollution free where hydrogen is provided by non fossil fuel sources. However, most current examples run on natural gas which is then converted (reformed) into hydrogen, resulting in some carbon emissions. Since the hydrogen is converted directly to electricity, a fuel cell can operate at much higher electrical efficiencies than internal combustion engines, extracting more electricity from the same amount of fuel. This higher electrical efficiency, coupled with the recovery of heat, means reduced energy use and less emission of CO_2.

The fuel cell itself has no moving parts - making it a quiet and reliable source of power. For building applications, fuel cell systems offer the potential for modularity, good part load efficiency across a wide range of loads and minimal environmental impact. More than 200 stationary fuel cell systems have been installed all over the world (many in CHP mode): in hospitals, nursing homes, hotels, office buildings, schools, etc. Although capital costs are still very high, fuel cells are likely to offer options for building integrated CHP in the future.

Case study - Fuel Cells

The first fuel cell CHP system supplying a building in the UK was installed in Woking Park in 2001. This provides heating, cooling and electricity to three swimming pools and a leisure centre 0.5km apart over a HV private wire, district heating and cooling system. The installation comprises a 200 kW_e CHP natural gas fuel cell, together with a new 836 kW_e reciprocating CHP engine and an existing 150 kW_e CHP unit, a 10kW_p photovoltaic system, a 540 kW_{cool} heat fired absorption chiller and a 100m^3 thermal store making a total distributed generation capacity of 1.2MW. Due to the thermal energy needs of the complex, the overall heating/cooling/power system generates surplus electricity, which is exported to sheltered housing residents over public wires under an enabling agreement for exempt supplier operation. The fuel cell CHP supplies heat to the HWS system and the district heating system plus chilled water to cooling and air conditioning systems via the absorption chiller.

This demonstration project is being monitored by the DTI to provide feedback as to how such technologies can be successfully implemented in the future. The fuel cell also generates approximately 1,000,000 litres of 100% pure water a year and this will be evaluated for a number of economic and environmental uses.

Woking Park - Leisure Lagoon/Pool in the Park and Woking Leisure Centre

- Woking Borough Council
- Building Sizes 4,625m^2 + 8,200m^2
- Swimming pool and leisure complex
- 200 kW_e fuel cell
- Installed December 2001
- ESCO contract (Thameswey Energy Ltd)
- Cost savings £77,820 per year
- CO_2 reductions 1,687 tonnes per year.

Fuel cell

CHP Applications

Common applications in buildings that have historically proved suitable for CHP are discussed below.

Universities and colleges

CHP can be suited to higher education buildings because the accommodation areas have high demand for domestic hot water providing an 18-24 hour demand. This demand can be supplemented by office/teaching buildings that need heat throughout the day whilst the accommodation buildings need heat during early mornings and evenings. Where there is a centralised heating system supplying a number of buildings then large reciprocating engines and gas turbines are the most likely prime movers. Where the site is decentralised then smaller scale engines or micro turbines are more likely.

Hotels

CHP is generally suited to hotels due to the 24 hour nature of the buildings and a strong need to maintain customer comfort. There is normally a high demand for domestic hot water in bedrooms, kitchens and for cleaning, all of which provides a useful base demand for heat. Hotels often include leisure facilities such as fitness centres with showers or full swimming pool facilities that add significantly to the base load heat requirements. Small scale reciprocating engines or micro turbines are the most likely prime movers, even in quite large hotels.

Case study - Small scale reciprocating engines

Two 300kW$_e$ reciprocating engines have been providing heat and power to a range of residential and faculty buildings at Coventry University since 1994. One CHP unit supplies residential buildings with seven day use and associated kitchens. The second supplies the original six buildings of Lanchester College of Technology, Students Union and laboratories. These units were funded under a supplier financed Discounted Electricity Purchase (DEP) scheme which includes a maintenance contract. Savings from each unit were £20,000 in the first year. The standby power capability from one unit avoided the cost of replacing ageing standby generators.

Coventry University

- Residential and faculty buildings
- 2 x 300 kW$_e$ reciprocating engines
- Installed 1994
- Capital cost - supplier financed
- Cost savings £20,000 per year under funded scheme.

Hospitals

Many health sector buildings have a need for high ambient temperatures for the benefit of patients and have high demand for domestic hot water from washing, cleaning and catering. With 24 hour operation, hospitals and residential care homes are therefore ideally suited to CHP. Where there is a centralised heating system supplying a number of buildings then large reciprocating engines and gas turbines are used as the prime movers. Where the site is decentralised then smaller scale engines or micro turbines are more likely to supply individual buildings.

MOD, Prisons and DSS Buildings

Most buildings with significant accommodation can provide opportunities for CHP. Public sector buildings such as MOD barracks, prisons and detention centres are 24 hour operation and have high demands for domestic hot water. Washing, bathing, cleaning and catering all provide significant demands for large parts of the day providing the base loads necessary to make CHP economic. Where there is a centralised heating system supplying a number of buildings then large reciprocating engines and gas turbines are the most likely prime movers. Where the site is decentralised then smaller scale engines or micro turbines are more likely.

Case study - absorption cooling and CHP

Freeman Hospital is a 806 bed acute services hospital in Newcastle upon Tyne. Two Jenbacher high-speed engine CHP units were installed in 1997 providing 2.7 MW_e. The high grade heat produced is used to run MPHW systems and absorption chillers while low grade heat is used to heat accommodation blocks. The project also included new dual fired boilers, 11kV switchgear and a boiler house extension. The plant is operated and maintained under a contract energy management agreement with Dalkia.

Freeman Hospital

- Freeman Group of Hospitals NHS Trust
- 806 beds
- Acute services hospital
- 2 x 1.35 MW_e spark ignition engines
- Installed in 1997
- Funded by Energy Services (Dalkia)
- Cost Saving £270,000 per year
- Power Efficiency 36%
- Heat Efficiency 39%.

Leisure centres

Leisure centres with swimming pools have a steady base load requirement for heat for 18-24 hours/day making them ideal applications for CHP. Showering and catering requirements also add to the base load. Dry sports centres (without a pool) are less suited but may still provide opportunities for CHP. Small scale reciprocating engines or micro turbines are the most likely prime movers, even in swimming pools where there is relatively high demand for heat.

Residential

Residential buildings often have a need for high ambient temperatures and have high demand for domestic hot water. Where dwellings are linked to a central LTHW system then a substantial base load heat demand can be provided. Residential community heating brings together many small intermittent loads to form a substantial base load demand for heat that is ideal for CHP. Sheltered housing, housing association properties and local authority housing can be linked in community heating schemes supplied by CHP. However, many community heating schemes supply public and commercial buildings ranging from hotels and offices to hospitals and leisure centres. The combination of residential and commercial properties provides a 24 hour demand pattern that is ideal for CHP. Large reciprocating engines and gas turbines are the most likely prime movers used.

Case study - community heating

Southampton City Council, in conjunction with energy services developers, has several different CHP schemes. One of these is based on a geothermal Community Heating scheme launched in 1987 to which a 5.7 MW CHP engine was added in 1998. The scheme is delivering heat, electricity and chilled water to over 40 major consumers in the city. They include the Civic Centre, four hotels, the Royal South Hampshire Hospital, Southampton Institute of Higher Education, an Asda supermarket, landmark West Quay Shopping Centre and 270 private dwellings. As the primary energy source for recreation complexes and a shopping centre it saves over 10,000 tonnes of $C0_2$ emissions per year. The Southampton scheme also incorporates absorption heat pump technology - in the summer it supplies the community chilling system.

Southampton City Council

- Various large public and commercial buildings
- 5.7 MW_e engine
- Installed 1998
- Finance option: Capital purchase through loans
- Cost savings £250,000 per year
- CO_2 reductions 11,000 tonnes per year.

Other applications with potential for CHP

CHP plant is less commonly applied in the applications shown below but these can be contenders for further consideration.

Less common applications for CHP schemes (based on: CIBSE AM12)

Application	Reason
Offices/town halls	Where normal occupancy extends into the evening. May be combined with absorption chilling.
Museums	Need to maintain stable temperature/humidity conditions, independently of opening hours.
Schools	Where there is extended occupancy e.g. • boarding schools • schools with swimming pools.
Retail stores/shopping centres	Extended operating hours. Potential benefit from an associated absorption chilling plant.
IT buildings/call centres	Large electrical and cooling loads. Potential benefit from an associated absorption chilling plant.

If the heat/power profile of a building does not immediately seem appropriate, further analysis may identify alternative conditions that would improve the viability. Examples include:

- Using heat-driven absorption chilling plant to extend the base load heat demand into the summer months. Absorption chillers use far less electricity than the conventional equivalents and avoid the use of greenhouse or ozone depleting gases.
- Energy linking with other nearby buildings that have a complementary heat/power profile. For example, university systems linking teaching blocks and halls of residence.

Project Appraisal

Feasibility Studies

Building designers, specifiers and operators should consider CHP as an alternative means of supplying energy in suitable applications. A brief option appraisal should be carried out when replacing major plant or designing new systems to identify if CHP might be viable, see appendix. If CHP begins to look like a leading option then a full CHP feasibility study should be carried out. Expert advice may be required at this stage in order to determine the detailed feasibility of CHP. For more detailed information, see CIBSE AM12. Before any CHP assessment is done, all 'good housekeeping' energy efficiency measures must be carried out. The site heat and electricity demand must be properly assessed to prevent any CHP from being incorrectly sized.

Practical issues

A key part of any appraisal is to identify and solve the likely practical issues that need to be addressed when installing CHP. Fuel supply is the most important to consider at an early stage. If a gas supply is not available, or too small, then the additional cost of connection may make the project uneconomic. Similarly, for the electrical connection, early discussions with the distribution network operator should take place, as there may be local network issues which may make the cost of connection high.

