EiBI
"Energy in Buildings and Industry and the Energy Institute are delighted to have teamed up to bring you this Continuing Professional Development initiative"
MARK THROWER MANAGING EDITOR
energy institute

Combined heat & power as an energy source

By Wayne Ward, managing director at Building Services Sustainability & Environmental Consultancy Ltd

Combined heat and power (CHP), or cogeneration, is a highly efficient process that capitalises on the heat generated as a by-product of the generation of electricity. Coal and gas-fired power stations can often be seen expelling wasted heat energy as clouds of steam from cooling towers. CHP systems exploit the heat energy that would otherwise be wasted in traditional electricity generation, to produce both electricity and heat in a single process.

The UK government states that installing CHP saves organisations around 20 per cent of their energy costs and reduces CO_2 emissions by up to 30 per cent. The main drawback with CHP is that to gain maximum efficiency it is recommended to be operated for around 4,500 hours per year.

CHP has been proven worldwide to be an effective means of reducing operating costs and environmental damage in domestic, commercial and industrial scenarios. It is widely used in countries like the Netherlands, Finland and Denmark. In Finland, 82 per cent of electrical power generation in 2012 was produced via cogeneration. Germany is on-course to provide 25 per cent of the country's power through cogeneration by 2020.

It is believed that the first CHP application was undertaken in the United States in 1882 with the Thomas Edison-designed Pearl Street Station, the world's first commercial power plant. This plant burned coal to generate enough electricity to power approximately 400 lamps, and the waste bi-product of heat was used to warm neighbouring buildings. The Pearl Street Station CHP was thought to be about 50 per cent efficient.

Today, CHP plants are able to work at an efficiency around 85 per cent, which is thought to be 25-35 per cent more efficient that the separate energy systems it replaces.

Electricity is generated by burning a variety of fuels (e.g. mains gas, gaseous waste fuels, commercial waste fuels etc.) in an engine or turbine that's connected to an alternator. During this process, a significant amount of heat is created as a by-product, which is usually wasted in conventional power generation. However, in a CHP application, the heat from the exhaust, oil cooling circuits and water jacket is recovered and distributed to a nearby heating system. This reduces the requirement to burn additional gas in a boiler or central heating system. Energy from CHP is nearly always produced locally to its end user, which limits the amount of energy loss due to transmission.

Excess electricity generated can be sold to the grid, and any shortfall in electricity can be purchased from the grid. As battery technology is increasingly reducing in cost, further benefit can be derived by storing the generated electricity for use during peak times, subsequently further reducing reliance on the grid. In addition, this helps to reduce reliance on the grid at times of fluctuating demand.

There are multiple types of CHP engines, each suited to different output requirements. The size of the unit will depend on the calculated or estimated base heat load (CHP is most economic when the unit is sized slightly over the baseload heat load).

An internal combustion engine in a CHP unit works in a similar way to the engine in a motor car. The unit burns a fuel (normally natural gas or compression-ignition diesel) which generates motive power. The power is turned into electricity via an alternator. The wasted heat will be used to heat a body of water, or sometimes to create steam. Exhaust gases can be as hot at 600°C, which produces low temperature hot water (LTHW) temperatures of up to 95°C.

Electrical efficiency of these units is low (20 per cent), but thermal efficiency is slightly higher (20-40 per cent).

These internal combustion engines are best suited for small sites which a high demand for hot water in comparison to electricity. The ratio of heat to power is approximately 1.5:1 but decreases with size.

Unit sizes vary from 50kWe – 1,500kWe.

They are used in: smaller (decentralised) hospital buildings, hotels, leisure buildings, individual university buildings, small residential buildings on a district heating scheme.

Gas turbines are the most common prime mover on larger scale CHP units.

