Overcoming Practical Challenges and Implementing Low-Carbon Heat in the UK: Lessons from the Balanced Energy Network (BEN) at LSBU

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Abstract

The challenge of decarbonisation of UK heating energy by 2050, highlights the need for efficient electric heating and a dramatic increase in the rollout of heat networks. Many studies consider low-carbon heat at a theoretical level, however there is a gap in understanding the implementation challenges, particularly for existing stock.

The paper presents the integration of electrified heat into existing building distribution systems and demonstrates how a Balanced Energy Network BEN system can assist in overcoming practical challenges to achieve to retrofit low carbon heat to existing building distribution systems.

The BEN system delivers a low-carbon, efficient and sustainable energy solution. It is analysed and evaluated as a concept through to becoming a live project. Key implementation challenges and learning outcomes are discussed.

Keywords Balanced Energy Network, Heat Pump, Cold Water Heat Network, Heat Exchanger, Demand Side Response

1.0 Introduction

In order to meet the UK's obligation of reducing emissions by at least 80% by 2050 compared to 1990 levels, we must overhaul nearly all aspects of the UK's energy system. We must halve emissions from industry, electrify transport, and nearly eliminate carbon from electricity generation. These are staggering systemic changes, and yet the UK government states that these will be easier than addressing heat: "Decarbonising heat is the UK's most difficult policy and technology challenge in meeting our carbon targets" (BEIS, 2017).

There are a number of studies and scenarios exploring the options for decarbonised heat. All of them require a dramatic uptake of both heat pumps and heat networks, and in particular retrofitting them to the existing stock. Very few have explored the practical onsite challenges of doing this. This paper addresses this gap with a detailed exploration of the Balanced Energy Network (BEN) case study at London South Bank University. It considers the information and site challenges of interfacing with existing systems and retrofitting low carbon heat to occupied buildings in densely occupied central London.

The paper is organised as follows. Firstly, the theoretical context for low carbon heat is given. The BEN project is described in overview. The qualitative research methods are described, outlining the data gathered through site surveys and semi-structured interviews with the project team. From this, lessons are distilled on the information challenges likely to face future projects. The paper closes by linking these findings to the theoretical and policy context for low carbon heat.

2. Literature:

The UK has a binding target of reducing carbon emissions by at least 80% by 2050 compared to 1990 levels (HMGov, 2008). The Committee on Climate Change states that this unachievable without a near complete decarbonisation of the heating sector (CCC, 2016). Heating represents approximately 40% of energy use (CCC, 2016) and there are a limited number of tools available for decarbonisation.

The core fuels available essentially amount to either electrification or carbon free gas, served be a range of enabling technologies such as heat pumps and heat networks. Many studies have explored the uptake of these options and invariably find that a combination of solutions will be essential, largely driven by local suitability of different solutions (National Grid, 2012) (DECC, 2013) (MacLean, et al., 2016).

There is a consensus that electrification of heat in buildings, primarily through heat pumps, is a critical component of any decarbonised heat scenario (National Grid, 2012). The uptake of low carbon gas solutions is far less understood, even at a theoretical level, with the Clean Growth Strategy stating that many long term decisions about the future of the gas grid will be made in the mid-2020s (BEIS, 2017).

Scenarios for low carbon heat are becoming increasingly precise in how they forcast the needs for the uptake of various solutions. For example the CCC ‘core decarbonisation’ scenarios call for over 600,000 heat pumps by 2020, increasing to 2.5 million by 2025 and 7 million by 2030 (ElementEnergy, 2014). There are currently 20,000 heat pumps per year installed in the UK compared to 1.6 million gas boilers.

The Clean Growth Strategy calls for all fuel poor homes to be brought to EPC level C by 2030 (BEIS, 2017). The Centre for Sustainability investigated the strategies and costs of delivering on this promise. They found that in addition to demand control measures such as improved fabric and low energy lighting, it will also require the installation of at least 600,000 low carbon heating systems in fuel poor homes (CSE, 2014).