The CHP plant will require plant room space with good ventilation. Noise and vibration do need to be considered and may necessitate siting the plant away from the main building to avoid disturbance e.g. in hotels. Equally, the exhaust needs careful siting to avoid noise and to meet any emissions regulations. Connecting the CHP to the heating system and installing appropriate controls to ensure it is always the lead boiler is probably the single greatest pitfall most sites have experienced. This requires careful design of the hydraulics and integration with the existing boiler/heating control systems.

Practical issues to consider:

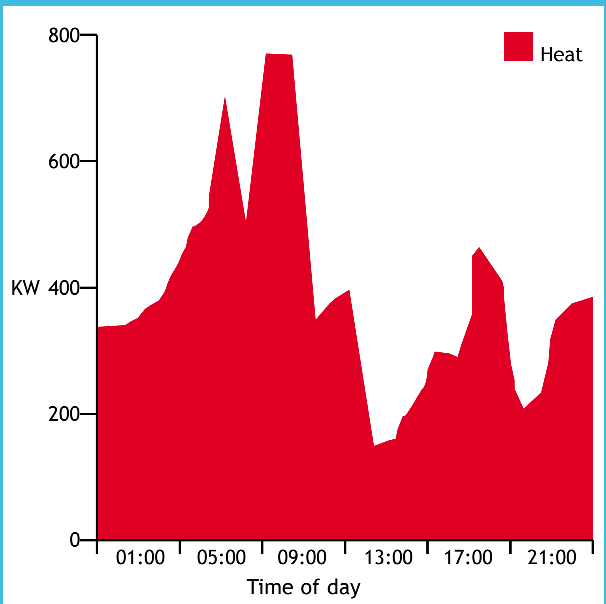
- Fuel (natural gas) infrastructure connection
- Plant space allocation
- Possible noise attenuation problems
- Possible vibration problems
- Plant room ventilation
- Exhaust location and emissions
- Electrical connections and controls
- Heating connections and controls.

Heat and power demand profiles

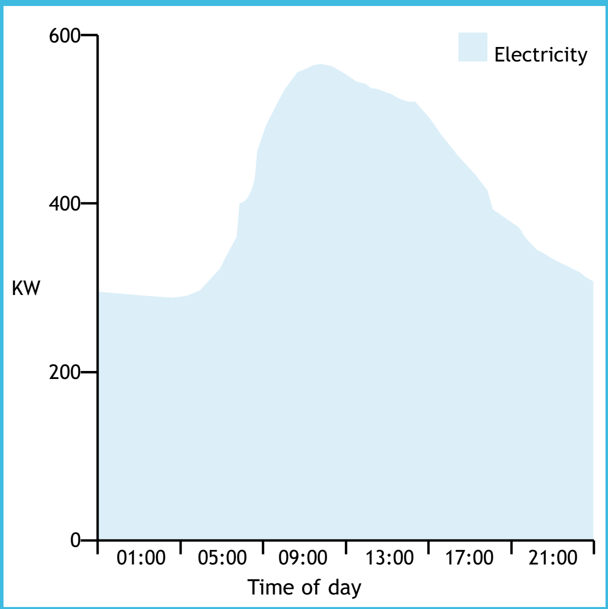
Economic viability is heavily dependent on the demand for heat and power, as well as the price of electricity and gas. Detailed energy demand profiles for both heat and electricity are fundamental to accurately sizing CHP and hence its ultimate viability. There are software packages available for initial feasibility and sizing of CHP schemes in buildings, and these can be useful aids in this process.

Any feasibility study must be firmly based on energy demand profiles and these best come from detailed data gathering. In existing buildings, energy data can come from a range of sources. Heat demand can come from metered fuel use from main and sub meters or there may be existing heat meters. Building Energy Management Systems (BEMS) also provides opportunities for measuring or helping to estimate heat demand profiles. In new build situations building simulation software can provide a valuable tool in establishing likely heat demand profiles. Electricity demands are usually easier to determine through monitoring main utility meters and sub meters using BEMS or temporary data logging equipment. Indeed, half hourly electricity demand data can be obtained from the building's electricity supplier. Example heat and power demand profiles from a hospital are shown below.

August – heat demand profile



August – Power demand profile



Plant sizing

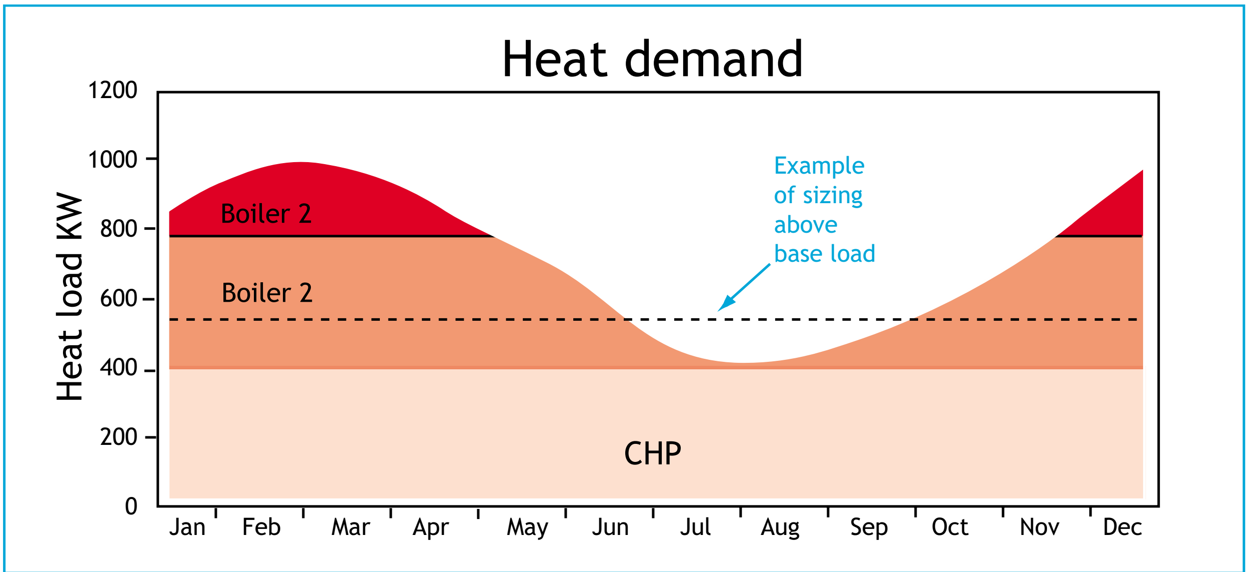
The capital investment in CHP plant may be substantial, so it is important to run plant to achieve maximum returns. Idle plant accrues no benefits, so it is important that the CHP plant operates for as many hours as possible. Basically, this means matching CHP capacity to base heat and power loads. CHP in buildings is usually sized on heat demand as shown below, as this is generally the limiting factor, although the most cost-effective solution often involves some modulating capability and/or heat dumping (e.g. dotted line in diagram) and/or heat storage. The increased savings during Winter outweigh the reduced revenue in Summer.

Any feasibility study should optimise the plant size by assessing the economics of a range of CHP sizes. Overall performance does fall when modulating or dumping heat whereas maintenance costs remain similar. A careful balance must therefore be achieved between the drop in performance and the increased savings. Boilers are invariably used to meet winter peak loads.

When sizing the CHP unit, it is important that all other no-cost and low-cost energy efficiency measures have been taken into account. This will help to avoid installing incorrectly sized plant. Measures that are implemented to reduce running costs may also lead to capital savings if the size of CHP scheme required can be reduced. Future changes in energy requirements should also be considered, especially the possibility of reductions in heat and/or power demands.

As a rule of thumb, applications which have a simultaneous demand for heat and power for more than 5,000 hours per year will be worth investigating in detail.

In practice, CHP must be sized using daily demand profiles/data like those shown on page 19 in order to accurately determine the actual amounts of heat and power that can be supplied to the building. Load duration curves can also be used to determine the number of hours for which a particular demand exists, although they have limited use as they do not recognise the varying value of electricity produced to satisfy a given heat demand at particular times. The control strategy is a key factor in achieving good viability. Where possible, thermal storage should be used to smooth the demand profiles and this can also have a significant effect on the overall economics of the CHP system.



Case Study - Small scale engines

Northampton General Hospital were so encouraged by their early success with CHP that they carried out a phased installation of CHP comprising two reciprocating engines totaling 680 kW_e followed by an 85 kW_e micro-turbine unit to supply a swimming pool, doctors accommodation and general recreation areas. The heat distribution system was gradually extended to give a better heat sink. With an availability greater than 90%, savings have been higher than expected. The building manager says "I would encourage people to go for CHP and use CEM/Discount Electricity Purchase financing options if they are not entirely sure."

Northampton General Hospital

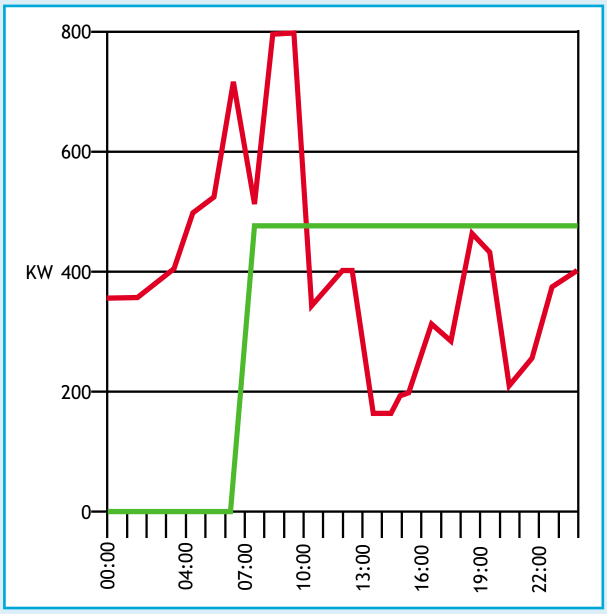
- Northampton General Hospital NHS Trust
- 740 beds
- Acute services hospital
- 220+450 kW_e reciprocating engines
- 85 kW_e micro-turbine
- Installed in 1995, 1997, 2001
- Finance: Capital purchase schemes
- Cost savings – £70,000/yr
- Simple payback – 4 years (reciprocating engines)
- Simple payback – 6 Years (projected for micro-turbine).

