Characterising the operation and flexibility of campus energy systems

Muditha Abeysekera, Xiandong Xu, Alexandre Canet, Jianzhong Wu |

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Summary

Campus energy systems are site-based local energy systems and large users of electricity and heat (hospitals, business parks, universities etc.). These energy systems are complex and typically contain multiple energy assets such as renewable power generation from solar PV or wind turbines, combined heat and power generation (CHP) units, gas boilers and energy storage. Campus energy systems are controlled 'behind the meter' (or by the energy user) typically to reduce site energy costs. Collectively many such campus systems across a region aggregate to a significant scale which, depending on the way they are operated, can either reduce or increase power flows in the electricity distribution and transmission networks. Campus energy systems are well placed to be smart, active participants in the wider power system and support efficient management of grid operation.

Natural gas-fired CHP generation units are a popular technology for campus sites. They are also a potential source of flexibility for the power system. They are economically attractive but are a source of carbon emissions and do not support the Net Zero ambitions of an organisation. This presents a dilemma for facility owners and operators on the medium-to-long-term energy infrastructure investment strategy.

This briefing paper presents findings from a study of two public sector campus energy systems with CHP generators and renewable power generation technologies installed on-site. Site operational characteristics and the role of CHP generators and thermal storage systems are analysed and discussed. The study highlights the challenges of incorporating renewable power generation technologies on campus sites and the conflicting economic and carbon performance from operating CHP generators. It highlights the need for a whole systems framework to assess the techno-economic and environmental impact of CHP generators.

Public sector campus energy systems

The public sector is the largest single buyer of gas and electricity in the UK (outside the big six energy suppliers). The public sector consumes 6% of the UK's energy and spends around £2billion per annum on its energy bill. The UK government expects the public sector to lead the decarbonisation agenda by introducing carbon reduction targets for its estate. Public sector organisations such as hospitals and universities often own and operate multi-vector energy supply systems of electricity, gas, hot water and chilled water networks. The drive towards reducing carbon emissions and increasing energy costs has led to the installation of on-site renewable energy technologies such as wind turbines and solar panels and energy storage technologies on a number of these sites. Figure 1 shows a schematic of a typical campus site energy system.

We modelled two campus energy systems using the concept of multi-vector energy hubs introduced by Geidel M. et al. (2007)[1]. The first case study is based on the Queen Elizabeth Hospital (QEH), a regional hospital in Kings Lynn, Norfolk, UK.

The second case study is of a larger campus site, the University of Warwick (UoW) campus. Both sites include on-site renewable generation, natural gas-fired CHP generators and gas boilers. The University of Warwick campus energy system also includes significant thermal storage. The electrical power generation from CHP generators provides an opportunity for optimisation of the site energy system. The operating strategy of a campus energy system has traditionally been to minimise site energy costs but can also be to maximise revenue from electricity exports, minimise carbon emissions, provide grid flexibility services or a combination of these objectives.

We developed mathematical models to study the operational behaviour of site energy systems at QEH and UoW. We used historic monitored energy data from QEH and UoW collated to hourly granularity and analysed the operational and flexibility characteristics of these two public sector sites.

