

Evaluating CHP management and outputs using simple operational data

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Abstract

Combined Heat and Power (CHP) systems can satisfy thermal and electrical demand within cities. But, operating CHP outside of optimal conditions can result in performance below the predicted level. This study uses a 6-year dataset collected by a Local Authority (LA) from a CHP-led heat network. The results show, the studied CHP electrical output fell by around 30% and was not quickly rectified. This resulted in an estimated loss of revenue for the LA of £18 500. The paper highlights the importance of a simple method to review key operational data from a CHP-led system and ensure consistent management and output.

Keywords: CHP; District Heat Network; management; operational data; Local Authority

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1 INTRODUCTION

In 2014, housing accounted for 27% of the total UK final energy consumption, equivalent to 444 TWh, exceeded only by the transport sector at 38% or 630 TWh [1]. In cities where there are a plethora of buildings that require both thermal and electrical energy, a cogeneration system may be a good solution to satisfying such a demand. Combined Heat and Power (CHP) systems fit this role well.

The UK has an aging housing stock. In 2014, 58% of the housing stock had been built prior to 1964 [2], and the number of dwellings built by LA's in England has decreased significantly over time, from 128 000 dwellings per year in 1969 to 1 500 dwellings per year in 2015 [3]. By 2050, a significant portion of the housing stock existing in 2005 will still be in use, accounting for approximately two-thirds of the 2050 stock [4]. Thus, implementing measures to reduce carbon emissions in the current housing stock will be vital to LA's meeting of future emissions targets.

In the UK, the use of Heat Networks, and in some cases CHP, is often encouraged by Local Authorities (LA) within their planning policies; including the three largest metropolitan areas, in London [5], Birmingham [6] and Leeds [7]. The use of heat networks and CHP as retrofit tools to reduce a buildings carbon emissions is also possible. The UK is committed to reducing carbon emissions to 'at least 80% below the 1990 baseline' [8]. The introduction of wider heat networks in areas which have multiple

high-rise housing blocks has also become a practical solution since the Ronan Point disaster in 1968 [9]. The event led to a ban on mains gas being installed throughout large panel system-build, high-rise tower blocks, limiting the solutions available for space heating and hot water in these developments.

The number of CHP systems in the UK has risen steadily since the early 1990s [10]. Advantages of CHP installation, whether individually or as part of a District Heat Network, are the economic and low-carbon benefits of on-site electricity generation. However, CHP systems which are not properly sized can easily fall below the designed performance and hence fail to produce the predicted carbon and financial savings [11]. Furthermore, poor management of a CHP system can also result in a similar effect [12]. The UK implements the CHP Quality Assurance (CHPQA) programme to improve CHP systems and to avoid such effects [13]. In the UK, at times where electricity generated by CHP cannot be used *in situ*, it can be sold to the National Grid, providing an additional revenue stream [14].

This study has been undertaken using a Local Authority case study site in the South of the UK. The site is a district heating network which is Local Authority owned and financially managed, but operated and maintained by a Public-Sector Company (PSCo). This type of network is categorized as an 'Option 2B' scheme under the CIBSE Heat Networks: Code of Practice (CIBSE CP1) for the UK [15]. The network was installed in

2003 and runs on Building Energy Management System (BEMS) software unique to the site. In contrast to the CIBSE CP1—‘Option A’ where the end goal would be profitability, the LA heat networks primary function is to minimize disruption of heat supply for vulnerable people.

The heat network provides heat to over 500 residential dwellings within 8 housing blocks (approx. 30 650 m² total lettable floor area), and 2 non-residential buildings (approx. 1 550 m² total lettable floor area). The scheme includes a 526 kW_{electrical} and 545 kW_{thermal} CHP and two 2 MW_{thermal} gas fired boilers, with a 70 m³ thermal store. All electricity generated by the CHP is currently sold to the national grid, except for the energy centre’s parasitic load. This limits the financial income from the network to the LA compared to using a private wire network and selling directly to network residents or to an anchor tenant such as an industrial site.