The National Grid Pathways, the CCC ‘Core Decarbonisation’ scenarios, and the Clean Growth Strategy promises all have two things in common: 1) they require step change increases in the deployment of low carbon heat, particularly in retrofit, and 2) they all consider this deployment at a theoretical level, with most practical considerations outside the scope of their work.

The literature landscape on the topic of low carbon heat contains many of these large scale scenario studies by decision makers and leaders such as BEIS, National Grid, and the CCC, as well as insightful analysis of these studies by academics and industry think tanks (see e.g. (Sansom & Strbac, 2012) (Leveque & Robertson, 2014) (Webb, 2016)).

It is logical to focus on the scale of the problem before the details, but the UK is rapidly approaching the point at which building owners and managers will be asking how they can implement low carbon heat in their own buildings. The design questions required to deliver this cost effectively are poorly defined. This paper addressed the literature gap on the practical delivery of low carbon heat by using the BEN case study.

3.0 The Balanced Energy Network (BEN) Case Study

The BEN project (May 2016 - Aug 2018) was created in response to an Innovate UK call for Integrated Supply Chains for Energy Systems. It received £2.8 million in funding towards an overall project budget of £4 million. As a research and demonstration project it contains several work packages with exploratory work outside the scope of a typical commercial project. One of the aims of both the BEN project and this paper in particular are to highlight learning outcomes that will aid future iterations of BEN to be viable as standalone commercial endeavours.

The BEN project consortium consists of five SMEs and two universities, each contributing a portion of an integrated heating, cooling, and electricity network as shown in Figure 1. This section will describe the role of each component in creating this system.

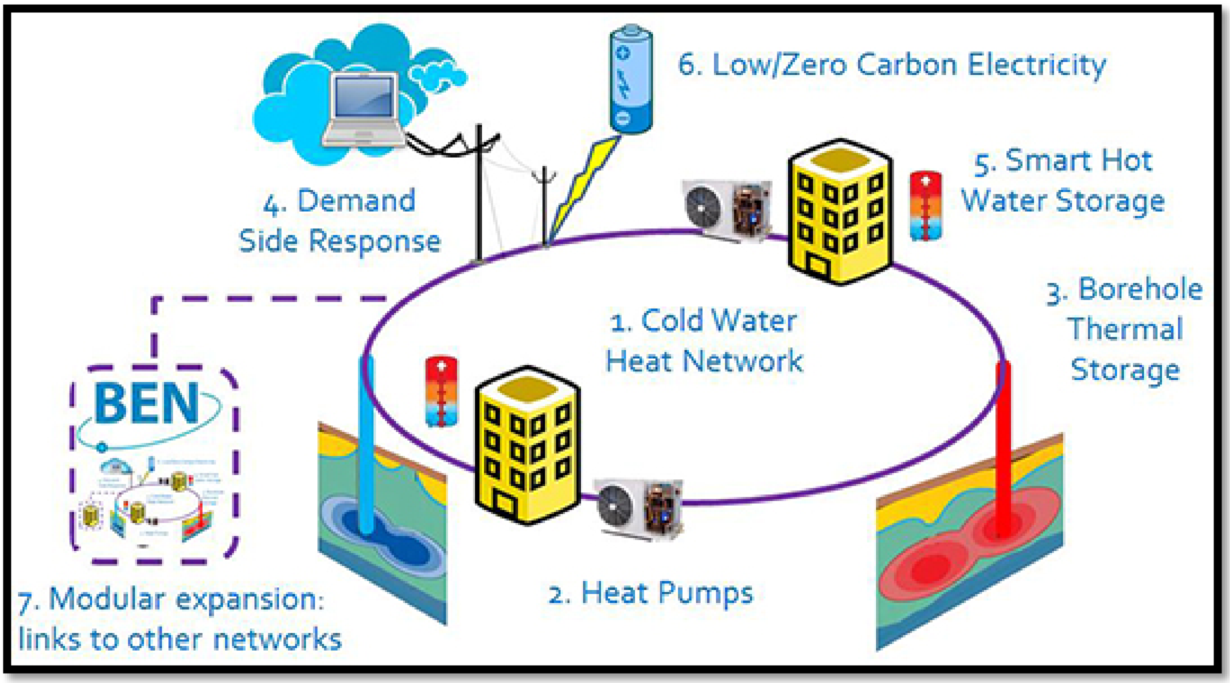

Figure 1 – The BEN system model (BEN, 2017)