In a gas turbine engine, a fuel is burned (normally natural gas) in a combustion chamber, causing heat and pressure to force air down the unit to drive a series of turbine blades. The pressurised air drives a generator, generates electricity via an alternator. The expelled heat is utilised by a heat exchanger to provide hot water. Typical entry temperatures are in the region of 900-1,200°C, with exhaust temperatures in the region of 500°C depending on the scale of the turbine. The heat to power ratio can be as high as 5:1 in certain applications if 'supplementary firing' is undertaken (which enables control over varying amounts of heat.

These setups are reported to be very reliable. However, they are very loud units, have a lower electrical efficiency than reciprocating engines and are not efficient at periods of low demand.

Smaller units (up to 500kWe) have a low electrical efficiency (around 20-30 per cent) so have to be used with a recuperator to preheat the air to ensure it qualifies as 'Good Quality CHP' as defined by the UK CHP Quality Assurance Programme.

It is possible to get micro turbines as integrated packages with absorption cooling to enable tri-generation.

They find use in: hospital buildings with a district heating system, universities (with district heating), large

multi-residential buildings
Micro units = 80 – 500kWe
Medium/Large units = in excess of 500kWe

This type of system can be used in combination with a steam turbine (below), which uses the heat from the exhaust to create steam. A system with a steam turbine is around 52 per cent efficient.

In a steam turbine, a fuel is burned to heat up water. The water turns into high-pressure steam to drive a turbine, which drives a generator to create electricity. Heat is then recovered from the steam via a heat recovery unit.

Electrical efficiencies in CHP applications are 10-20 per cent. Overall efficiencies are in the region of 80 per cent, although the efficiency depends on the pressure at which steam is extracted.

These units are particularly useful for applications where steam is needed (for example, industrial uses). They are typically suited to large-scale applications where the heat requirements is significantly greater than the amount of power.

In a steam turbine, a fuel is burned to heat up water. The water turns into high-pressure steam to drive a turbine, which drives a generator to create electricity. Heat is then recovered from the steam via a heat recovery unit.

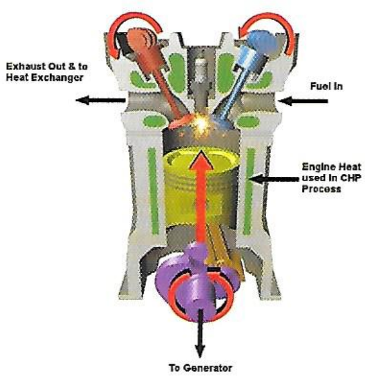
Electrical efficiencies in CHP applications are 10-20 per cent. Overall efficiencies are in the region of 80 per cent, although the efficiency depends on the pressure at which steam is extracted.

These units are particularly useful for applications where steam is needed (for example, industrial uses). They are typically suited to large-scale applications where the heat requirements is significantly greater than the amount of power.

Fuel cells are electrochemical cells that use hydrogen-rich fuels to generate heat and electricity. Hydrogen is fed to an anode, which it divides into hydrogen ions and electrons. Positively charged ions are attracted to a negatively charged cathode – however, they cannot penetrate the Proton Exchange Membrane and therefore have to find a way to the cathode via an external circuit. In doing so, an electric current is created. Heat emitted as a by-product is recovered and used for heating.

Electrical efficiencies of fuel cells are around 55 per cent, which is higher than combustion engines as the process is a clean electrochemical reaction rather than fuel combustion. In addition, the

Fig 1. The internal combustion engine in a CHP unit



process is silent, which reduces waste energy and increases the versatility of the units.

If the hydrogen fuel was sourced sustainably, this generation of heat can be considered emission free. However, in reality this is difficult and expensive to achieve, meaning that most existing examples operate from reformed (converted) natural gas.

The major drawback is the excessive capital cost of fuel cell technology, as building an inexpensive, efficient fuel cell is complex. Hydrogen fuel is also less readily available than many other types of fuel, and the specific type of hydrogen required depends on the type of electrolyte (e.g. alkali, molten carbonate, phosphoric acid etc.) used in the design of the unit. If pure hydrogen is used, a reformer is required to purify the fuel.

Modern CHP units nearly always use synchronous generators because they can modulate power output over a wide range, do not require power factor correction and can act as standby generators.

