THE CONTINUING PROFESSIONAL DEVELOPMENT PROGRAMME

Fundamentals CPD

Combined heat and power – the view from 2021

by Gareth Veal PhD, MEI, CEng, Chartered Energy Manager

Combined heat and power has been a strong card in the energy manager's deck for several decades now. However, the context within which CHP sits is shifting and this article explores some of the factors that anyone currently exploring a potential CHP investment will find relevant.

Traditional cases for CHP, in both cost and environmental terms, have been with reference to a National Grid dominated by fossil fuel generation. In this comparison, a grid-scale fossil fuelled power station without heat recovery will typically reject significant quantities of heat to the atmosphere. In the case of CHP, such waste heat is recovered and used to meet on-site heat demands. The performance of CHP versus this reference case is illustrated in Figure 1.

Two options for meeting a local heat demand of 160kW and a power demand of 100kW are compared.

The left-hand side shows the CHP option, where an engine is used to generate electricity, and waste heat is captured for use on site. For any given hour, the CHP system requires a primary energy input of 325kWh to supply 260kWh of useful energy, so the efficiency of this system is 80 per cent.

The right-hand side of Figure 1 shows the alternative of using an onsite boiler to meet the heat load, plus grid electricity to meet the electrical demand. The waste heat from a traditional 'thermal/'fossil fuel' power station is typically not recovered. Transmission and distribution losses of ~7.5 per cent are also incurred in the delivery of the electricity to site. In this case, for any given hour, the 260kWh of useful energy requires an input of 465kWh of primary energy, delivering a system efficiency of 56 per cent.

This reference case has been appropriate over recent decades. However, it is timely to revisit it, since the penetration of renewables has increased and the greenhouse gas content of grid electricity has reduced dramatically.

The latter part of this article explores the implications of these changes for the environmental benefits of CHP going forwards. Also considered is CHP's attractiveness when viewed against alternatives, such as the use of heat pumps to meet local heat requirements, paired with grid electricity supply.

However, before we explore these new dynamics the traditional considerations when reviewing the case for a CHP investment still stand, and are worth revisiting, as summarised in Figure 2.

Figure 1: Energy balance of Onsite CHP vs. Boiler plus Grid Electricity

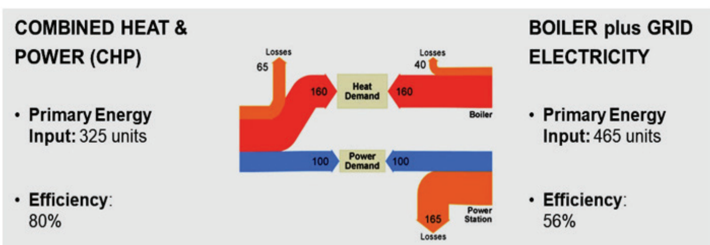


Figure 2: Standard considerations during a CHP investment appraisal[1]

1) CHP under consideration:

- ENERGY HIERARCHY: exhaust all viable efficiency opportunities first;
- Site plans? Significant changes anticipated in scale/occupancy / activity types?;
- Significant heat load onsite, or nearby?;
- Appropriate infrastructure in place?;
- Existing energy contracts?;
- Regulatory considerations?; and
- Reference options to consider e.g. heat pumps, traditional condensing boilers, joining local heat network, etc?

↓

2) Developing the operating model / business case:

- Gather energy data;
- Develop heat and electricity demand profiles;
- Establish estimated energy, maintenance and capital costs;
- Review environmental performance considerations;
- Construct draft operating model;
- Use model to optimise CHP size and investigate the potential for including a thermal store / tri-generation; and
- Final feasibility model reported.

Energy efficiency first

During the early stages of considering a CHP investment, the following factors are important:

• One of the most common issues with a CHP project is that of 'oversizing'. When considering an investment in CHP, it is important to bear in mind the energy hierarchy and exhaust all viable energy efficiency opportunities first. For example, typical estimates are that zero- to low-capital energy efficiency investments can reduce a site's demand by 5 per cent to 30 per cent. As well as offering highly attractive savings, if these projects are implemented after the CHP is installed, then they will alter the site's demand profiles and most likely render the CHP oversized and incorrectly specified.

• It is also important to check for any anticipated changes to the site's occupancy levels, or activity levels and types. Any significant changes on site will change the heat and electricity demand profiles and should be taken account of as the case for CHP is developed.

