FOCUS
TECHNICAL INNOVATION & OPTIMISATION

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OPTIMAL OPERATION OF A MULTI VECTOR DISTRICT ENERGY SYSTEM IN THE UK

The large price drop in solar PV and electrical batteries offer new opportunities for optimizing district energy plants, but requires a more complex daily operation of these plants. Solar PV production used locally by a ground source heat pump (GSHP) with a minimal use of the national grid is one opportunity. Even if, for the benefit of the GSHP, the share of electricity for boosting the temperatures of district heating water goes up when lowering forward temperatures in the network down to as low as 45 °C, the overall operational income is improved.

Despite its actual share of less than 2 % of the entire UK heat market, district heating (DH), due to its flexibility and capacity to integrate low-grade heat sources, has been recognised as a key technology in the transition towards a low carbon society. In fact, heat networks will play an important role in the future UK energy market to help securing energy supply and reducing CO_2 emissions. It was estimated by the Department of Energy and Climate Change (DECC) – now restructured as the Department of Business, Energy and Industrial Strategy (BEIS) – that DH could supply in a cost-effective way up to 14 % and 43 % of the total UK heat demand in buildings by 2030 and 2050 respectively. This would be quite significant in the decarbonisation of the UK economy as heating and cooling consume nearly half of national primary energy.

In a mature DH market such as Denmark's, typical yearly average supply/return temperatures experienced in the network are 80/40 °C and real-time operations of four existing DH networks in Denmark can be found at www.emd.dk/energy-system-consultancy/online-presentations. Aiming to integrate alternative low-grade heat sources and reduce the distribution losses, their current efforts are seeking to achieve a load dependent supply/return temperatures of 50/20 °C, defined in literature as the 4th generation DH (4GDH) concept.

The challenge is to ensure the same levels of space heating (SH) and domestic hot water (DHW) in existing buildings, as well as for new low-energy ones, with these lower operating temperatures. The design conditions used to size heating systems rarely occur during normal winters; hence, lower operating temperatures, even in existing heating systems, can be adequate to maintain the same indoor comfort for the majority of the time. In low-energy buildings, with low temperature, heat emitters such as underfloor heating (UFH) or low temperature radiators (LTR), inlet temperatures in the range of 35/45 °C can be appropriate to guarantee indoor comfort. In practice, regulations on legionella bacterium limit the lower temperature for DHW. In the UK, water must be heated to 60 °C in storage tanks or 50 °C if heated instantaneously.

TRENT BASIN AND PROJECT SCENE

The work presented in this article illustrates the optimal operation of a multi-vector district energy system, assessing the main techno-economic parameters and different scenarios for a community energy system. It is based on a new housing development in Nottingham which is part of a large regeneration of the ex-industrial areas alongside the River Trent. Project SCENe (Sustainable Communities Energy Networks) is an initiative supported by Innovate UK and the Energy Research Accelerator (ERA). It looks to accelerate the adoption of Community Energy Systems (CES). This approach represents a different way of generating and supplying heat and electricity to homes and commercial buildings where locally produced energy is used locally with minimal use of the national grid. The benefits are, potentially, reduced cost and more efficient use of distributed renewables to reduce the overall carbon emissions from the energy system.

The investigation described here focused on 33 new low-energy buildings assuming their connection to a low temperature district heating (LTDH) network, fuelled by a ground source heat pump (GSHP) with a maximum heat capacity of 350 kW. The energy system will also embed 20 m3 of thermal storage, 450 kWp of solar PV and a battery bank of 2.1 MWh, representing the largest domestic application in North Europe and the first of its kind in the UK.

As presented in the schematic view of Figure 1, a local Energy Service Company (ESCO) will manage and operate the multi-vector district energy system, supplying heat to the end-users, whereas the electricity demand will be covered through a typical domestic contract with the local energy supplier. As this will not affect the operation of the CES, the domestic electricity demand was disregarded in the analysis presented. The multi-vector energy system was simulated using energyPRO, an advanced energy software that allows for the simulation and optimisation of complex energy systems.