London South Bank University (LSBU)

LSBU is located in central London approximately 1 km South of the river Thames. It hosts 17,000 students and 1,700 staff over several city blocks. It is a densely occupied urban environment with buildings ranging from early 20th century to new builds, with most being of 1950s-1960s era construction. In building age, use, and form, LSBU represents a typical cross-section of London's architecture and thus represents an ideal demonstration venue for implementing low carbon heating solutions. Historically it has strong links with construction and building services, being the result of the 1970 merger between Brixton School of Building, founded 1908 and The National College of Heating Ventilating Refrigeration and Fan Engineering founded 1947. Lessons gleaned from transforming LSBU buildings will be extremely relevant to much of London, and indeed the wider UK non-domestic building stock.

The BEN system demonstrator links two buildings, Tower Block (TB) and J-Block (JB), which are separated by approximately 100 m as shown in Figure 2. Key data for TB and JB are summarised in Table 1.

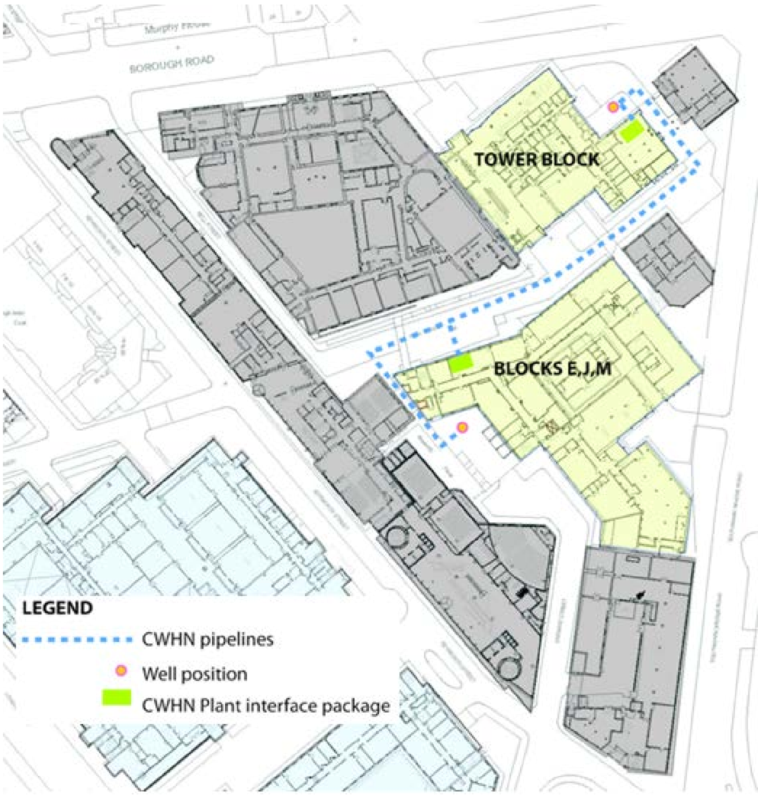

Figure 2: Proposed layout for CWHN demonstration. (Gillich, et al., 2016)

Building Name	Heating Cons. (MWh)	Area (m^2)	Peak (kW)
M Block, J.L. Building, & Ext. Block	1,312	10,610	600
Tower Block	1,044	9,077	340

Table 1: Data for BEN buildings J Block and Tower Block (Gillich, et al., 2016)

The following sections detail the contributions of each partner and are numbered to correspond with Figure 1.

1, 2. Cold Water Heat Network (CWHN) - delivered by ICAX Ltd.