Example of sizing

Electrically led with heat rejection available

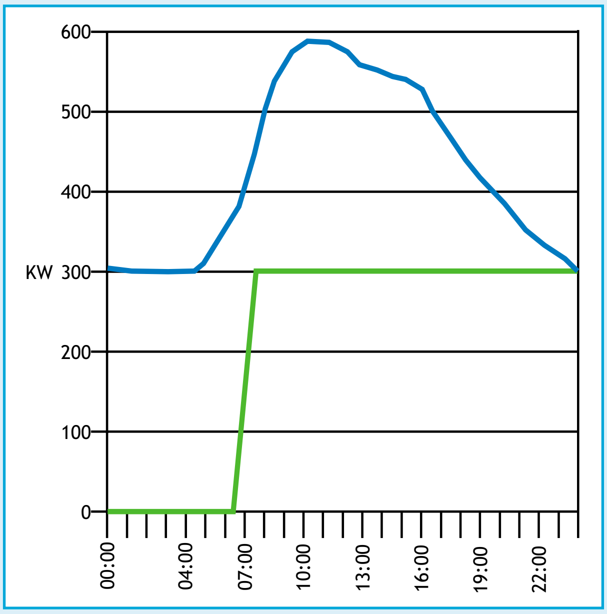
August – Heat demand profile

CHP Building



August – Power demand profile

CHP Building

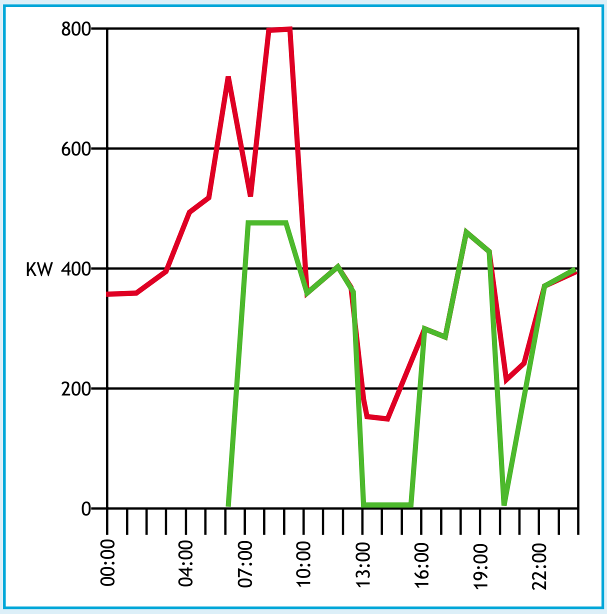


The machine will modulate or heat will be rejected during the afternoon because there is not enough heat demand.

Heat led without heat rejection available

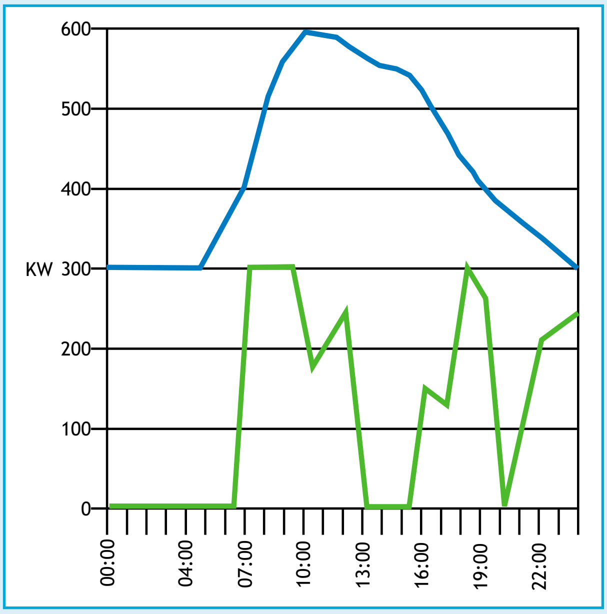
August – Heat demand profile

CHP Building



August – Power demand profile

CHP Building



The machine switches off during mid afternoon because there is not enough heat demand.

Capital costs

Whilst the capital and installation costs of CHP are significantly higher than for conventional boiler plant, CHP can yield very considerable savings in running costs. In the right applications, it can provide economic returns on the investment. Typical installed capital costs per electrical unit output for small-scale packaged plant are shown below. This indicates that installed capital costs are more expensive per kW for smaller plant.

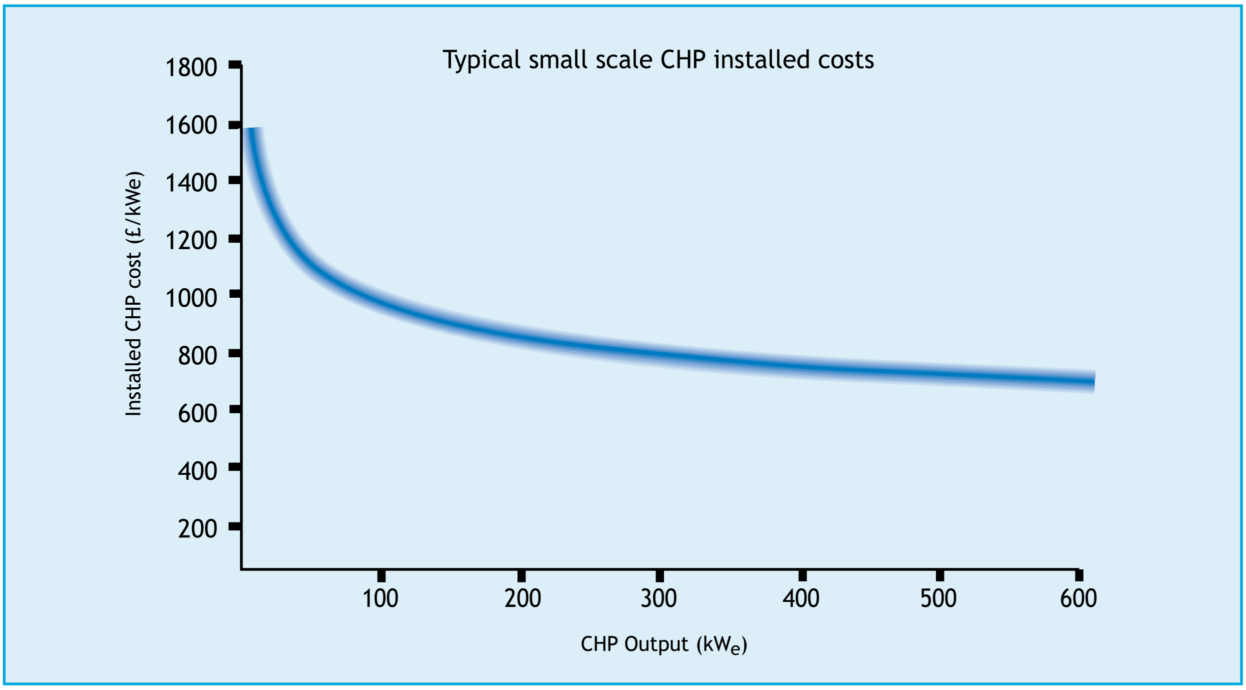
Running costs

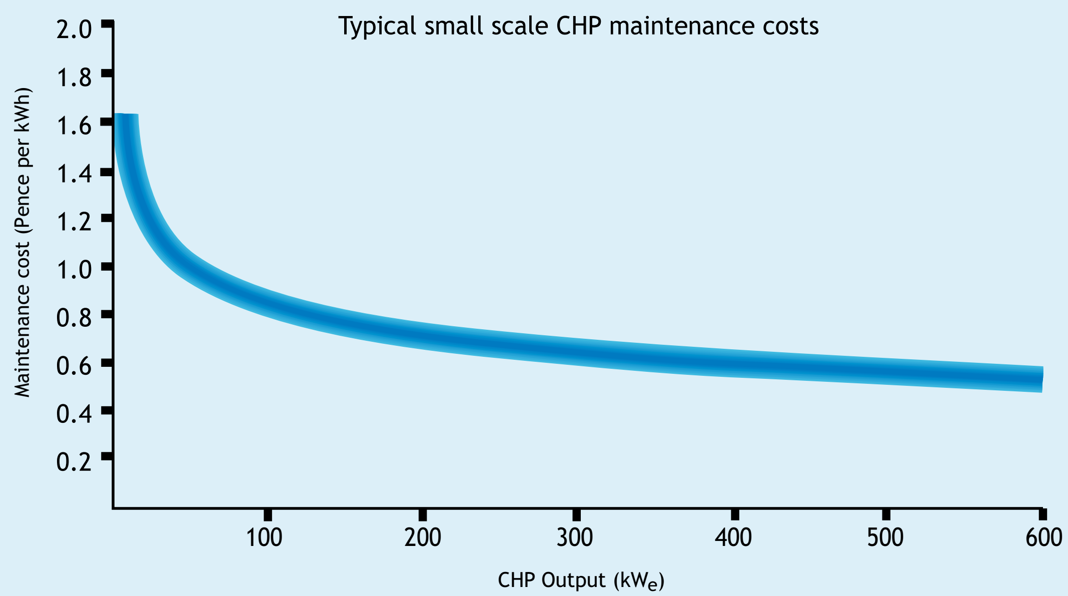
Fuel – is the main running cost. Most small-scale CHP installations in the UK run on natural gas, with a few running on diesel oil or biogas.

Deregulation of the gas supply industry has enabled reductions in costs to be achieved by price negotiation. When agreeing on a supplier, consideration should be given to security of supply, length of contract and price. The likely future price of gas is a very important parameter as the economics of CHP are sensitive to changes in gas costs and particular consideration should be given to projected prices.