Local Authorities in the UK are under increasing pressure to reduce spending and prioritize staff workloads to core tasks due to cuts in government funding [16]. As such, while a LA may be able to collect plentiful amounts of data, either remotely or through third parties, there is limited capacity for LA employees to regularly interrogate the data to look for anomalies or inconsistencies against historical data. As such, the network studied here has long been considered successful for heat delivery to residents due to the maintenance support provided by the PSCo which required minimal involvement by the LA, however, council officers had suspicions that network performance might not be as successful overall. The authors’ task is to interrogate the collected data and provide guidance to the LA as to the best management strategies and on the economics of the network.

2 METHODOLOGY

2.1 Primary data

This study assessed a 6-year data set, collected by a Local Authority as standard practise. Whole-site gas use and electricity import from the national grid data was available at half-hourly intervals, stored remotely through a third-party energy data site. The above data sets can be manipulated and displayed as graphs, which indicate how the heat network has been operated and managed across the life of the data set (Table 1).

2.1.1 Whole site gas use data

The whole site gas use data shows the gas use for all three heat sources combined (CHP and two Gas boilers) and provides an indication of the amount of energy required by the network at

any one time. Data for the individual boilers and CHP was not collected by the LA for this period.

2.1.2 Electricity export to the national grid

The network does not benefit from a private wire electrical network, thus, nearly all the electricity generated by the CHP is sold to the national grid. The electrical demand of the energy centre is fulfilled by the CHP electrical generation, when the CHP is running. There is no electrical battery store, so when the CHP is not in operation, the energy centre imports electricity from the national grid.

2.1.3 Electricity import from the national grid

As discussed above, the energy centre only imports electricity from the national grid when the CHP is not in operation. The heat network is always in operation, and there should be no instances where there is not an electrical demand from the plant within the energy centre. Within this dataset, when the CHP is in operation, import from the grid will be zero.

2.2 Secondary data

2.2.1 CHP runtime

The number of run-hours per day was calculated from the electricity import from the national grid dataset. In instances where electricity is being imported from the grid, we know that the CHP engine is not running. Therefore, the half-hourly data readings were switched to a binary series, where 1 represents a half hour period where the CHP is running (and no electricity is imported from the national grid) and 0 where the CHP is not running (and electricity is being imported from the national grid).

2.3 Displaying the data

The data is best displayed on line graphs, with combinations of the above data sets displayed at any one time. The most informative combination of data was simply the daily CHP runtime and daily electricity export to the national grid over time.

The data is displayed with CHP runtime (hours) on the left y-axis, over a 1-year period. Energy Centre Gas Use and Electricity export to the national grid is displayed on the secondary right y-axis as Energy (kWh). Where the CHP runtime is 24 h per day, this would be displayed as a flat line along the top of the graph.

Graphs are displayed as ‘heating seasons’, where the years will run from August to August. This is because the run strategies are most likely to be decided prior to the start of the heating season, thus, we can observe the methods employed for each heating season.

Table 1. Primary gas and electricity data used for this study.

Data set	Data collection period
Whole-site gas use (half hourly)	Jan 2011–Jul 2016
Electricity export to the national grid (half hourly)	Nov 2012–April 2017
Electricity import from the national grid (half hourly)	Jan 2011–May 2017

3 RESULTS

3.1 Heating season profiles

Figure 1 shows the CHP run profile and the Energy Centre Gas Use profile for the 2011/12 heating season. Note—there was

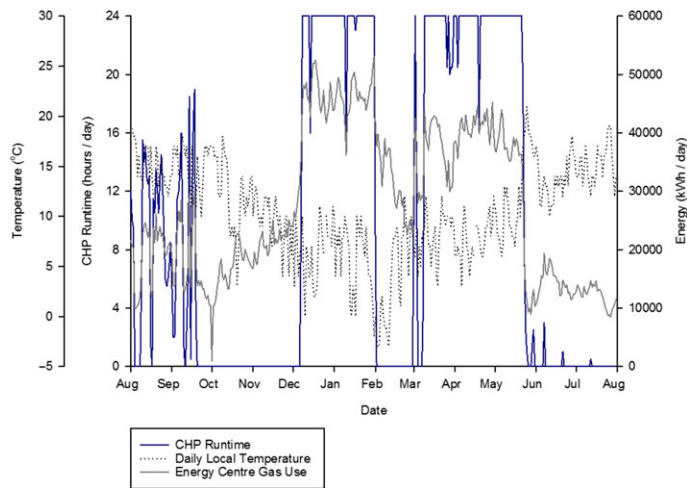


Figure 1. CHP daily runtime (hours), Daily Local Temperature and Energy Centre gas usage, August 2011–July 2012.

not half hourly electricity export data available for this period. The first observation from this data is that the CHP was planned to run throughout the year in 2011 as the CHP is in operation during August and September. This indicates that in previous years the CHP may have operated all year-round.