CHP can offer a wide range of benefits:

• **Financial savings** – CHP can save the end user 20 per cent in energy costs (at current rates) compared to traditional methods of receiving electricity and heat. In addition, CHP is exempt from the Climate Change Levy (CCL), qualifies for exemptions of business rates and is eligible for payments from the Renewable Heat Incentive.

• **Straightforward operation** – Once CHP systems are installed, they are considered fairly 'hassle free' in comparison to other low-carbon generation methods such as biomass, which often require 'feeding' and large amounts of dry fuel storage. However, CHP plants do require regular maintenance, which is usually covered by a maintenance contract as discussed later.

• **Simple integration** – In terms of installation and operation, CHP is relatively straightforward to install and use compared to other environmentally friendly methods of energy generation. Small to medium CHP systems (up to 2MWe) are delivered in 'packaged' units, which are pre-manufactured, boxed units that allow for quick installation. Larger CHP systems (greater than 2MWe) are often designed specifically for each application and need to be assembled on site, which is a longer and more costly process.

• **Loss reduction** – There are two significant losses in conventional power generation from a typical power station: losses from waste heat and losses from transmission. Transmission and distribution losses through the National Grid and local distribution networks are estimated to consume about 7 per cent of the energy that is being transferred. CHP, however, provides localised heat and electricity, effectively removing both of these barriers, subsequently increasing the efficiency significantly.

• **Fuel neutral** – CHP is referred to as 'fuel neutral'. This means that it can operate on a variety of fuel types: fossil fuels and renewable-based fuels. As a result, fuels considered to be 'clean' or 'carbon neutral' can be burned to generate electricity and heat at a high efficiency, reducing the environmental impact of generation. Furthermore, this fuel versatility often removes geographical limitations/barriers of where CHP plants can be located, which is a significant advantage over other methods of generating energy.

• **Supply security** – As end-users are generating their own energy, CHP gives the user an increased security of supply.

• **Environmentally friendly** – In most cases, CHP plants burn combustible fossil fuels to generate electricity and heat, which is not considered clean energy generation. However, in comparison to most other methods of energy generation, CHP is significantly more efficient (up to 85 per cent efficient). It is estimated to reduce CO2 levels by up to 30 per cent and SOx levels by up to 20 per cent compared to individual creation of heat and electricity. CHP, however, emits around 430mg/kWh of NOx, which is around 20 times more polluting than other types of heat generation such as biomass (18mg/kWh).

• **Legislative compliance** – Installing CHP in a new building will assist with meeting required environmental standards, such as Part L compliance. In addition, it helps to meet the Carbo Reduction Commitment Energy Efficiency Scheme (CRCEES) targets.

• **Tri-generation** – A further advancement of cogeneration is tri-generation. This is the use of a CHP unit in conjunction with an absorptio chiller to provide cooling. The waste heat from the CHP unit is recycled to provide the energy required to produce chilled water. This is an effective option for buildings that hav a steady, continuous cooling demand throughout a year.

CHP is efficient and effective when installed at sites which have a continuous, year-round baseload hea demand. As a general rule, CHP plants are considered economic if they run f 4,500 hours per year or more (roughl 12.5 hours/day). CHP is particularly effective when installed in the followi applications:

Hotels
• High base heat load
• 24hr/day heat requirement
• High number of bedrooms with bat showers
• Catering use
• Leisure facilities (spas, swimming pools)

Hospitals
• High base heat load
• 24hr/day heat requirement
• Warm water required for cleaning/ washing
• Onsite catering

Leisure facilities
• High base heat load
• Up to 18hr/day heat requirement
• Warm water required for showers/ spas/saunas/pools
• Requires much more heat than electricity

Universities / colleges / schools with leisure facilities and boarding facilities
• Require significantly more heat than electricity
• Warm water required for leisure facilities
• Heating required in communal buildings and accommodation faciliti

Prisons
• 24hr/day requirement for heat and domestic hot water (DHW).
• Showers, catering, washing and cleaning requirements.