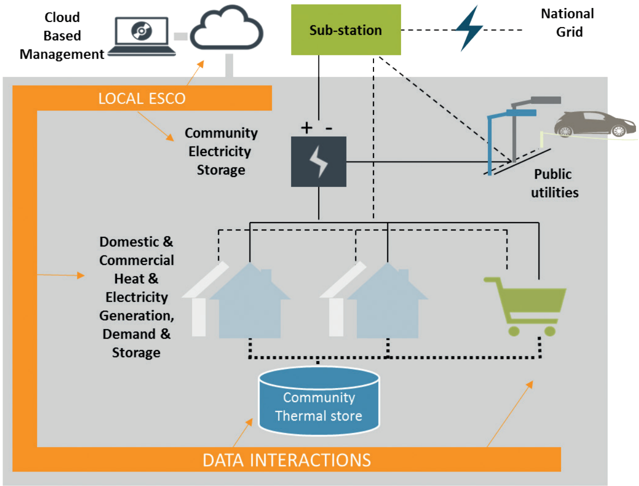

Figure 1: Schematic of the multi-vector energy system

Heat is supplied to each end-user through de-centralised heat interface units (HIU). Two dedicated plate heat exchangers (PEXs) will be installed for SH and DHW, and a ΔT of 5 °C was assumed between the heat network and the secondary loops. UFH and LTRs are the chosen heat emitters for the SH systems, so supply temperatures in the range of 35-45 °C would be adequate to guarantee indoor comfort. For the instantaneous DHW preparation, a 32 kW PEX will be installed and an electric heater will also be placed on the secondary side of the DHW loop to boost the temperature if below the required limit of 50 °C. This will add more flexibility in the system operation, as supply temperatures even lower than 50 °C could be possible in the heat network, without any risks associated with Legionnaires' disease.

OPERATION STRATEGY AND ENERGY PRICES

The dynamic demand profiles for each end-user were obtained using a stochastic approach and the results were validated by comparing these to typical UK profiles available in literature for similar buildings, occupancy and use. The strategy implemented to optimally operate the CES was focused on a cost optimisation to maximise the local use of the generated electricity both for direct use and storage/export, and as a consequence to minimise the import of electricity from the main grid. Three main scenarios were evaluated, considering the system operation under different operating temperatures: 55/25 °C, 50/25 °C and 45/25 °C.

Yearly simulations were performed with energyPRO assuming the UK retail electricity price for 2016. This is composed of the day-ahead price (spot market) (47 % of total cost) and the remaining 53% of grid costs, taxes and commodities. When exporting electricity, the ESCO receives only the day ahead electricity price, hence it is important to carefully identify when the system should import or export electricity. The heat tariffs associated with DH networks are site-dependent and vary within the UK heat market. This was set to 95 £/MWh for this investigation by assuming that this is the average price an end-user would pay in the UK for useful MWh of heat using a typical individual gas combi boiler. The tariff includes the average gas price, the cost of the boiler and its efficiency and maintenance.