The run schedule of the CHP is likely to have been heat-led, with an overall aim of running 24 h per day during the heating season (October–March), and variable hours during the summer. CHP runtime is seen to increase from August 2011 onwards, however, before the end of September there is a clearly an issue which prevents the CHP from running. A CHP would not commonly be prevented from running during October through December, especially when it has been run throughout the summer months. It is likely that if runtime management were to have been implemented based on local ambient temperatures, the CHP would have been shut down over the warmest summer months, rather than autumn/winter months. The Energy Centre Gas Use during this period shows an increase, as would be expected in the UK, which is met through the two gas boilers.

Assuming there is adequate heat demand, it should be possible to run a CHP engine continually throughout the year. In this instance, the thermal store would be used as a buffer for excess heat, although once this store is full, the CHP would not be able to operate due to return water temperatures being too high. For a CHP to be able to operate continually all year round it would need to be sized to meet the domestic hot water load. The additional space heating load determined by ambient temperature would be met by the two gas boilers.

Due to the variation in runtime over the summer months, is likely that this CHP is being run to meet the hot water heat demand, with some smoothing provided by the thermal store. Although not visible in this graph, the data shows that the CHP is stopping and starting (cycling) throughout the day during this time, which will reduce the overall efficiency of the engine and increase engine wear. This indicates that the CHP is clearly oversized to meet the domestic hot water load of this network.

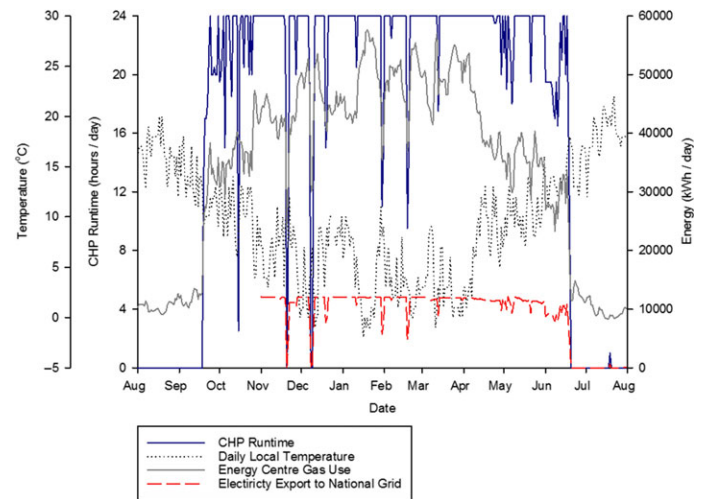


Figure 2. CHP daily runtime (hours), Daily Local Temperature and Energy Centre gas usage, August 2012–July 2013. Electricity export to the national grid available from November 2012.

This period of hard running could be a contributing factor to the apparent breakdown of the engine between October and December 2011. Additionally, there is a period throughout February where the CHP is assumed to be broken-down, given that it is during the heating season and it is not operating.

The 2012 data show a change in run strategy for the CHP, with the engine shut down at the start of June. This could be a result of wishing to avoid a repeat of the prolonged down period after running during the summer months in 2011 or a realization that the low summer heat demand makes it non-viable to operate during this period. In addition, previous years may have shown that the use of the CHP over the summer was not financially advantageous, or the cost per unit of gas and/or the price paid per unit of electricity sold to the National Grid could have changed, reducing the ‘spark gap’—the difference between unit gas (or CHP fuel) and unit electricity costs [17]. In the instance of this case study site where there is no private wire network, the cost of electricity is taken as the price paid per unit of electricity sold to the national grid, which is much lower than the cost to purchase electricity, giving a smaller spark gap but greater sensitivity to gas price. To counter this, LA’s are able to purchase gas in much larger quantities because of their scale of use, enabling them to negotiate a better gas tariff than is commonly available to the public.