• A site must also have a fairly constant heat demand to make use of the heat recovered by a CHP system. A rule of thumb suggested by the Carbon Trust is that CHP is worth investigating when

For details on how to obtain your **Energy Institute CPD Certificate**, see ENTRY FORM and details on page 20

operating hours are anticipated to be more than ~4,500 hours per annum.

• **A successful CHP project will require some basic infrastructure to be in place or available.** For example, a CHP is likely to reduce electrical demand and increase demand for the CHP unit's fuel, which is typically gas. It is important to check that the required gas, or other fuel supply, is present or available to meet the increased demand. Furthermore, if the business case includes a proposal to export some of the power generated, then it will be necessary to check with the local distribution network operator that they have capacity to accept this export. Further considerations such as the age and condition of existing boiler plant and plant room configurations will influence the case for CHP. It can be beneficial at an early stage of the project to invite a few potential providers to perform initial site visits and review these considerations.

• **The cost of gas and electricity in both relative and absolute terms will significantly impact the business case for CHP.** It is worth checking the current energy contract unit rates and the contract durations. CHP is likely to decrease the site's electricity imports- making it important to check for any long-term electricity contracts with 'take or pay' clauses that impose a penalty for not meeting the anticipated electricity consumption agreed with the supplier. If such a contract exists, it may be worth exploring the potential options to alter it. Alternatively, the contract's expiry date can be taken into account when planning the timing of a CHP investment.

• **It is important to consider the regulatory requirements governing your proposed project to see what their implications might be for CHP feasibility.** For example, CHP in London faces a significant hurdle in that the London Plan is targeting reduced local air pollution and is also introducing climate targets that potentially favour electric-led building services via heat pump technologies.

• **A sound business case will not be constructed to ask 'CHP: yes or no?' Instead it will explore the relative merits of a number of options.** These reference options could include, but are not limited to: focusing first upon efficiency projects to drive down consumption, heat pumps, traditional condensing boilers, or joining a local heat network.

When developing a CHP operating model and business case the first step is to gather site energy data on the electrical and heat demands that detail their scale and also their 'shape' over the year. The starting point is that CHP applications are typically sized to meet the continuous or baseload site requirements, with back up boilers topping up heat demand and incoming electricity supplies topping up electrical demand. This is because CHP business cases tend to require long hours of operation to achieve acceptable payback periods, so sizing for relatively infrequent peak loads would result in a system that is oversized and less financially attractive.

Fig 3a: CHP GHG emissions

	Onsite Consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG consumption (kg CO_{2e})
Gas	325	0.184	59.8
			59.8

Fig 3b: Reference case GHG emissions: boiler plus grid electricity

	Onsite Consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG consumption (kg CO_{2e})
Gas	200	0.184	36.8
Electricity	100	0.256	25.6
			62.3

The more granular the data, the better the confidence in the CHP sizing process will be. This will help with the identification of demand profiles within cycles such as: day-night, weekday-weekend, and across the months and seasons of the year. Half hourly data is the ideal level of granularity for the development of CHP modelling. Where sufficient quality data is not available, it is worth installing temporary metering to fill any gaps and give adequate confidence in the demand profiles and hence the CHP sizing.

Anticipated energy costs

The final costs required for the draft operating model of the CHP will also include the anticipated energy costs, plus the O&M and capital costs. These should not be underestimated, both in terms of cost, but also operational risk. A common challenge with the operation of CHP is in achieving the levels of reliability required to deliver the operating hours necessary for acceptable payback periods that justify the investment.

Once this basic operating model has been constructed and initial options have been identified, then the next level of detail can be added and eventually an operating model should be able to:

• determine whether the CHP is worth operating, based on the relative fuel and electricity prices in each time period considered;
• determine whether the output of the CHP is to follow the heat demand or electricity demand, taking account of part-load operation, and hence the CHP fuel used;
• establish the heat needed from the peak and standby boilers and hence the boiler fuel used;
• make allowance for CHP downtime for maintenance;
• include any constraints on number of starts;
• model the operation of a thermal store;
• determine the net import or export of electricity and the costs / revenue implications; and
• calculate the operating costs and other financial metrics to compare with the non-CHP reference scenarios.

> **"A sound business case around CHP will not be constructed to ask: 'yes or no?'"**

The model will also be useful in testing the sensitivity of the findings to key variables, such as:
• heat and power demands;
• gas and electricity prices; and
• capital costs.

While all of the traditional considerations given above still stand, it is also important to explore the changing context for CHP, as grid electricity shifts towards renewables, and also as other technologies such as heat pumps gain momentum.