Large multi-residential buildings / apartment complexes
• 24hr/day requirement for heat and domestic hot water (DHW).
• Requires connection through distric heating system
• Substantial baseload due to fluctuating use in multiple apartments
• If CHP unit fails, all connected

buildings have no heating

District heat networks with a combination of buildings

- A network may contain residential properties and buildings used in the daytime, therefore there is potential for 24hr/day heating
- Generally no requirement to export excess electricity to the grid

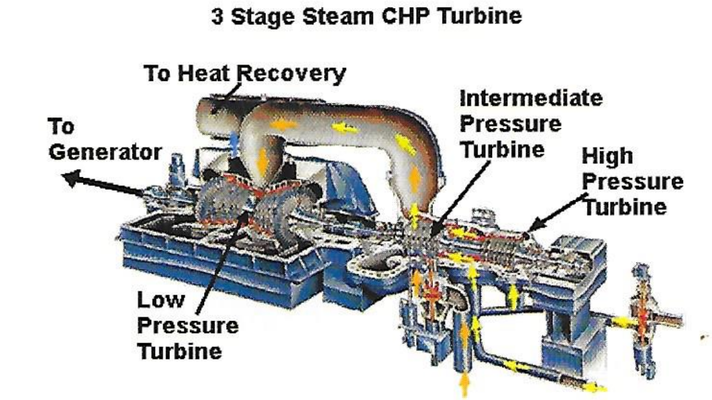
CHP is not considered an effective method of low-carbon energy generation if the plant is used for less than a recommended 4,500 hours per year as efficiencies begin to decrease. However, thermal storage can be investigated as a potential option to increase efficiency if the baseload hours falls close to, but just below, this figure.

CHP will be most effective if the design and installation is considered in conjunction with a full heating plant replacement, or the design of a new building. This is because there are less barriers to overcome when integrating it into a new system. In addition, CHP is most efficient when a new heating distribution system is being installed into a building as it can be designed to maximise efficiency at the given design temperature of the unit. CHP can, however, be integrated into an existing heating system, although the efficiency may not be as high as a new system.

If a building falls into one of the above categories, a full feasibility study should be undertaken to better understand the viability of installing CHP in the building. The following steps should be undertaken to assess this:

- establish if the current wet heating system will be compatible with a CHP plant, and that appropriate controls can be sourced to ensure that the CHP can work asthe lead boiler with the existing boiler as a secondary;
- assess the suitability of the available fuel supply. If natural gas is not available, or the pipe is too small, alternative fuels will need to be considered or the system may not be viable. Similarly, if the exportation of electricity is being considered, early discussions should be held with the district network operator (DNO) to identify any potential barriers with connection to the grid;
- evaluate the suitability of potential plant rooms, as CHP plants are loud, vibrate and require good ventilation. The exhaust needs to be in a place where noise will be limited and environmental / emissions regulations are met;
- conduct a detailed analysis of energy profiles for both heat and electricity (for which half hourly data is particularly useful). This will enable a summer heat baseload to be established. Half hourly data and/or BEMS are ideal for this task. CHP is most economic when the unit is sized slightly over the baseload heat load. Oversizing will result in excessive heat dumping, reducing the efficiency;
- calculate the heat to power ratio;
- determine the constant outlet for heat (the number of hours per year at, or above, the baseload). If the baseload is lower than 4,500 hours, options for thermal storage should be investigated;
- select the appropriate size and type of plant. It should be sized to match the base heat load to maximise efficiency;
- calculate the estimated emissions and financial savings. Ensure that the latest UK Government-published emissions figures are used and account for the reduced emissions from electricity generation due to it being generated through CHP.
- opportunities may also exist for local heat and power networks which could have an effect on the viability of an installation.

Fig 2. In a steam turbine a fuel is burned to heat up water



More detailed step-by-step information regarding the feasibility assessment phase can be found in the CIBSE AM12 Combined Heat and Power for Buildings (CHP) guide and the Carbon Trust's Introducing Combined Heat and Power guide.