When the CHP is shut down, we can see a correlating reduction in gas use. The heating demand for the site will still be met, using the gas boilers rather than the CHP, therefore the difference in gas use accounts for the difference in thermal efficiency of the CHP and gas boilers. While the gas boilers have a thermal efficiency of 91.2%, the CHP is much lower at 47.1%, as 39.2% of energy input is used to produce electricity.

Figure 2 shows that the 2012/13 run strategy for the CHP was to run 24 h per day. The run season is from October 2012 through to late June 2013. The gas use data indicates the

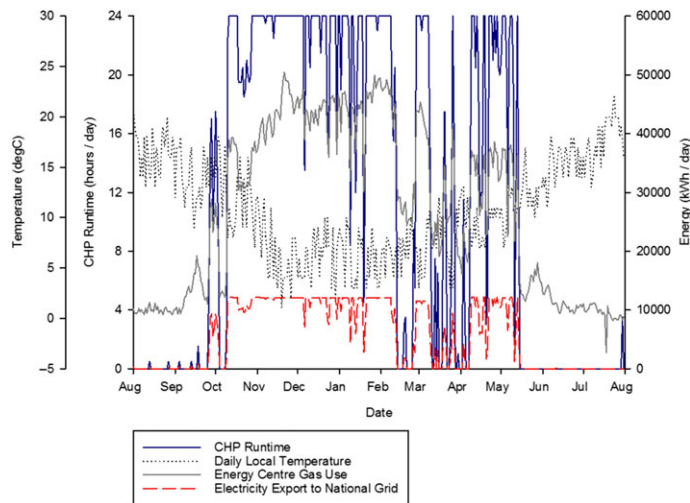


Figure 3. CHP daily runtime (hours), Daily Local Temperature, Energy Centre gas usage and Electricity export to the national grid, August 2013–July 2014.

network heat demand was greatest between January and April. During October and after May, CHP runtime hours varies slightly (18–20 h per day), indicating that CHP runtime parameters must be set to reduce runtime if demand is not sufficient to avoid the dumping of excess heat.

The electricity export to the national grid dataset is only available from November 2012, as this data is provided by the Distribution Network Operator (DNO). With the addition of the electricity export to the national grid, we can validate the CHP runtime data, which is calculated from the electricity import from the national grid. Electrical output from the CHP should be 526 kW or 526 kWh/hr CHP runtime. We can expect to see a slightly lower figure to account for the parasitic electricity load of the energy centre of up to 11 kW. Throughout this heating season, electricity export to the national grid averages 496 kWh/hr CHP runtime. If the CHP was to run for 24 h, the daily export would be 11 904 kWh as shown in Figure 2.

The 2013/14 heating season, shown in Figure 3, appears to follow the same strategy as the 2012/13 season. However, there are a significant number of days where the CHP does not run for the full 24 h, and several where the CHP does not run at all. While the CHP is again started at the beginning of October, it is shut down for the summer during May, over a month earlier than in 2013. This may be based on lessons learned from 2013, where the CHP runtime began to decrease after April.

The 2014/15 heating season, Figure 4, again appears to follow the same run strategy as used for the two previous heating seasons, although the CHP run season is only until the 1st of April, 1.5 months shorter than 2013/14. The CHP is clearly supposed to run from the 1st of October, however it runs for only 3 h and then is shut down until later in the month, and once re-started, the engine runs inconsistently until mid-December.

From the time that the CHP runs constantly until it is shut off at the end of March, the electricity export to the national grid

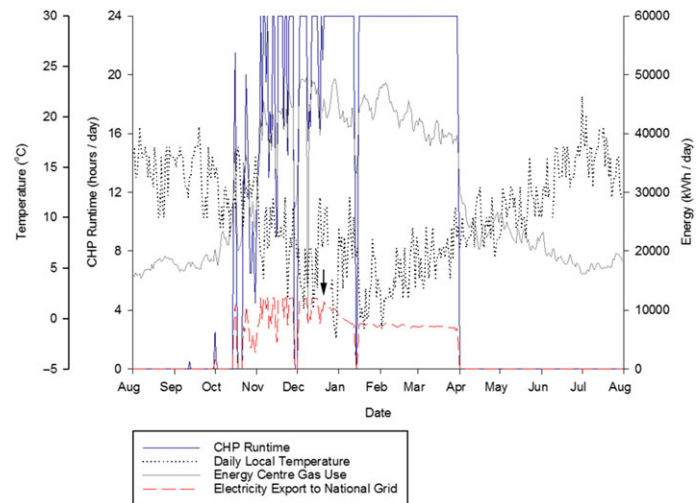


Figure 4. CHP daily runtime (hours), Daily Local Temperature, Energy Centre gas usage and Electricity export to the national grid, August 2014–July 2015. 19/12/2014 – CHP fault event shown by arrow.