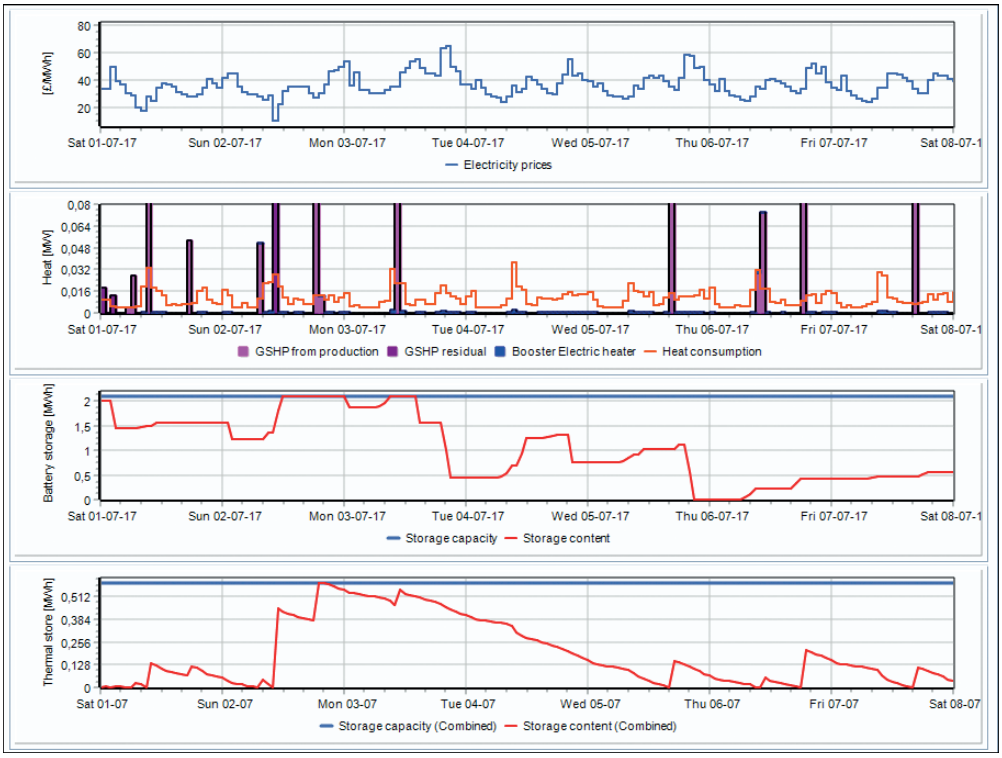

Figure 2: CES optimal summer operation

An extract of a weekly summer operations for the scenario with forward temperature of 55 °C, simulated hourly with energyPRO, is presented in Figure 2, highlighting the optimal operation for the CES analysed. The battery and thermal store are key components optimised to reduce the intermittency of the electricity generated by the PV and ensure that the heat demand is always met. In particular, the thermal store allows to run the GSHP using mainly the electricity locally generated; whereas, the battery to trade with the main grid, exporting the electricity generated on-site when the prices of the spot market are higher.

SCENARIOS COMPARISON

The comparison between the three scenarios is summarised in Figure 3, where the total heat generated, GSHP electricity consumption and distribution losses were calculated. The three scenarios, SCENe_55, 50 and 45, differ for the average forward temperatures in the network and highlighted the impact of temperature variation in the operation of the system.

The reduction of flow temperatures in the network was predicted to have a positive effect on the operation of the GSHP and reduced distribution losses, and this is also emphasised by the relative higher coefficient of performance (COP) values as illustrated in Table 1. Therefore, the choice to circulate supply water at temperatures as high as 55 °C could only be justified for the new housing development in question, if the HIU was not equipped with electric heaters or other devices necessary to boost the DHW temperature to the required level of 50 °C.

Table 1: Summary of main CES operation results

Scenarios	Net Operational income (£)	COP	GSHP from renewable energy	Share of booster heater electricity for heated DHW (%)
SCENe_55	55,440	4.1	52	-
SCENe_50	56,512	4.5	50	19.0
SCENe_45	57,681	4.9	47	30.9

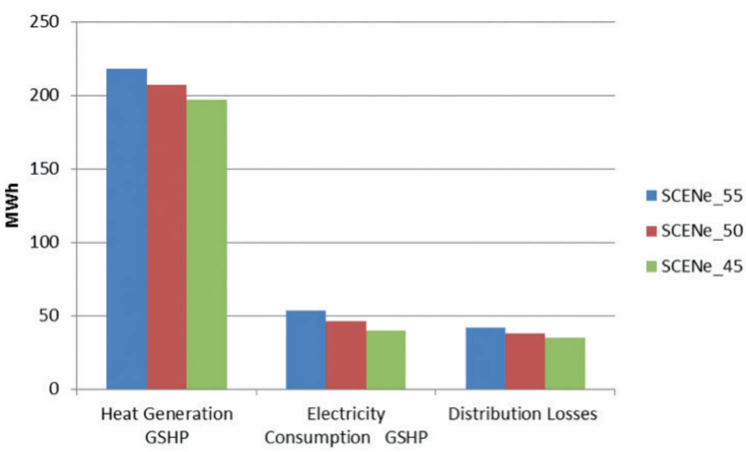

Figure 3: Heat network operation at different temperatures

However, as expected, the reduction of the supply temperatures in the network would affect the operation of the system by increasing the share of electricity needed to achieve the DHW temperature of 50 °C, as summarised in Table 1. The installation of electric heaters in the HIUs offers larger operation flexibility, giving the ESCO the opportunity to operate the heat network with flow temperatures even below the limit of 50 °C. This is particularly valuable to reduce distribution losses and to increase efficiency in systems where heat generation is sensitive to low supply temperatures, as for heat pumps.

The calculated shares of the electricity for heated DHW presented in Table 1 are in line with the findings presented in a recent Danfoss report, where the HIU with electric heaters were tested in a real domestic application in Denmark. Finally, a few recommendations need to be considered in the design process to avoid sub-optimal operations of the electric heaters. These need to be controlled by correctly delaying the start of the operation to avoid unnecessary electricity consumption at the beginning of each DHW draw-off and the possible increase in the peak electricity demand needs to be assessed in particular if a limit is imposed by the local electricity supplier.

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