Maintenance - is the other major operating cost. Good maintenance underpins economic outcome, maximising availability and minimising downtime. It is important to plan and carry out regular maintenance on CHP units to ensure they continue to operate correctly. Maintenance is nearly always contracted out to a specialist company, usually the CHP supplier itself.

Contracts are usually based on performance, typically guaranteeing an availability above 90%. In addition, most contracts will also provide an emergency service to ensure that down time is kept to a minimum. Typical maintenance costs vary significantly with the level of service provided, the length of the contract and whether performance is guaranteed in the contract but normally include the cost of any replacement parts. Any maintenance contract should be of sufficient duration to cover the first engine rebuild. Example maintenance schedules are shown in AM12. The graph on page 24 indicates that maintenance is more expensive per kWh of electricity produced for smaller plant.





What is Good Quality CHP

The CHP Quality Assurance programme defines the threshold criteria for Good Quality CHP. These are set in the CHPQA Standard (see www.chpqa.com). The programme is a voluntary programme to define, assess, monitor & certify CHP based on energy efficiency & environmental performance. CHP schemes that are certified under the programme qualify for a range of benefits (see earlier box on incentives). There are two Threshold criteria for Good Quality CHP, namely:

- A Threshold Power Efficiency Criterion e.g. 20%
- A Threshold Quality Index Criterion e.g. 100

- The Quality Index (QI) is calculated as (X x Power Efficiency) + (Y x Heat efficiency) where X and Y vary depending on the size, type and fuel of the scheme. The Power and Heat Efficiencies are defined as follows:

$$\text{Power efficiency} = \frac{\text{Total power output}}{\text{Total fuel input}}$$

$$\text{Heat efficiency} = \frac{\text{useful heat output}}{\text{Total fuel input}}$$

Case Study - Micro CHP

Elizabeth House in Rochester, Kent provides sheltered housing for the retired and is owned and operated by private social landlord mhs homes. The extensive property has a total of twenty-one flats heated by a common centralised plant. Two gas fired reciprocating engine CHP units have been installed at Elizabeth House and each unit provides around 5 kW_e of electricity and 12 kW of thermal energy used for space heating and domestic hot water. These micro CHP units were manufactured by SENERTEC GmbH, a Baxi Group company, based in Germany and were the first to be installed in the UK. Around 8,000 units have been installed to date throughout Europe.

Elizabeth House, Rochester

- mhs homes
- 21 sheltered accommodation flats
- Two 5 kW_e reciprocating engines
- Installed October 2002
- Finance option: Capital purchase
- Power efficiency 24%
- Heat efficiency 55%.

Financial appraisal

The appendix provides a simple methodology for assessing the financial benefits of introducing CHP. There are a number of well-established techniques for carrying out a financial appraisal. Simple payback may be acceptable at an early stage of the investigation, but a more rigorous approach using discounted cash flow and life cycle costing is likely to be required for the detailed appraisal. CHP economics vary significantly with changes in fuel and electricity prices and a sensitivity analysis should be carried out to assess the risks of future changes in fuel prices.

Potential pitfalls

- Savings are reduced if the heat is not utilised
- Savings are per hour, therefore CHP needs to run as much as possible
- Savings are dependent on fuel costs and electricity prices
- Don’t rely on supplier feasibility studies.

Integrating CHP with the site

CHP cannot be considered in isolation and requires good integration with other energy systems on site. It is unlikely that all the power and heat requirements will be supplied by the CHP unit. Additional heat and/or power will usually be required from conventional sources, and there may even be excess available for export in some cases.

CHP should always operate as the lead boiler to maximise savings. The electricity generated is best utilised on site, as greater value is realised for it. However, it is also possible to export electricity back to the electricity grid and this can be worthwhile, particularly where on-site demand is low.

Connection to heating plant

CHP units usually work alongside the existing boilers with the boilers providing top-up heat to meet peak demands.

In some applications, heat produced by the CHP unit may be used for purposes other than heating or domestic hot water. For sites with summer cooling loads, absorption refrigeration may provide a suitable demand for heat. Such opportunities for increasing the utilisation of the CHP should be considered when investigating the suitability of CHP.

Most small-scale plant provides low temperature hot water (LTHW), i.e. 80-90°C, and can therefore be directly connected to standard building heating systems. Plant is also available that can provide medium temperature hot water (MTHW), i.e. 90-120°C, directly although these are less common.

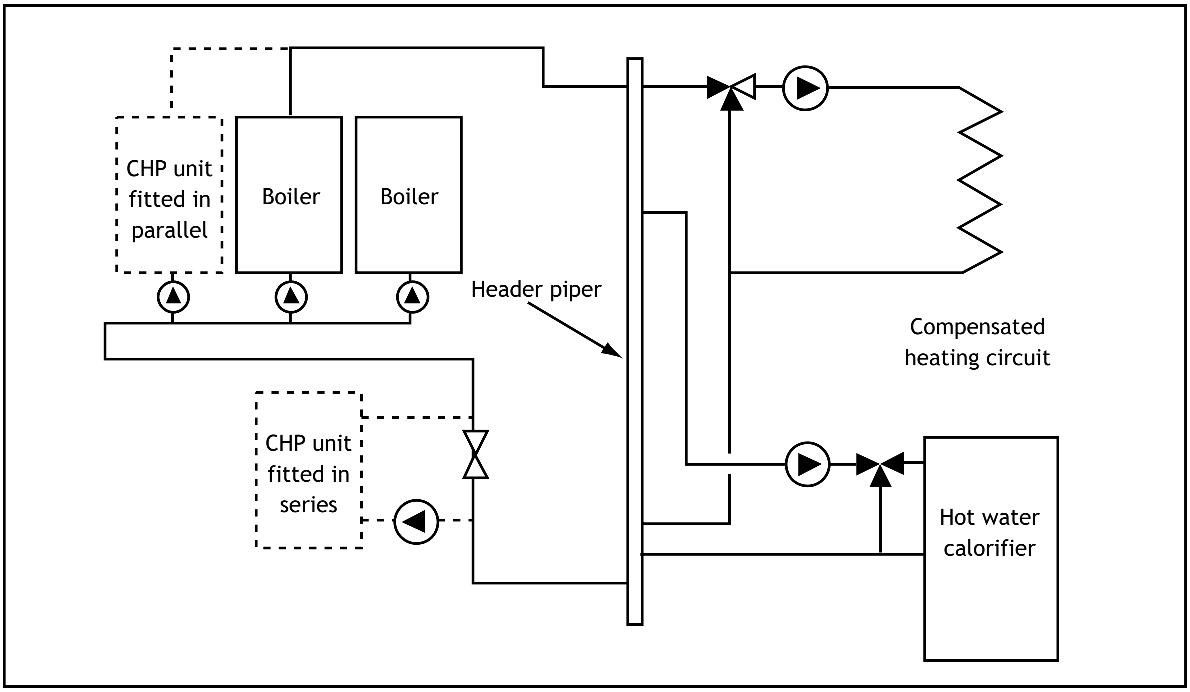
There are essentially two ways of connecting a CHP plant with conventional boiler plant as shown below:

- in series in a suitable return to the boilers
- in parallel with the boilers.

Connection in series is most frequently used when retrofitting CHP to an existing heating system, as it creates the minimum interference with existing flow and control arrangements. Connection in parallel is more common in completely new installations, especially where the CHP plant is likely to supply a significant proportion of the total heat load. Where possible it is preferable to use a single primary pump to ensure good sequence control.

Whichever connection method is used, it is vital that the control system ensures that the CHP unit runs as the lead boiler, thus maximising its operating hours.

Careful consideration must be given to the integration of the CHP unit into the heating circuit to ensure correct balancing of flows through the various items of plant. Due to the number of heat exchangers, CHP has a significantly higher water flow resistance than conventional boiler plant.



CHP plant: alternative connection methods (series and parallel) with conventional boiler plant

Connection to electrical services

In building applications, the CHP generator is most commonly connected to the low voltage distribution network, see opposite. The grid can either meet the peak demand or supply the whole demand if the CHP is not operating.

In order to operate the CHP in parallel with the grid, technical approval must be obtained from the local Distribution Network Operator (DNO). It will be necessary to ensure that the CHP unit can be isolated from the grid in the event of a failure of either the CHP or the grid. The existing electrical services may require some modification in order to achieve this when installing CHP.

In cases where the CHP generates more electricity than can be used on site, excess power can be sold back to the electricity supplier or, under certain circumstances, another site through payment of Distribution Use Of System (DUOS) charges. In both cases, an export meter will need to be installed in addition to the normal import meter. When exporting back to the grid, care should be taken to ensure that sell-back tariffs are high enough to justify doing this.