The typical lifespan of the main components of a CHP system is 10-15 years, with maintenance required 6-10 times per year. Most sites with CHP do not have the resources to carry out servicing and maintenance of the unit themselves. A contract with the equipment supplier or specialist O&M engineers is an effective method of providing the necessary support to ensure the long-term reliability and performance of the plant. Annual maintenance contracts vary dramatically, depending on the size of the unit and the level of service required.

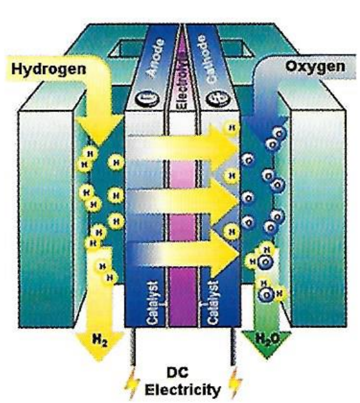
A typical maintenance package may include:

- 24 hour remote monitoring
- Automated SOS alerts via SMS
- Part identification
- Safe oil disposal
- Oil analysis
- A dedicated site engineer
- Planned preventative maintenance (PPM) schedule
- Parts & Labour
- Warranty
- Submission process for Climate Change Levy tax relief

The control of a CHP package is largely automated and requires little input from site staff. Provided that the systems connected to the unit continue to function correctly, the unit should be capable of continuous operation using its own control system.

In 1996, the UK produced the Combined Heat and Power Quality Assurance (CHPQA) scheme to encourage and regulate the installation and production of CHP. The Quality Index is a measure of the energy efficiency and environmental performance of a CHP system.

Fig 3. Fuel cell electrical efficiencies are around 55 per cent



Successful CHPQA certification grants eligibility to:

- Renewable Heat Incentive
- Carbon Price Floor (heat) relief
- Climate Change Levy exemption (in respect of electricity directly supplied)
- Enhanced Capital Allowances
- Preferential business rates.

In order to comply, the Quality Index must exceed a minimum value, based on the mean annual thermal and electrical efficiencies, and the fuel selected.

QI = X x Y

Where:

X = Power Efficiency (Total Power Output (MWhe) / Total Fuel Input (MWh))

Y = Heat Efficiency (Qualifying Heat Output (MWhth) / Total Fuel Input (MWh))

CHP has the potential to deliver significant financial benefits for organisations with a high base heat load and can save around 20 per cent of energy costs and 30 per cent of CO2 emissions. CHP units are straightforward to operate, simple to integrate into existing systems, relatively environmentally friendly, fuel neutral and can help buildings to comply with environmental regulations. However, the units have high maintenance requirements and a short life span in comparison to other technologies. If it is believed that a CHP unit may be appropriate for a building or district heating network, a full feasibility study should be undertaken to determine the base heat load and the most appropriate type of prime mover. A life cycle cost analysis should be undertaken to ensure that it is financially viable.

Further reading

The following documents can be used to find further information:

- UK Government CHP Site Assessment Tool - http://chptools.decc.gov.uk/CHPAssessment/(S(ceup3z3lxmwh3kyds2ngmqgv))/default.aspx
- Carbon Trust Guide Introducing Combined Heat and Power -https://www.carbontrust.com/media/19529/ctv044_introducing_combined_heat_and_power.pdf
- CIBSE AM12 Combined Heat and Power in Buildings (CHP) guide - http://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7nsAA

CPD SERIES **15** | MODULE **05** | OCTOBER **2017**

ENTRY FORM

COMBINED HEAT & POWER

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

QUESTIONS

1. What carbon savings can be achieved by installing CHP?
- ☐ 10 per cent
- ☐ 20 per cent
- ☐ 30 per cent
- ☐ 40 per cent

2. What type of engine would be best suited to a building with a 60kWe load and a supply of natural gas, with a high demand for both heat and electricity?
- ☐ Internal combustion engine
- ☐ Large scale turbine
- ☐ Steam turbine
- ☐ Fuel cell