gradually decreases, while CHP runtime remains mostly consistent at 24 h per day. Export to the grid falls from around 500 kWh/hr CHP runtime to around 330 kWh/hr CHP runtime, a 34% reduction. On the 19th December 2014 (indicated on the graph), there was a CHP fault where all water jacket pressure was lost, causing a breakdown. The water jacket issue was rectified, and the system tested and noted as ‘all ok’. This event coincides with the subsequent decrease in electricity export to the national grid and no other faults were raised during this time. The engine was shut down on the 15th January 2015 as a service was conducted, yet the reduction in electricity export was not noticed.

By observing the summer months, and only accounting for days where the CHP does not run, we can see the approximate electricity consumption of the energy centre, excluding the consumption of any plant which is only used when the CHP is in operation. This is shown in Figure 5. The data shows there was an overall increase in consumption from the national grid between 2011 and 2014, followed by a greater increase in 2015, which is maintained in 2016. From this we can assume that the existing plant within the energy centre requires a greater amount of electricity each year to run, and there are no notes within the site maintenance and fault logs to suggest that new plant has been installed which has a higher electrical consumption.

The increase in electricity import in 2015 may appear large relative to the previous years, however, the electricity export to the national grid had fallen by around 170 kWh/hr CHP runtime. Thus, the greater electrical consumption of mechanical plant (~1% of CHP generation, <2 kWh/h) cannot be a major contributor to the reduction in electricity export to the national grid. Therefore, the reduction in electricity export to the national grid is most likely due to a decrease in the efficiency of the CHP.

The 2015/16 heating season, Figure 6, shows another change in run strategy, running only for 10.5 h per day. The CHP appears to regularly not run for several days at a time, throughout

the heating season. The consistency of running decreases towards the end of February and throughout March, before being shut-down for the summer. The lower rate of electricity output to the grid, as seen towards the end of the 2014/15 season, continues until the beginning of November where it increases back up to around 500 kWh/hr CHP runtime. This output is maintained until December, when it appears to begin to fall again. No faults were noted around these times. Note—whole-site gas use data is not available from April 2016 onwards due to a fault with the remote monitoring gas metre, which was not repaired at the time this study was conducted.

The final heating season recorded over 2016/17, Figure 7, shows another change in run schedule. The CHP starts off running for 12 h per day, only on weekdays, which increases in

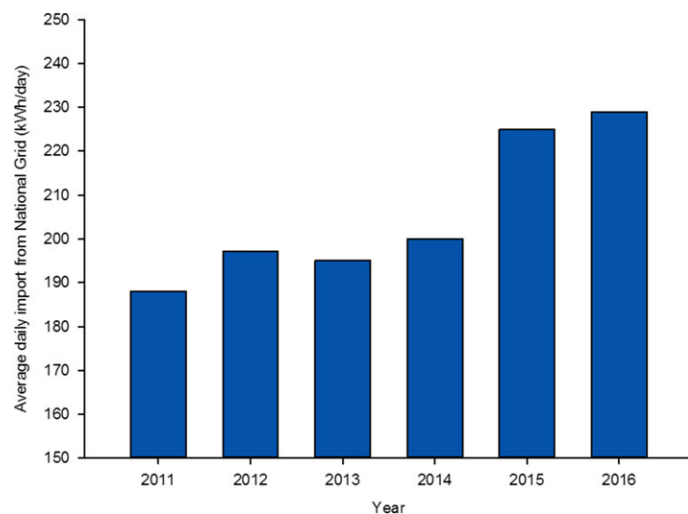


Figure 5. Average daily electricity import from the national grid—days where CHP does not run, June, July, August 2011–2016.