CHP as standby generators

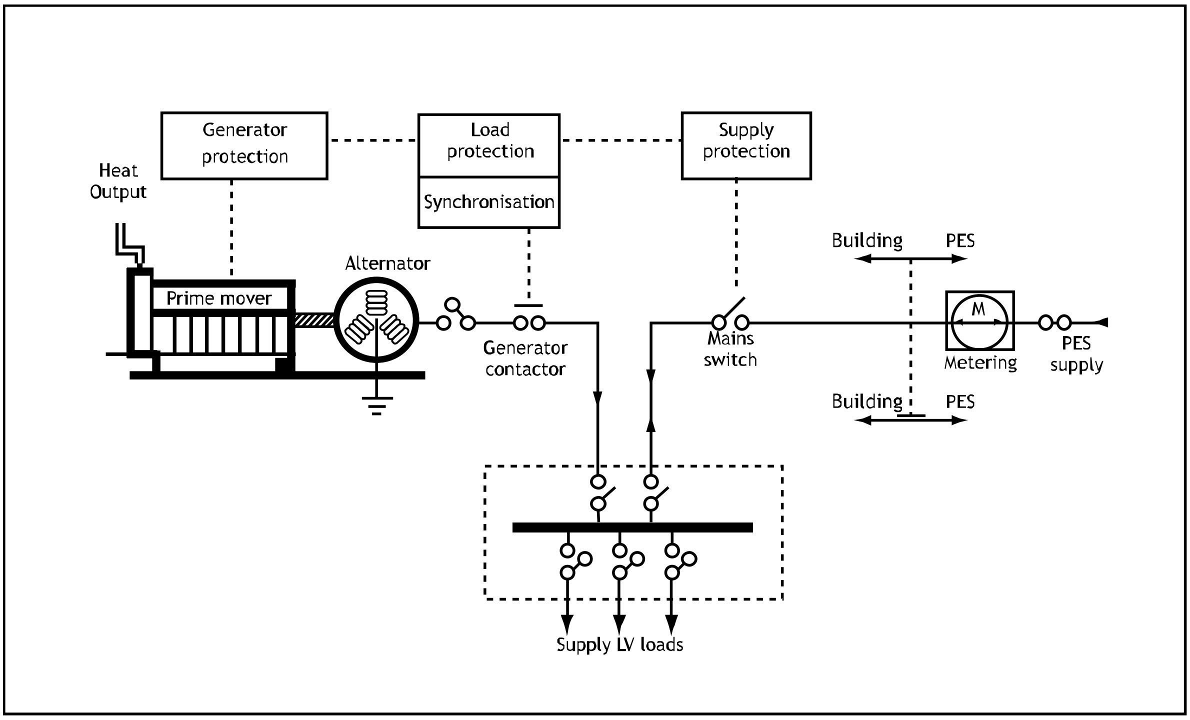
Where standby generators are required, there is an opportunity to use CHP to provide all or part of the standby capacity. By using CHP, the reliability of the standby facility is sometimes improved over conventional generators as the engine is operated more frequently and for longer periods. Furthermore, the capital saved by reducing conventional standby capacity can be offset against the cost of the CHP.

However, if CHP is to provide all the standby capacity, it may be necessary to install more than one CHP unit to ensure that the facility is available even when maintenance is being carried out. Heat dump radiators may be required so that the CHP can still provide standby power when there is a low heat demand. It is also important to take into account the special control requirements necessary for any standby generators; see CIBSE Applications Manual 8 (AM8).

Controls

Most small-scale packaged CHP units incorporate continuous monitoring as part of the control system. These often feed data back to the maintenance staff via a modem as a form of 'condition-based maintenance'. Maintenance is then carried out before things go wrong, based on the monitored condition of the machine. This approach has significantly improved CHP reliability. The main functions of the control system are to:

- control the start-up and shut-down sequence of the system, both routine and emergency
- maintain optimum performance from the system, taking into account heat and power demands
- ensure that the CHP unit operates correctly with other energy systems on site, through an integrated control system
- monitor the system to detect faults, malfunctions or under-performance so that corrective action can be taken before a system failure
- monitor the system to audit the return on investment.



Simplified diagram of typical low voltage combined heat and power electrical system (Source: CIBSE AM12)

Financing options

A range of alternative financial arrangements exist to pay for the capital and installation of CHP units including:

- **Capital purchase;** in this case the host organisation bears all the capital cost, and realises all the subsequent savings.

- **Equipment Supplier Finance (ESF)***, where CHP suppliers offer an arrangement whereby they supply and maintain the equipment free of charge. Under such an arrangement, the host site typically pays for the gas consumed by the CHP unit and purchases the generated electricity from the supplier at a reduced price, as well as receiving the heat at zero cost. The saving in electricity and boiler fuel costs exceeds the cost of the gas consumed by the CHP, providing a net saving. Under this arrangement it is especially important to ensure the heat is utilised at all times as savings quickly evaporate if heat is dumped. Under this set up benefits are shared. This approach is typically for the site that does not have funds available and is looking for a straightforward 'one-stop' approach to CHP. It also transfers much of the risk to the equipment supplier.

- **Energy Services Companies (ESCO's)** previously called Contract Energy Management (CEM companies), where an organisation contracts out its energy services. Contracts can be based on a fixed fee, an agreed unit price for energy (energy supply) or a shared savings approach. The ESCO takes over host site plant for a long term contract, typically 7 to 10 years (can be longer). The ESCO invests in CHP and takes on all operation and maintenance. The host passes some of the cost benefits to the ESCO in return for cost certainty and reduced risks but rewards are also reduced.

CHP DOES…

- Reduce site electricity costs
- Increase site gas consumption and therefore gas costs
- Reduce net site energy costs
- Reduce primary energy by around 30%
- Reduce CO_2 emissions by around 30%.

CHP DOES NOT…

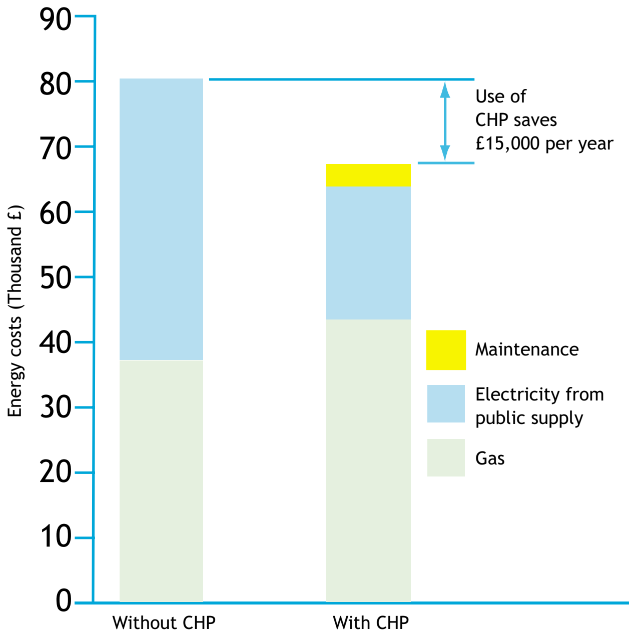
- Produce free electricity
- Automatically save money
- Save money if it doesn't run
- Stack-up if large amounts of the heat produced is thrown away

*ESF is sometimes called Discounted Electricity Purchase

- **Action Energy interest free loans** are available as a financing method that is particularly relevant to smaller CHP applications. These provide up to a maximum of £50,000 to be paid back within 5 years and are only available to small and medium sized enterprises.

  Under both ESF and CEM schemes, maintenance costs are generally included but the host organisation takes a reduced share of any savings. Further guidance on financing CHP can be found in AM12.

Comparison of energy costs with and without CHP



Case Study - Small scale engines

Arnold Leisure Centre has a 25m swimming pool, learner pool, licensed bar, a theatre and a library. Gelding Borough Council decided to replace a defective boiler with a CHP unit that would supply base load heat and electricity. The local authority did not wish to use its own capital resources so the Equipment Supplier Finance (ESF) option was investigated. Under this arrangement, the supplier financed the supply, installation, commissioning and maintenance of the machine. In return, the client supplied the gas to run the unit and agreed to purchase all the power generated at an agreed tariff, less than that available from the local electricity supplier. With no capital outlay, net savings of £5,000 per year to the local authority proved very attractive.

Arnold Leisure Centre

- Gelding Borough Council
- Swimming pool, theatre & library
- 75 kW_e reciprocating engine
- Installed 1992
- Finance option: Equipment supplier finance
- Cost savings £5,000 per year
- CO_2 reductions 400 Tonnes CO_2 per year.

Implementing and operating CHP

Detailed design, specification, tendering and installation all follow a fairly normal route and are covered in more detail in AM12. However a few key items need careful consideration:

Ventilation – is vital to ensure that the plant does not overheat and has adequate combustion air.

Acoustic attenuation - is often necessary for CHP units. Packaged plant usually comes in a purpose-built acoustic enclosure. In addition, silencers must be fitted to the exhaust system. Anti-vibration mountings and couplings are standard on most plant.

Exhaust systems - must be constructed of materials that will resist the corrosive properties of exhaust gases, and condensate drains are usually required. Exhaust outlets should be sited carefully to avoid any noise and pollution problems.

Commissioning & testing – plays a key part in getting CHP right. The plant must be tested under a range of loads and in line with the manufacturer's instructions. Pumps, electrical switchgear, controls all need careful commissioning to ensure they are operating as designed. Test that synchronizing, paralleling and disconnecting electrical output can be carried out safely. Where installed, heat rejection systems need to be tested across a range of loads and to establish that the likely heat duties can be rejected to avoid overheating. Commissioning should also ensure that the CHP unit interacts in the correct way with the existing heating system, see earlier.

Handover – Proof of commissioning must be handed over along with good documentation on how to operate the system. In particular, the CHP system must be included in the building log book required by the Building Regulations. The correct permits and approvals should be handed over and a number of the site staff should be trained to monitor the plant. Most of this is usually carried out by the CHP supplier but is ultimately the client's responsibility.

Post project evaluation – it is vital to monitor the immediate and ongoing success of the scheme. In the initial days and weeks of operation, it is essential to carry out detailed monitoring to establish overall efficiency and economic viability. Beyond that, continuous monitoring will be required to ensure the long term performance, particularly in relation to changes in fuel costs and electricity prices.

Monitoring systems – should allow operators to monitor CHP performance for maintenance and economic purposes. As a minimum the following should be monitored:

- CHP running hours
- Fuel consumption
- Electrical power generated in each tariff period (less any parasitic losses)
- Usable heat generated
- Duration & cause of any plant failure
- Cost of fuels, maintenance etc.

BEMS are ideal for monitoring CHP units to provide ongoing proof of viability. Most packed CHP comes with monitoring systems included that are connected to the maintenance engineers (usually the equipment suppliers) to provide immediate feedback on performance and maintenance requirements. Also the monthly operating reports provided by suppliers give part of the information needed to identify long term performance.