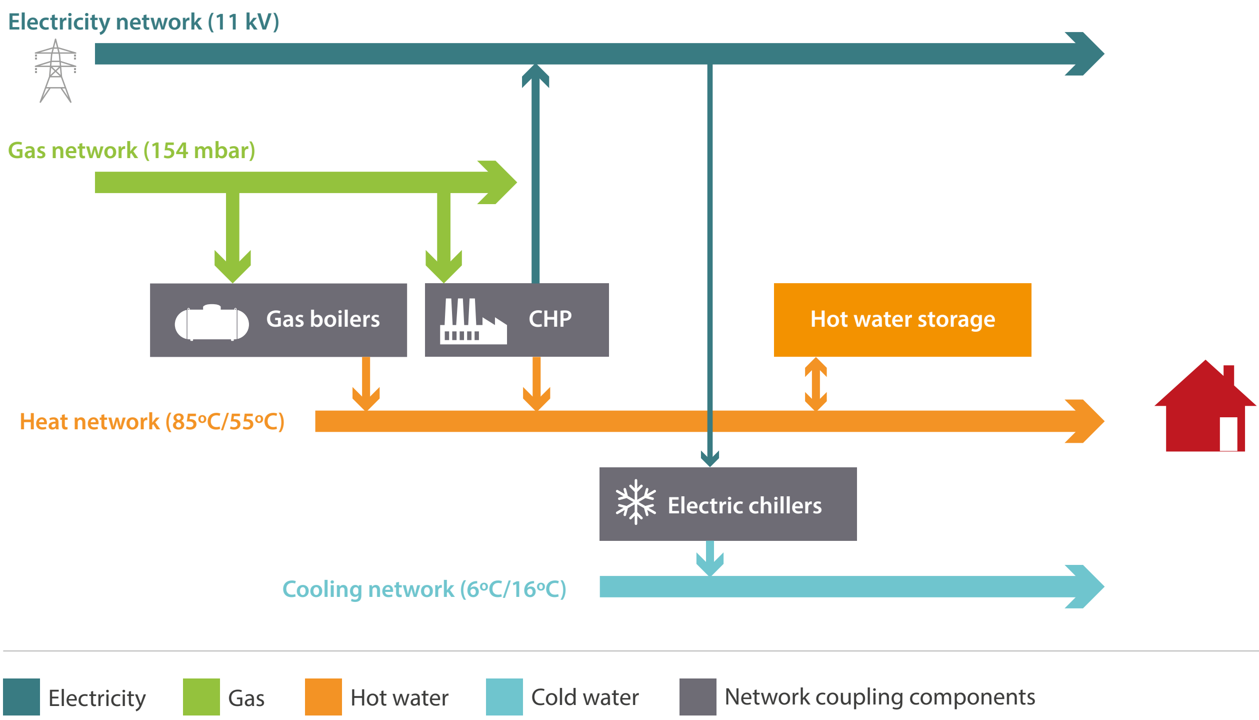

Figure 1: Typical energy supply systems of a campus energy system

1 Geidl, M. & Andersson, G. 2007. Optimal Power Flow of Multiple Energy Carriers. Power Systems, IEEE Transactions on, 22, 145-155.

Key insights

Electricity and heat demand in campus sites and the role of renewables

- Electricity and heat demand on these campus sites show a predictable pattern. This is useful for optimising site energy systems and for providing grid services.
- The electricity demand for both sites has a regular diurnal and weekly profile linked to occupancy. The site heat demand shows a seasonal variation that is correlated with ambient air temperature.
- On-site renewable power generation reduces grid electricity imports and, depending on the carbon intensity of grid generation, reduces the carbon emissions of the site. The University of Warwick has 593kWp of solar PV generation and Queen Elizabeth Hospltal an 800 kW wind turbine. For the one-year period studied, 14% of the Queen Elizabeth Hospital and 8% of the University of Warwick annual electricity requirements were met by on-site renewable power generation.

The role of combined heat and power generation units and thermal stores

- Natural gas-fired CHP units play a central role in meeting the electricity and heat demands of a campus site. CHP generation units supplied 57% at QEH and 60% at UoW of the overall energy used (i.e. electricity and natural gas).
- CHP units are operated to reduce site electricity imports or to meet the site heat demand.
- Thermal storage tanks provide operational flexibility for the CHP generation units. This was evident from the UoW case where some of the mismatch between site electricity and heat demand was accommodated by the thermal storage acting as a buffer.
- In the UK, combined heat and power is popular due to its economic advantages. However, its carbon saving advantage has reduced substantially over the past decade with the rapid decarbonisation of grid electricity.