3. What is the recommended minimum number of hours per year that CHP has to operate to be efficient?
- ☐ 3,500 hours
- ☐ 4,000 hours
- ☐ 4,500 hours
- ☐ 5,000 hours

4. Which of the following applications is ideal for CHP?
- ☐ A domestic household
- ☐ A small office block
- ☐ A leisure centre
- ☐ A large non-boarding school

5. What level of efficiency can CHP plants operate at?
- ☐ Up to 75 per cent
- ☐ Up to 85 per cent
- ☐ Up to 95 per cent
- ☐ Up to 100 per cent

6. What is the most useful information to have when calculating base heat load of an existing building?
- ☐ Number of occupants
- ☐ Quarterly billing data
- ☐ Half hourly metered data
- ☐ An external consultant's estimate

7. What is the typical lifespan of a CHP unit?
- ☐ 5-10 years
- ☐ 10-15 years
- ☐ 15-20 years
- ☐ 20-25 years

8. What is the scheme implemented by the UK government to encourage and regulate the installation of CHP?
- ☐ The Climate Change Levy
- ☐ The CHPQA
- ☐ The CRCEES
- ☐ Part L regulations

9. In traditional power stations, what percentage of energy is lost through transmission losses?
- ☐ 3 per cent
- ☐ 5 per cent
- ☐ 7 per cent
- ☐ 10 per cent

10. How regularly does a CHP unit have to be maintained?
- ☐ Once a year
- ☐ Twice a year
- ☐ 6-10 times a year
- ☐ Twice a month

Please complete your details below in block capitals

Name .... (Mr. Mrs, Ms) ....

Business ....

Business Address ....

....

....

.... Post Code ....

email address ....

Tel No. ....

Completed answers should be mailed to:

The Education Department, Energy in Buildings & Industry, P.O. Box 825, GUILDFORD, GU4 8WQ

Produced in Association with

CPD fundament

THE CONTINUING PROFESSIONAL DEVELOPMENT

How to obtain a CPD accreditati from the Energy Institute

Energy in Buildings and Industry and the **Energy Institute** are delig have teamed up to bring you this **Continuing Professional Developm** initiative.

This is the fifth module in the fifteenth series and focuses on **Combir and Power**. It is accompanied by a set of multiple-choice questions.

To qualify for a CPD certificate readers must submit at least eigh ten sets of questions from this series of modules to EiBI for the Ener Institute to mark. Anyone achieving at least eight out of ten correct an eight separate articles qualifies for an Energy Institute CPD certificate. T obtained, on successful completion of the course and notification by th Institute, **free of charge** for both Energy Institute members and non-m

The articles, written by a qualified member of the Energy Institute, wi to those new to energy management and those with more experience c subject.

Modules from the past 14 series can be obtained free of charge. your request to editor@eibi.co.uk. Alternatively, they can be dowr from the EiBI website: www.energyzine.co.uk

SERIES 14
MAY 2016 - APR 2017
1 Biomass
2 Behaviour Change
3 Energy Management Standards
4 Air Conditioning
5 Internet of Things
6 Training for Energy Management
7 Data Centre Management
8 Metering & Monitoring
9 Battery Storage
10 Demand Side Response

SERIES 15
MAY 2017 - APR 2018
1 Lighting Technolog
2 Boilers & Burners
3 Compressed Air
4 Water Management
5 Combined Heat and
6 Drives & Motors*
7 Underfloor Heating*
8 Energy Purchasing*
9 Photovoltaics*
10 Heat Pumps*

** ONLY available to download from the website after publication date*

energy institute

The Energy Institute (EI) is the professional body for the energy industry, developing and sharing knowledge, skil and good practice towards a safe, secure and sustainable energy system. The EI supports energy managers by offe membership and professional registrations including Chartered Energy Manager, as well as workshops, events, training and networking opportunities across the UK and overseas. It also produces a number of ...