Maintenance - Underpins the economics achieved and should aim to maximise availability and minimise downtime. Maintenance can occasionally be carried out by the host site's in-house staff but it is most commonly done by the equipment suppliers under a maintenance contract. These contracts are normally based on performance guarantees which transfers the risk to the contractor. Typical maintenance schedules are shown in CIBSE AM12 Appendix 8.

What to do next

Review your building design

You should now review the buildings/designs for which you are responsible, in order to identify any potential applications of CHP. Carry out a brief option appraisal to identify if CHP might be viable. Where CHP looks as if it might provide benefits then a full detailed feasibility study should be carried out to establish the practicality and likely economics. In future, you should, where appropriate, consider CHP as an option when making decisions on energy supply in buildings.

Get more information

The Action Energy programme provides a wide range of free publications on CHP, available on **www.actionenergy.org.uk** Relevant publications include GPG234 - Guide to community heating and CHP and GPG256 - An introduction to absorption cooling.

CHP issues are covered more fully in CIBSE Applications Manual AM12 - Small scale CHP in buildings (available on **www.cibse.org**) and also GIR082 – Managers Guide to Packaged CHP systems – and GIR083 – Managers Guide to Custom built CHP systems – (both available through the CHP Club).
It should be stressed that this document is not intended as an appraisal or design guide and should not be used as such.

Get a free survey

Tell your clients that the Action Energy programme provides free site-specific independent advice and surveys on all aspects of energy efficiency including CHP. It is important to consider CHP at the start of a project to ensure that the optimum benefit can be obtained. If your clients are considering a change to their heating or electrical supply, then contact Action Energy, CHPA or CIBSE for further information.

Identify available funding

Small and medium sized enterprises may be eligible for an interest free loan from Action Energy, see **www.actionenergy.org.uk**. The Energy Saving Trust (**www.est.org.uk**) manages initiatives in the residential sector and may provide direct financial assistance to encourage the use of CHP. The Carbon Trust (**www.thecarbontrust.co.uk**) also manages initiatives on CHP.

Join the CHP Club

Encourage your clients to join the CHP Club. The CHP Club helps potential and existing CHP users by putting them in touch with information and support from those that have already succeeded with CHP. Registration is available on-line at **www.chpclub.com**

SUMMARY

- Always conduct a brief option appraisal
- A detailed feasibility study is essential
- Don’t overestimate heat and power demands
- Implement low cost energy saving measures first
- Analyse a range of CHP types and sizes
- Consider all the practical issues carefully
- Assess all the environmental benefits/issues.

*Call the Action Energy helpline on **0800 58 57 94**.*

Sources of Information

Further reading

CIBSE Applications Manual AM12 - Small scale CHP in buildings (London, Chartered Institution of Building Services Engineers) (1999) (Tel: 020 8675 5211) **www.cibse.org**

CHPQA – A quality assurance programme for combined heat and power, The CHP QA Standard Issue 1, (Harwell: ETSU) **www.chpqa.com**

The Building Regulations Part L: Conservation of Fuel and Power (London: Stationery Office) (2002)

The Building Standards (Scotland) Regulations Part J: Conservation of Fuel and Power 2002 Technical standards for compliance with the Building Standards (London: Stationery Office) (2002)

The Building Regulations (Northern Ireland) 1994 Technical Booklet F: Conservation of Fuel and Power (London: Stationery Office) (1994)

CIBSE Applications Manual AM 8 – Private and standby generation (London, Chartered Institution of Building Services Engineers) (1992) (Tel: 020 8675 5211) **www.cibse.org**

CIBSE Guide F – Energy efficiency in Buildings (London, Chartered Institution of Building Services Engineers) (2004) (Tel: 020 8675 5211) **www.cibse.org**

Ellis F W, Fuel cells for building applications – (Atlanta, GA: American Society of Heating, Refrigeration and Air Conditioning Engineers) **www.ashrae.org** (2002)

Action Energy publications

For free information on Combined Heat and Power, benchmarking, energy management and metering etc. visit the Action Energy website at **www.actionenergy.org.uk** or call the helpline on **0800 58 57 94**. Relevant publications include:

- GPG234 - Guide to community heating and CHP
- CHP Sizer (CHP002) – a computer software package
- GIR082 Managers Guide to Packaged CHP systems (available through the CHP Club)
- GIR083 Managers Guide to Custom built CHP systems (available through the CHP Club)
- GPG256 - An introduction to absorption cooling

Useful web sites

The Action Energy programme
ww.actionenergy.org.uk

Enhanced Capital Allowances
www.eca.gov.uk

Combined Heat and Power Association
www.chpa.co.uk

CIBSE CHP Group
www.cibse.org/CHP

The Energy Savings Trust
www.est.co.uk

The Carbon Trust
www.thecarbontrust.co.uk

The CHP Club
www.chpclub.com

Appendix – Plant sizing and viability, a worked example

This worked example shows how to assess the sizing and viability of CHP. It begins with a very simple example to assess the viability of a CHP scheme to only meet the base heat load. A range of machines are then considered to assess the optimum machine. This example only shows simple payback calculations in order to make it easy to follow. In practice, this would only provide an initial assessment of viability at an early stage in the project. Net present value calculations based on a whole life costing approach should always be used to determine actual project viability.

The Building and Services

- A NHS Trust's main health care facility is a hospital built in the 1970's. The hospital has 400 in-patient beds and a floor area of 30,000m^2.
- The heating system is based on a centralised low temperature hot water (LTHW) system. The LTHW is used for space heating and hot water. Small steam requirements for sterilisation and humidification are met by dedicated separate steam raising plant.
- There is a low voltage ring providing electricity to the site and the main LV distribution board is within the boiler house building.

The assumptions

The assessment is based on:

- Daytime electricity price = 3.75p per kWh (including Climate Change Levy)
- Gas price = 0.9p per kWh (including Climate Change Levy)
- Maintenance cost = 0.9p per kWh electricity produced
- Anticipated running hours of CHP are 07:00 to 00:00 to coincide with day time electricity prices.

Estimating the base loads

An understanding of site energy demands is essential in order to make any assessment of the viability of a CHP scheme. The first step in any evaluation of CHP is to gather information about the energy demands of the building.

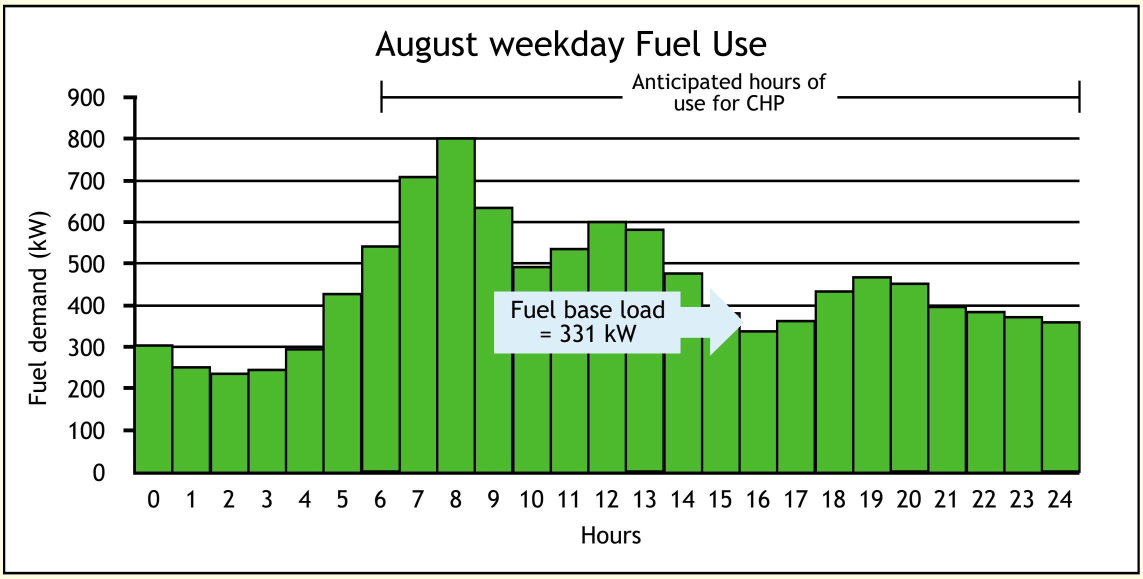
The table below shows gas and electricity meter readings taken throughout a typical August weekday when the base load heat demand is likely to occur. The volume readings were taken electronically at hourly intervals from the gas meter in the boiler house (measuring gas supply to the boilers only). These were automatically converted to kWh readings using the calorific value of the gas. Hourly readings were also taken from the main electricity meter. The average fuel/electricity consumption in each hour can then be calculated and plotted as a graph (see opposite). As the consumption in kWh per hour is being determined, this corresponds to the average heat demand in kW.