The calculations below compare the GHG emissions from the two scenarios described in Figure 1, i.e. an onsite CHP option versus the reference case of purchasing grid electricity and using an onsite boiler for heat generation.

These calculations show that, using DEFRA's 2019 GHG reporting factors, the CHP will achieve a reduction in emissions of 2.6kg CO_2e per hour, or approximately 10.5 tonnes CO_2e per annum. These values are reached by assuming annual CHP operating hours of 4,031h, the average observed in data from the government's CHPQA programme which monitors CHP performance in the UK.

The hourly CO_2e emissions for both cases are calculated as shown in Figs 4a and 4b.

These GHG savings are significantly lower than they would have been historically. Reference to Figure 4 shows that the 2.6kg CO_2e per hour saving using DEFRA's 2019 factors would have been approximately ten time greater, at 25.5kg CO_2e per hour when calculated using the GHG factor for grid electricity as of 2009. Although there have been some changes to how the GHG intensity of grid electricity has been calculated over the past decade, the numbers are still indicative of the overall trend in the decarbonisation of the UK's grid electricity.

Future climate performance

The future climate performance of CHP becomes increasingly challenging when taking into account the government's projected reductions in the GHG intensity of grid electricity over the coming decade. Reference to Figure 3 shows that the anticipated GHG performance of the CHP is actually worse than that of the reference case of using grid electricity and an onsite boiler; giving an increase in GHG emissions of 13.0 kg CO_2e per hour when calculated using the projected GHG factor for grid electricity for 2029.

These modelled results correspond with measured trends in performance, for example as reported in the 2019 Digest of UK Energy Statistics: "The absolute CO_2 savings delivered by CHP in 2018 were lower than in 2017. This is due to the provisional values for CO_2 intensity of electricity displaced by CHP electricity being lower in 2018 than in 2017, rather than falls in the outputs of CHP, or efficiency of operation."Figure 4: Comparing the GHG performance of CHP to Air

Figure 4: Comparing the GHG performance of CHP to Air Source Heat Pumps using historic, current, and forecast GHG factors for grid electricity

2009 VALUES[2]				2019 VALUES[3]				2029 VALUES[4]			
REFERENCE (BASE) CASE: Boiler for heat demand, plus grid electricity											
	Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})		Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})		Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})
Gas	200	0.184	36.7	Gas	200	0.184	36.8	Gas	200	0.184	36.8
Elec	100	0.485	48.5	Elec	100	0.256	25.6	Elec	100	0.100	10.0
			85.3				**62.3**				**46.8**
OPTION 1: CHP											
	Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})		Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})		Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})
Gas	325	0.184	59.7	Gas	325	0.184	59.8	Gas	325	0.184	59.8
			59.8				**59.8**				**59.8**
OPTION 2: ASHP* for heat demand, plus grid electricity: *, e.g. the Mitsubishi Q-ton heat pump: https://mhiae.com/q-ton/ (COP 4.3)											
	Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})		Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})		Energy consumption (kWh)	GHG factor (kg CO_{2e}/kWh)	GHG emissions (kg CO_{2e})
Elec to ASHP	37.2	0.485	18.0	Elec to ASHP	37.2	0.256	9.5	Elec to ASHP	37.2	0.100	3.7
Elec to site	100	0.485	48.5	Elec to site	100	0.256	25.6	Elec to site	100	0.100	10.0
			66.5				**35.1**				**13.7**
	CHP saving (kg CO_{2e}):		**25.5**	CHP saving (kg CO_{2e}):			**2.6**		CHP saving (kg CO_{2e}):		**-13.0**
ASHP plus Grid elec saving (kg CO_{2e}):			**18.7**	ASHP plus Grid elec saving (kg CO_{2e}):			**27.3**	ASHP plus Grid elec saving (kg CO_{2e}):			**33.0**

Source Heat Pumps using historic, current, and forecast GHG factors for grid electricity.