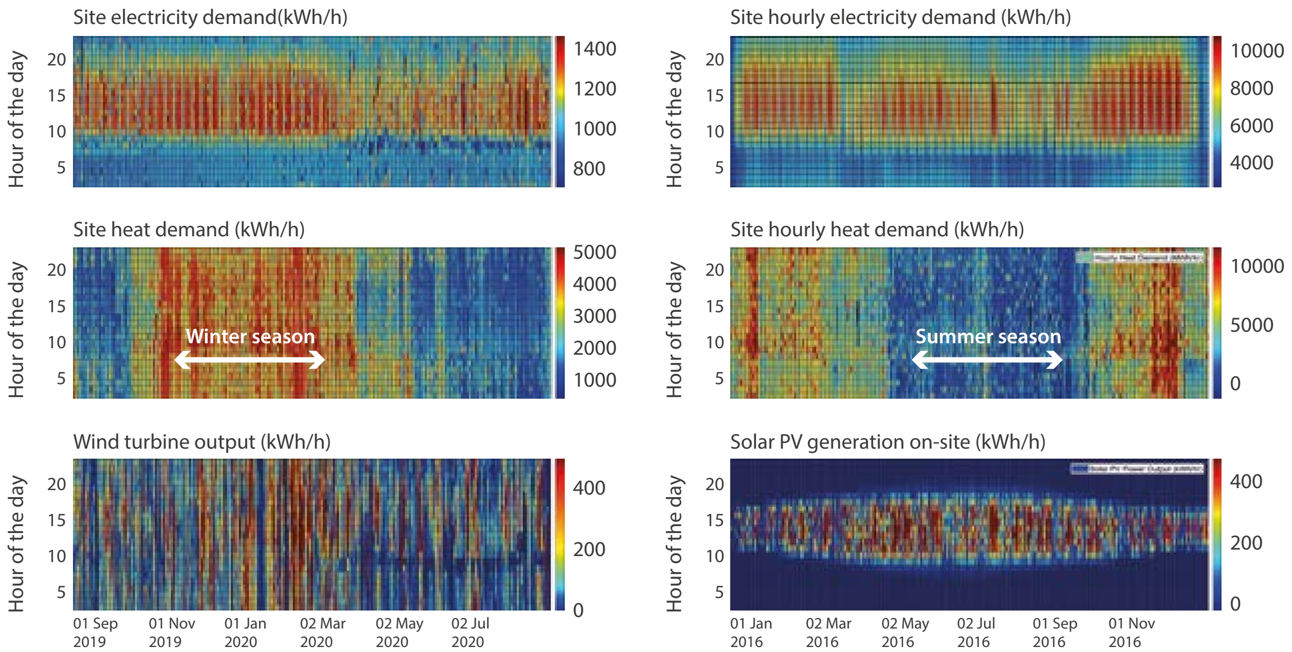

Figure 2: Operational data for hourly electricity demand, heat demand and on-site renewable generation at Queen Elizabeth Hospital (Left hand) and University of Warwick (Right hand) campus for one year.

Available flexibility from campus energy systems

- Flexibility is the ability to increase or decrease on-site electricity generation or demand and can be offered as a service to the power grid. Campus energy systems with natural gas-fired CHP units have the potential to provide flexibility to the power system. Results of the study show both the QEH and the UoW sites have the potential to provide flexibility by increasing or reducing on-site power generation.
  - » The capacity to increase on-site power generation is termed "Upward Flexibility"
  - » The capacity to reduce on-site power generation is termed "Downward Flexibility"
- The flexibility available at a given time is determined by the power capacity of the CHP generation units and the seasonal and daily energy requirements of the site. Table 1 below shows a summary of the results on the flexibility of the case studies. The indicative costs and the carbon emissions of providing flexibility (on-site carbon emissions from gas combustion and emissions associated with grid electricity import) for different heat seasons and electricity demand levels are shown using a colour code and values shown.
- To provide 'downward flexibility' to the public power grid, QEH and UoW can reduce on-site power generation on-demand. Reducing power output from CHP generation units would increase electricity imports and increase the heat required from gas boilers. Therefore, the site owner would require remuneration. When the carbon intensity of grid electricity is above 240gCO2/kWh this would reduce overall carbon emissions.
- The ability to increase on-site power generation (upward flexibility) is less frequently available (limited to off-peak electricity demand periods) due to the high utilisation of the CHP units. Increasing on-site power generation would often reduce site energy costs for the site operator. This creates additional revenue from electricity sales and provides extra heat that is useful, particularly during the winter period. However, this would increase carbon emissions from the site.
- Thermal storage tanks help reduce waste heat and thereby reduce the cost and carbon emissions of providing flexibility to the power grid.

Table 1: Available power flexibility from campus energy systems

Heat system state	Electricity system state	Upward flexibility			Downward flexibility		
		Availability	Cost	CO_2	Availability	Cost	CO_2
Summer conditions	Low demand (night time)	Yes	−7p	+480g CO_2	No		
	High demand (night time)	Yes	−4p	+680g CO_2	Yes	+4p	−580g CO_2
Winter conditions	Low demand (night time)	Yes	−10p	+180g CO_2	Yes	+7p	−354g CO_2
	High demand (night time)	No			Yes	+10p	−454g CO_2

Flexibility cost: **Green** indicates a negative cost where the provision of flexibility reduces overall energy costs for the site owner, **Red** indicates a positive cost where the provision of flexibility will increase the overall energy costs for the site owner

On-site carbon emissions associated with flexibility provision: **Green** indicates reduced carbon emissions where the provision of flexibility reduces overall carbon emissions for the site owner, **Red** indicates positive carbon emissions where the provision of flexibility will increase the overall carbon emissions for the site owner

Policy considerations

- The UK Net Zero ambition and wider power system challenges are driving campus energy systems to reduce their carbon footprint and to invest in renewable generation, low carbon heating and energy storage technologies. There is a significant opportunity for these sites to be active participants in the power system by providing services to support efficient management of the grid and so create revenue.
- Natural gas-fired CHP generation units are still a popular technology for campus sites. They are economically attractive but are a source of carbon emissions and do not support the Net Zero ambitions of a campus site. This presents a dilemma for site operators.
- Many campus sites with natural gas-fired CHP units and on-site renewables would benefit from a Flexible Grid Connection that allows increased electricity exports where network conditions allow. Otherwise, renewables often need to be curtailed or the CHP units to be constrained off and heat generated by gas boilers
- The provision of flexibility from campus gas-fired CHP generation units can have conflicting economic and emissions performance. A whole systems framework to assess its techno-economic and environmental impact is required.

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@EnergyREV_UK

EnergyREV

info@energyrev.org.uk