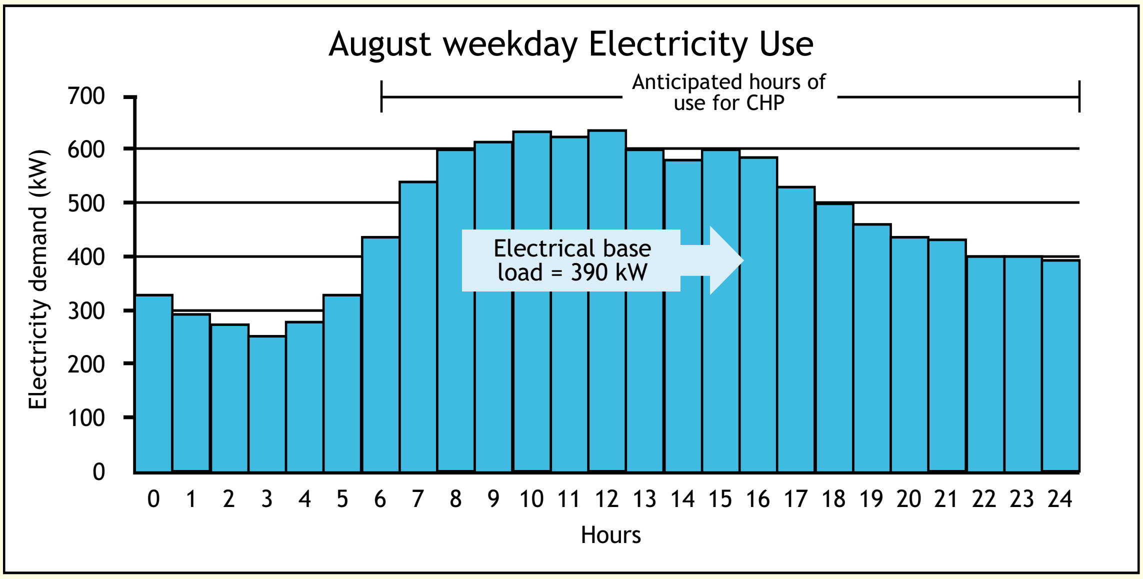
Time	Gas Reading (kWh)	Average fuel demand (kW)	Electricity reading (kWh)	Average electricity demand (kW)
00:00	69440	298	82237	328
01:00	69738	248	82565	294
02:00	69986	225	82859	269
03:00	70211	230	83128	252
04:00	70441	292	83380	279
05:00	70733	421	83659	325
06:00	71154	535	83984	428
07:00	71689	689	84412	535
08:00	72378	796	84947	589
09:00	73174	625	85536	607
10:00	73799	479	86143	625
11:00	74278	527	86768	617
12:00	74805	596	87385	623
13:00	75401	567	88008	598
14:00	75968	467	88606	573
15:00	76435	371	89179	592
16:00	76806	331	89771	578
17:00	77137	357	90349	527
18:00	77494	423	90876	489
19:00	77917	455	91365	457
20:00	78372	441	91822	435
21:00	78813	389	92257	424
22:00	79202	378	92681	403
23:00	79580	367	93084	398
24:00	79947	352	93482	390

The graphs below show that between 07.00-24.00 (when the CHP will be ON) the base **fuel** load is 331 kW and the base electrical demand is 390 kW. Some sites that have ignored the electricity demand in the sizing of a unit have inadvertently ended up exporting power and not getting any revenue from it.

331 kW represents the minimum energy passing through the gas meter. To convert this to represent the actual heat load of the site an allowance must be made for the efficiency of the boiler system. Assuming a boiler efficiency of 75% then:

Actual Base **Heat** Load = 331 x 0.75 = 248 kW





Sizing the CHP plant to the base heat demand

The base heat load represents the heat that can be used from a CHP unit for this particular sizing approach. To determine which unit to select we must look at the heat and electrical power characteristics that are produced by various CHP units, as shown below (note these figures are purely indicative).

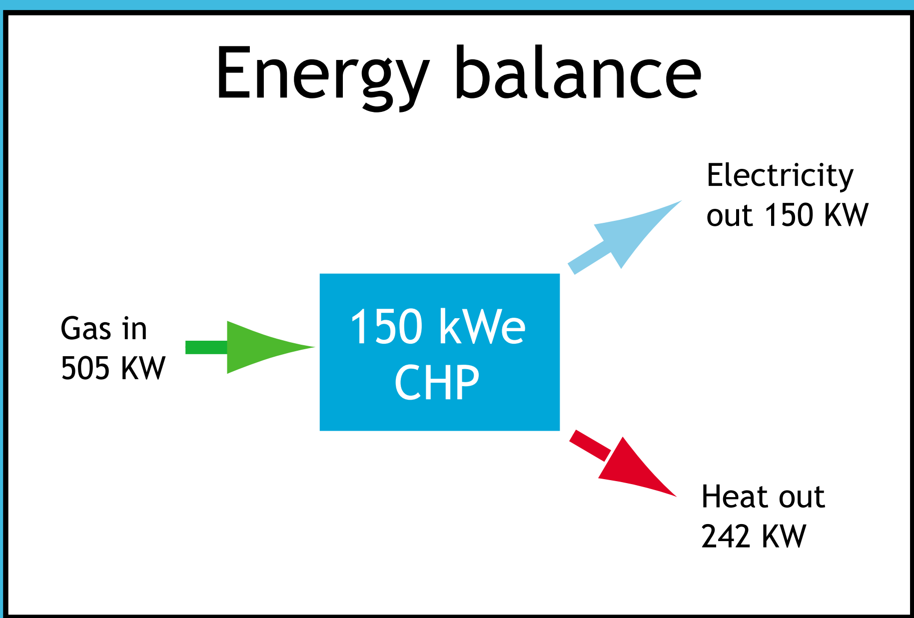
The machine just under the base heat load has a heat output of 242 kW. The selected machine therefore has the following characteristics:

Fuel input	=	505 kW
Electrical output	=	150 kW
Heat output	=	242 kW

It is also important to check that the base electrical demand is above the output of the CHP unit, which in this case it is i.e. $390kW_e > 150\ kW_e$.

Small-scale reciprocating engine CHP unit ratings (based on Gross Calorific Value)

Electrical Output kW	Thermal Output kW	Fuel Input kW
100	165	340
150	242	505
200	317	669
300	465	995
400	610	1318
600	895	1959
800	1174	2596
1000	1449	3229

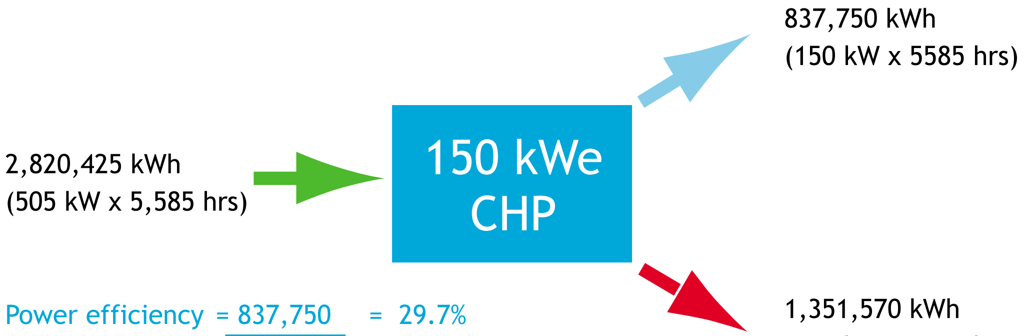


Evaluating the savings

Once the base load machine has been selected, the likely savings can be assessed. If the CHP unit is sized to the base heat load it will operate all year around with full heat utilisation.

- The plant has an availability of 90%
- The plant will run for 5585 hours per year (17 hrs per day x 365 days per year) x 0.9 (availability)
- Efficiency of the existing boilers is 75%
- Gas costs 0.9 p/kWh and electricity costs 3.75p per kWh (including Climate Change Levy)
- Maintenance cost is 0.9p/kWh electricity generated
- Capital cost of the plant is £110,000.

Annual efficiency



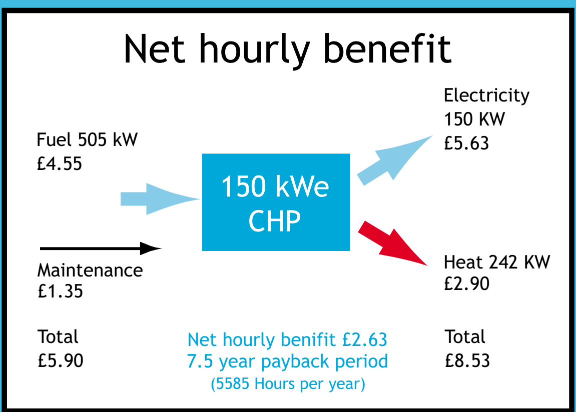
Power efficiency $= \dfrac{837,750}{2,820,425} = 29.7\%$

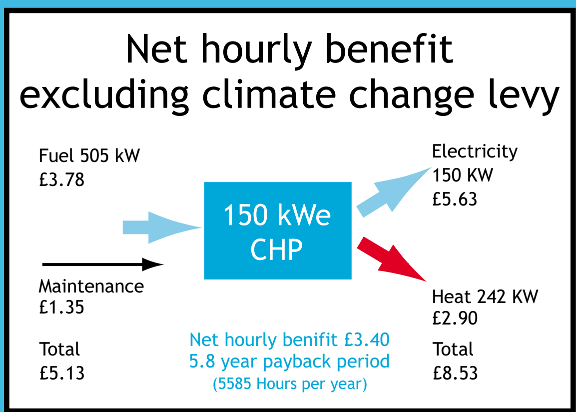
Heat efficiency $= \dfrac{1,351,570}{2,820,425} = 47.9\%$

Overall efficiency $= 77.6\%$

Given the information/assumptions as page 39 and the CHP machine characteristics, the simple payback of the project can be calculated.

Annual energy input/output calculation		
Electricity output (kW_e x Hrs run)	= 150 x 5,585	= 837,750 kWh per year
Displaced boiler fuel (kW x Hrs run/0.75)	= (242 x 5,585)/0.75	= 1,802,093 kWh per year
Gas Input (kW x Hours run)	= 505 x 5,585	= 2,820,425 kWh per year
Savings		
Displaced Electricity Savings	= 837,750 x 0.0375	= £31,416
Displaced Boiler Fuel Savings	= 1,802,093 x 0.009	= £16,219
TOTAL SAVINGS		**= £47,635**
Operating costs		
CHP Fuel cost	= 2,820,425 x 0.009	= £25,384
Maintenance cost	= 837,750 x 0.009	= £7,540
TOTAL COSTS		**= £32,924**
Financial return		
Net benefit per annum	= 47,635 - 32,924	= £14,711
Capital Cost (£)	= £110,000	
Payback		= 7.5 Years





Does the base load CHP scheme meet the threshold criteria for Good Quality CHP?