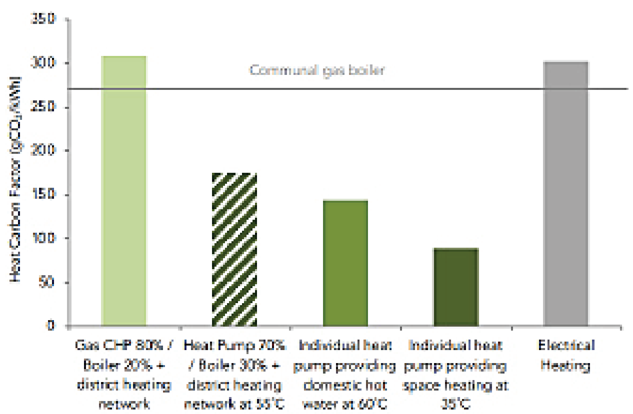
Heat pump technologies offer two attractive possibilities that are bringing them to the forefront of discussions as to how to meet future heat demands for domestic and commercial properties. The first is the consideration that, as they run on electricity, they offer the potential to track the decarbonisation of the grid as a low carbon source of heat. The second is that they do not create any local combustion emissions, an important consideration in urban areas where air quality is becoming an increasingly pressing issue.

With respect to their GHG performance, the bottom section of Figure 5 explores how an air source heat pump solution might compete with the CHP installation illustrated in Figure 1.

A reference example of a Mitsubishi Q-ton heat pump[5] designed for applications such as hotels is explored. To meet the hourly 160kWh heat load, the unit's COP 4.3 is used to estimate a requirement for 37.2 kWh of electricity to drive the heat pump. The 100kWh of electrical demand is met by the national grid.

Using the 2009 grid GHG intensity factor, the CHP comfortably outperforms the ASHP solution. However, using 2019 factors, the ASHP solution delivers approximately ten times the carbon saving of the CHP system. This performance gap grows further when projected 2029 factors are applied, with the CHP becoming more carbon intensive than the reference case, while the savings offered by the ASHP solution continue to rise.

Figure 5: Comparison of carbon intensity of different heat sources (GLA study of heat pumps[6])



Potential of heat pumps

These observations are consistent with the finding of a study of examining the potential of heat pumps to provide low carbon heat as a policy recommendation under consideration by the Greater London Authority, as summarised in the figure below.

With these findings in mind, it becomes clear that a heat pump solution should be appraised as an alternative 'reference' option to the installation of a CHP. This is especially true if climate change mitigation, or local air quality objectives are driving the project; either for internal organisational reasons, or as imposed by external authorities such as during planning applications.

Finally, it should be noted that this discussion has assumed the GHG emissions factor related to natural gas remains relatively stable. There is ongoing research that may cause this assumption to fail, for example into the potential to develop 'green gas' such as 'biomethane' which can be produced via anaerobic digestion, or to modify the gas network to carry hydrogen. While this observation simply provides more uncertainty, it is another example of how the base assumptions underpinning historical business cases for CHP require careful examination and that the assumption that energy, carbon and cost savings will go hand in hand for a CHP project can no longer be taken for granted.

REFERENCES

1) See CIBSE AM12: 'Combined heat and power for buildings' for more detail https://www.cibse.org/knowledge/knowledge-items/detail?id=a0q20000008I7nsAAC
2) https://webarchive.nationalarchives.gov.uk/20120312120248/http://www.defra.gov.uk/environment/economy/business-efficiency/reporting/
3) www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019
4) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794590/updated-energy-and-emissions-projections-2018.pdf
5) https://mhiae.com/q-ton/
6) https://www.london.gov.uk/sites/default/files/low_carbon_heat_-_heat_pumps_in_london_.pdf

CPD SERIES 19 / Module 04
Combined Heat & Power

Produced in Association with energy institute

ENTRY FORM

Please mark your answers below by placing a cross in the box. Don't forget that some questions might have more than one correct answer. 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, return it to the address below. Photocopies are acceptable.

Questions

1) Define combined heat & power

- ☐ CHP is a term used to refer to processes that require both electrical power and heat to drive them.
- ☐ CHP involves the simultaneous generation of usable heat and power in a single process.
- ☐ CHP refers to dual fuel energy contracts that can often deliver cost savings.
- ☐ CHP is a means of providing efficient supply of energy to sites that are geographically very remote.

2) How does a CHP unit reduce total energy use, as compared to electricity from the grid and heat from a boiler?

- ☐ CHP rejects the waste heat generated locally to avoid problems with heat utilisation.
- ☐ CHP plant tends to use cleaner fuels which burn more efficiently than those used in grid scale power plants.
- ☐ A fossil fuel power station will reject heat to atmosphere. In the case of CHP, waste heat is recovered and used to meet on-site heat demands.

3) What is the primary consideration when reviewing a potential CHP investment?

- ☐ To avoid siting the CHP in a location that spoils future aesthetics of the site.
- ☐ To make sure that the CHP unit fits with the corporate image.
- ☐ To take account of any changes anticipated with regards to the site's occupancy levels, activity levels, or types of activity.
- ☐ To avoid any conflicts of interest between the organisations that occupy the site.