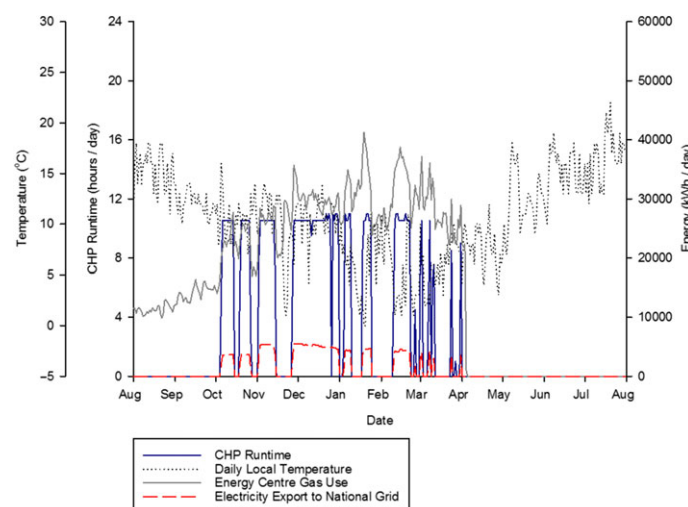


Figure 6. CHP daily runtime (hours), Daily Local Temperature, Energy Centre gas usage and Electricity export to the national grid, August 2015–July 2016.

November to 16 h per weekday. Throughout this heating season, the CHP runtime is very consistent, with only 1 prolonged shutdown period being 10 days during January. There are several of days where the CHP either does not run, or runs longer than scheduled, but these are much less frequent than in previous years. Notably, the CHP is shut-down for the summer from the 8th March, 23 days earlier than the previous year. The mean Daily Local Temperature for March 2017 was an average of 2°C warmer than the previous year (6°C in 2016, 8°C in 2017) and thus, could indicate that the shut-down was instigated by the PSCo to prevent excessive heat generation.

3.2 Profiles summary

After reviewing the above data, it is clear that over the past 6 years there have been several management strategies deployed at the case study site. However, since 2011, there has been a clear evolution in the strategy, progressing from a year-round, 24-h run strategy, to one which sees the CHP run on weekdays only, with limited run hours.

There was an event which saw the electricity export to the national grid decrease significantly during the 2014/15 heating season, from which the network never appears to have recovered fully. The electricity required to operate the site is increasing on a yearly basis, which may be due only to aging mechanical plant but this represents around 1% of the reduction in grid export.

3.3 Electricity losses/gains

Through the review of the data in a graphical form, it was determined there was an increase in electrical demand from the plant within the energy centre since 2015, and the level of that demand has varied during that time. The variation in CHP electricity export to the national grid is shown in Figure 8.

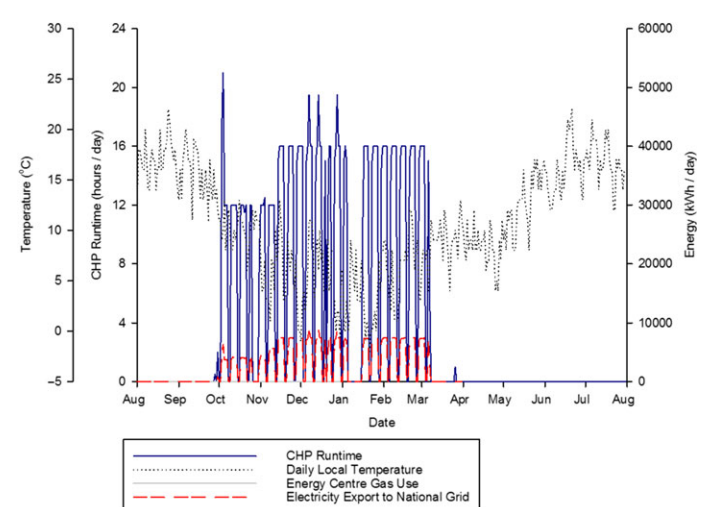


Figure 7. CHP daily runtime (hours), Daily Local Temperature, Energy Centre gas usage and Electricity export to the national grid, August 2016–July 2017.

Since the 2013/14 heating season, electricity export to the national grid has been at a lower rate than expected. A 526kWe CHP should produce 526kWh per CHP run hour. The first two recorded heating seasons for this study (2012/13 and 2013/14, this dataset is not available for 2011/12) produce an export rate around 500 kWh, an acceptable figure allowing for the small parasitic load of up to 6.5 kW and efficiency losses since the CHP installation in 2003. However, the following three seasons have notably lower electricity export to the grid, with the 2014/15 season being the lowest at an average of 408 kWh/CHP run hour while the parasitic load increases slightly, with load ranging up to a maximum 11 kW.