If a CHP scheme reaches the relevant threshold criteria for Good Quality CHP, as defined by the CHP Quality Assurance (CHPQA) programme (see **www.chpqa.com**), it will be possible to claim Climate Change Levy exemption for its entire fuel input (and power output). This can have a significant impact on the financial return of a given CHP scheme.

For a new small scale scheme (<$2MW_e$) with no heat rejection facility to meet both the threshold criteria for Good Quality CHP, it must have:

- a power efficiency greater than or equal to 20%
- a quality index greater than or equal to 105.

Calculating the performance of the scheme:

Power efficiency	=	(837,750/2,820,425) x 100	=	29.7%
Heat efficiency	=	(1,351,570/2,820,425) x 100	=	47.9%

The quality index calculation for Reciprocating Engines is shown below:

QI	=	(200* Power efficiency)	+	(125* Heat Efficiency)
	=	200 x 0.297	+	125 x 0.479
	=	119.3		

The 150kW_e base heat load scheme reaches both the threshold criteria for Good Quality CHP and the full benefits of CCL exemption can thus be included. Therefore, take off 0.15p/kWh from the CHP gas unit price, i.e. reduce it in this case to 0.75p/kWh, and repeat the calculations. The displaced electricity savings, displaced boiler fuel savings and maintenance costs remain the same, however the CHP fuel cost reduces.

NEW CHP fuel cost	=	2,820,425 x 0.0075	=	£21,153
NEW Net benefit per annum	=			£18,942
NEW Payback	=			5.8 Years
The payback is the improved by				22 %

Optimising CHP capacity

Traditionally CHP has been sized to match the base heat load of a site. In reality, there are usually benefits to be achieved by optimising the size of the CHP scheme. This frequently involves discarding a small proportion of the heat produced (this waste heat can be used for absorption cooling). To optimise the size of a CHP scheme a range of engines, with and without heat rejection equipment, need to be considered. The table below repeats the previous exercise for a range of schemes with heat rejection facilities (the difference in payback for the 150kW$_e$ scheme is the capital cost of the heat rejection equipment) – Note: the effects of CCL exemption are applied later (see following pages).

Optimising the size of CHP: results for CHP engines electrically led with heat rejection facility

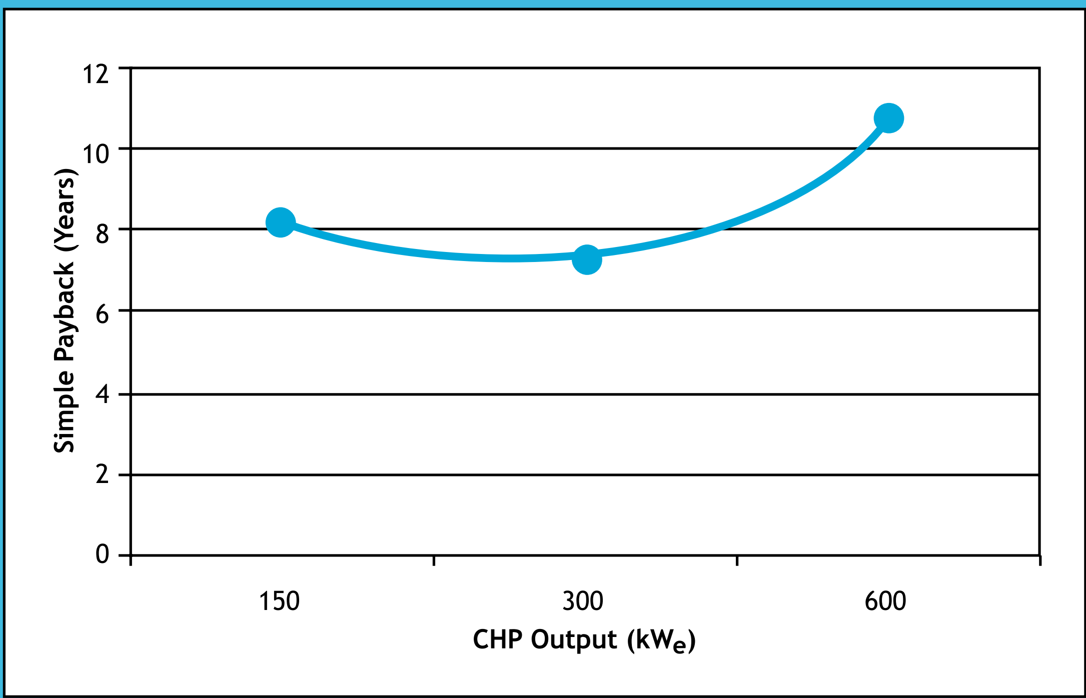
	CHP Electrical Output (kW$_e$)	150	300	600
	CHP Heat Output (kW)	242	465	895
	CHP Fuel Input (kW)	505	995	1959
	SAVINGS			
	Hours run	5,585	5,585	5,585
	Heat Utilisation (%)	98	92	84
	Heat Supplied (MWh/annum)	1330	2398	3338
A	Displaced Boiler Fuel Savings (£k/a) @ 0.9 p/kWh	15.9	28.8	40.0
	Displaced Electricity (MWh/annum)	838	1675	2450
B	Displaced Electricity Savings (£k/a) @ 3.75p/kWh	31.4	62.8	91.9
C	Total Savings [A + B]	47.3	91.6	131.9
	OPERATING COSTS			
	CHP Fuel input (MWh/annum)	2,820	5,557	8,280
D	CHP Fuel Input cost (£k/a) @ 0.9p/kWh	25.4	50.0	74.5
E	Maintenance cost (£k/a)	8	13	21
F	Total Operating Cost [D + E]	33.4	63.0	95.5
	FINANCIAL RETURN			
G	Net Savings [C - F] (£k/a)	13.9	28.6	36.4
H	Capital Cost (£k) Inc heat rejection plant	114	209	384
	Simple Payback [H/G] (years)	8.2	7.3	10.5

Note: the 600kW$_e$ unit is modulating its power output to stay within the electrical demand of the site.

Plotting simple payback, see below, then indicates the optimum machine. Using CHP simulation models allows this optimisation to be done in a quick and efficient manner.

This shows the optimum size is the 300 kW_e scheme with a payback of 7.3 years. The machine characteristics would be:

Fuel input	=	995	kW
Electrical output	=	300	kW
Heat output	=	465	kW



This unit has a power efficiency of 30% and a heat efficiency of 43%, and thus meets both Threshold Criteria for Good Quality CHP (QI = 113.8). Applying the CCL exemption, the net savings increase to £36.9k per annum and the payback period reduces to 5.6 years.

Key issues are:

- The optimum scheme produces twice as many savings as the base heat load unit for a better financial return.
- The optimum plant utilises 92% of its heat output but has to dump 8%. Using a thermal store could reduce this.
- The optimum size CHP scheme will save more CO_2 per year than the base heat load scheme. A 300kW$_e$ scheme without a heat dump may well (depending on the assumptions used) produce more environmental savings but it would also cycle on and off for large parts of the year, causing greater wear on the engine.

This example only shows how to make an initial assessment of viability, based on simple payback calculations, in order to make it easy to follow. In practice, a whole life costing approach should always used, based on more sophisticated calculation methods (e.g. net present value), to determine actual project viability.

Glossary of terms

Capital purchase: Purchasing an asset outright as opposed to leasing it under an operating lease.

Compression-ignition (CI): System used in reciprocating engines whereby fuel is injected after compression of the air and is ignited by the increased temperature caused by compression.

Demand, maximum: The rate at which energy is required, expressed in kilowatts (kW) or megawatts (MW). It is usually related to a time period, typically half an hour: e.g. 7 kWh used over half an hour is a demand rate of 14 kW. Maximum demand is the highest half-hourly rate at which electricity is required during a month or year.

Discounted cash flow: A cash flow analysis where the time value of cash is taken into account.

Energy services company (ESCO): A company offering an integrated and wide range of energy-related services.

Finance lease: A lease that transfers substantially all the risks and rewards of ownership (other than legal title) of an asset from the lessor (i.e. the finance company) to the lessee (i.e. the business customer).

Heat to power ratio: The amounts of heat energy relative to electricity produced by a CHP unit, expressed as a ratio.

Internal Rate of return: That value of discount rate used in a discounted cash flow analysis that gives a Net Present Value of zero.

Net Present Value (NPV): The aggregate value of all future costs/savings after they have been discounted back to the present time at an annual percentage figure equal to the discount rate.

Performance guarantees: May be defined by reference to absolute measures such as absolute quantity of heat or power produced. However, these will depend on uncontrollable factors such as warm or cold winters. Alternative measures attempt to assess the degree to which the plant was capable of providing its specified output. These indicators are availability, reliability and utilisation and are defined below.

A = actual hours plant was run in period
P = planned operating hours in period
S = scheduled plant downtime for maintenance
U = unscheduled plant downtime for plant defects.

Availability defines what might reasonably be expected of, or is achieved from, the plant allowing for scheduled and unscheduled downtime.

$$\text{Availability} = \frac{P-(S+U)}{P}$$

Reliability measures the unscheduled downtime of the plant.

$$\text{Reliability} = \frac{P-(S+U)}{P-S}$$

Utilisation is a measure which takes into account when the plant was actually running and so includes all occasions when the plant was prevented from operating by external factors e.g. low heat load.

$$\text{Utilisation} = \frac{A}{P}$$

Reciprocating engine: When mechanical power is produced by the to-and-fro (reciprocating) movement of a piston within a cylinder, machines are referred to as reciprocating to distinguish them from purely rotating machines like turbines.

Simple payback: The length of time before a project's cumulative cost savings equal its capital cost.

Spark-ignition: A reciprocating engine that utilises an electrical spark to ignite the compressed air/fuel mixture in the cylinders.

Synchronism: The condition whereby generator frequency and voltage levels match those of the public supply. When operating in Parallel Mode, the generator has to be synchronised to the mains supply before being connected, and must remain in synchronism.

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