4) Why is it important to understand and minimise site loads before considering a CHP investment?

- ☐ To follow the 'energy hierarchy' and ensure that all efficiency opportunities, are implemented before finding new ways to supply energy.
- ☐ To avoid oversizing the CHP unit which will make it difficult to operate in a cost effective fashion.
- ☐ To allow the business model for the CHP to factor in seasonal and other time-based fluctuations in site demands.
- ☐ To achieve all of the objectives listed above.

5) What is the primary reason that the anticipated operating hours are important to a CHP business case?

- ☐ Because they determine the energy use of the CHP.
- ☐ CHP feasibility relies upon high hours of operation to deliver savings high enough to pay back the capital investment.
- ☐ Because they impact upon the likely hours of operation of backup plant such as gas boilers.

6) What site characteristic represents an essential part of an attractive CHP business case?

- ☐ A site must have a peaky and intermittent heat demand that allows the CHP to cycle in a fashion that increases its efficiency.
- ☐ A site must have a fairly constant heat demand over large parts of the year to make use of the heat recovered by a CHP system.
- ☐ A site must have a heat demand that is closely controllable and largely independent of site activity.

7) What type of data represents the ideal basis for modelling likely CHP performance?

- ☐ Estimates based upon long-term 'hands-on' knowledge of the site.
- ☐ Half hourly data.
- ☐ Meter reads.

8) Which of the following site infrastructure considerations should be reviewed when examining the case for CHP?

- ☐ Check that the required gas, or other fuel supply, is present or available to meet the increased demand.
- ☐ Check with the local distribution network operator that they have capacity to accept any planned electricity exports.
- ☐ Both of the above

9) What trend is making it important to closely examine the GHG/climate performance of CHP?

- ☐ The GHG intensity of grid electricity is falling as we transition away from fossil fuels and towards renewables.
- ☐ GHG reporting conventions have changed in a manner that reduces the apparent attractiveness of CHP.
- ☐ CHP units are now available with integrated carbon capture.

10) What potential developments in the gas delivery network could challenge the assumptions behind the answer to the previous question?

- ☐ Development of 'green gases' such as 'biomethane', or mixing of hydrogen in the mains gas supply may reduce the GHG emissions of mains gas, altering the GHG balance of CHP applications.
- ☐ The GHG intensity of mains gas is rising as gas is supplied from further afield.
- ☐ Security of supply concerns may make gas-fired CHP less viable in the future.

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.
Or scan and e-mail to: editor@eibi.co.uk.
All modules will then be supplied to the Energy Institute for marking

"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

How to obtain a CPD accreditation from the Energy Institute

This is the fourth module in the nineteenth series and focuses on **Combined Heat & Power**. It is accompanied by a set of multiple-choice questions.

To qualify for a CPD certificate readers must submit at least eight of the ten sets of questions from this series of modules to EiBI for the Energy Institute to mark. Anyone achieving at least eight out of ten correct answers on eight separate articles qualifies for an Energy Institute CPD certificate. This can be obtained, on successful completion of the course and notification by the Energy Institute, **FREE OF CHARGE** for both Energy Institute members and non-members.

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

Modules from the past 18 series can be obtained free of charge. Send your request to editor@eibi.co.uk. Alternatively, they can be downloaded from the EiBI website: www.eibi.co.uk

SERIES 19 JUNE 2021 - MAY 2022

1. Electric Vehicles
2. Refrigeration
3. Underfloor Heating
4. **Combined Heat & Power**
5. Humidification*
6. Smart Buildings*
7. Photovoltaics & Batteries*
8. Air Handling*
9. Variable Speed Drives*
10. Boilers & Burners*

** Only available to download after publication date*

CPD Fundamentals
THE CONTINUING PROFESSIONAL DEVELOPMENT PROGRAMME

Terms: in submitting your completed answers you are indicating consent to EiBI's holding and processing the personal data you have provided to us, in accordance with legal bases set out under data protection law. Further to this, EiBI will share your details with the Energy Institute (EI) with whom this CPD series is run in contractual partnership. The EI will process your details for the purposes of marking your answers and issuing your CPD certificate. Your details will be kept securely at all times and in a manner complaint with all relevant data protection laws. For full details on the EI's privacy policy please visit www.energyinst.org/privacy.

To hear more from the EI subscribe to our mailing list: visit https://myprofile.energyinst.org/EmailPreferences/Subscribe