3.4 Electricity losses/gains summary

Assuming a theoretical average electricity export to the national grid per CHP run-hour of 511 kWh, equivalent to the best performing heating season, Table 2 shows the losses incurred due to the reduced electricity export to the national grid per CHP run-hour observed from the 2014/15 heating season onwards. Over the three heating seasons, the reduced export has resulted in a loss of revenue to the council of over £18 500, assuming an average export rate of 3p/kWh.

While the level of electricity export to the national grid has not improved to those observed in the 2012/13 and 2013/14 heating seasons, there has been an improvement after the 2014/15 season. Running at shorter intervals would cause an overall decrease in efficiency, but it is unlikely that this would cause a

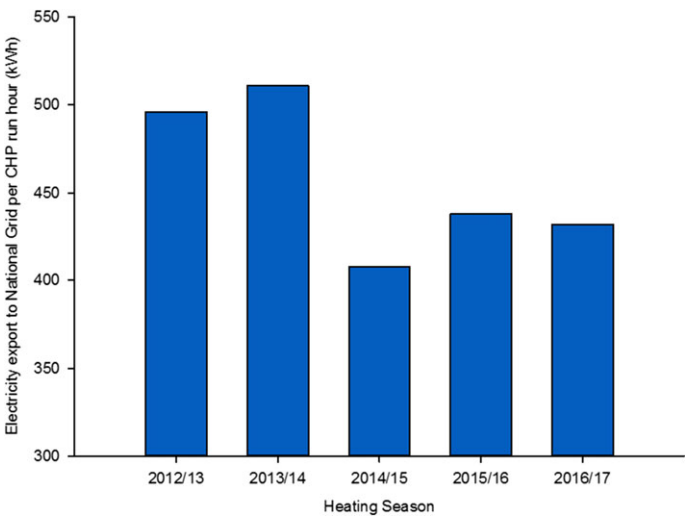


Figure 8. Average electricity export to grid per CHP run hour by heating season.

Table 2. Summary of electricity export reduction vs. theoretical.

Heating season	Theoretical total	Actual total	Difference	% Difference	Value
2014/15	1 782 879	1 338 398	444 481	25	£13 334
2015/16	509 978	443 412	66 566	13	£1997
2016/17	761 390	654 296	107 094	14	£3213

11–12% difference from the conservative, theoretical export rates expected. Thus, it is likely that the event which caused the significant reduction in electricity export in 2014/15, has not been fully rectified. Given that the CHP is not operated during the summer, it is assumed that the overall efficiency may be decreasing, but not at a significant rate. The likely cause of the decrease in electricity export is an on-going fault with the CHP, causing a decrease in electrical efficiency, however, from the available data it is not possible to say whether there is also a decrease in the thermal efficiency of the CHP. This may either coincide with the increase in electricity consumption of another piece of mechanical plant within the energy centre, or the two events may not be linked.

4 CONCLUSIONS

Through analysing the graphical representations of large data sets, it was possible to describe the management strategies and determine the level of heat network optimization, using data that is theoretically available from all CHP-lead heat networks. The data showed that due to two events, of which one was not quickly rectified, losses of income to the LA of over £18 500 were incurred.

Where it is not uncommon for management personnel to change, and hence, historical knowledge of the evolution of heat network or CHP management strategies to be lost, this method of analysis can be used to better understand a heat network or CHP’s run history. Furthermore, the method can be used to enable persons without an engineering or relevant background to understand how and why a CHP is run.

Using graphical representation of several data sets, the method allows more subtle changes in the data to be observed, which could be missed when observing data readings individually or numerically. The method used in this study is an efficient way to annually review heat network and CHP run strategies, which is of great advantage to Local Authorities who currently work on stringent timescales. Where a PSCo is used to maintain and operate a CHP/heat network, the LA may have little input on the run strategy beyond short discussions on an annual basis. Using this simple method of interrogation provides a clear demonstration of the performance of the CHP/heat network in a basic form, allowing a LA to make informed decisions throughout any point of the year.

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