At its core, BEN uses an ambient temperature CWHN to share heat between the TB and JB buildings. This is a novel district heating system that circulates water at a temperature of approximately 13°C. CWHN enables buildings to be connected hydraulically enabling heat to be abstracted when a building requires heating or rejected to when a building requires cooling.

The TB and JB buildings are currently served by a series of gas fired boilers operating in a cascade system. This will be a typical situation as we shift from gas to electricity as a source of heat and the most efficient combination to match the building needs will be required. The BEN project links heat pumps into this cascade system, which requires matching the distribution temperatures for the common header. Bespoke high temperature heat pumps were created to deliver these higher output temperatures efficiently.

3. Borehole thermal storage – delivered by TFGI

In theory, if the buildings linked to the CWHN loop had perfectly balanced heating and cooling loads it would be possible to use the rejected heat from one building to supply much of the source heat for another. In practice, both TB and JB are heating dominated buildings that will be removing heat from the CWHN for much of the year. In order to maintain the 13°C circulating network temperature, the CWHN is linked to an open loop borehole thermal storage system. The geothermal boreholes are each 110 m deep, reaching the chalk aquifer beneath London and delivering water at a rate of 20 l/s.

4. Demand side response (DSR) – delivered by Upside Energy

DSR typically links to distributed storage assets such as batteries and stand-by generators. This project is novel in developing the capability to manage heat pumps and industrial sized storage cylinders. There is considerable potential to expand on this distributed storage capacity by linking DSR control systems directly into the heat network itself. BEN will use dynamic price signals to turn the heat pumps and cylinder storage systems on and off at optimal times, generating DSR revenue as well as limiting the impact of the electrified heat at peak times. The electrical infrastructure challenges of adjusting both the national grid to cope with intermittent renewable generation and massive electrification and local electricity networks to allow widespread introduction of heat pumps into buildings are significant.

5. Smart hot water storage – delivered by Mixergy

The BEN system incorporates two smart hot water cylinders, each 10,000L, to enhance the storage resources available for DSR flexibility. The two cylinders can be charged either from the heat pumps or via direct electric immersion heaters.

6. Carbon negative Fuel Cell Calciner – delivered by Origen Power and Cranfield University

The BEN system can potentially link with nearly any low and zero carbon electricity generation devices and waste heat sources. It provides a local platform to integrate the resource with minimal distribution losses, and distributed storage options can provide a buffer against intermittency.

The Fuel Cell Calciner (FCC) developed by Origen Power and Cranfield University to generate electricity in a way that actively removes carbon dioxide from the atmosphere (Hanak, et al., 2017). The amount of heat engendered breakdown limestone ($CaCO_3$) into pure carbon dioxide (CO_2) and lime (CaO). It is estimated that all of the CO_2 produced from this process will be 99% pure and can be easily and economically geologically repossessed, the cost of purification being a significant issue with carbon capture and storage technologies. The lime (CaO) produced during the process will be converted to $CaCO_3$ by absorbing CO_2 from the air (Hanak, et al., 2017).

This process is expected to remove 800g of CO_2 for every kWh generated on site compared to 400g from all other technologies currently used. When developed at sufficient scale, the FCC could potentially link to the BEN system, providing negative carbon emissions electricity and heat.

7. Modular expansion links to other networks

At present the existing CWHN connects the TB and JB however, there are plans in the near future to connect this to a network of buildings through the CWHN pipes adding both cooling and heating demand with a view to improving the balance of the network overall and also via a cloud system to take advantage of the DSR.

The ultimate objective of the BEN project is to form a smart energy heat sharing network system by which low carbon and relatively inexpensive heating and cooling is produced and can grow organically across cities and towns.

4. Method

As outlined in the literature review, delivering low carbon heat is not a theoretical exercise. It requires detailed knowledge of plant rooms and existing building distribution systems which may not always be easily available. Therefore, in addition to studying the technical objectives and performance of the BEN system, there is considerable knowledge to be gained in studying the installation process itself.

The following research questions were set out:

1. What information was available for early stage design decisions and how were information gaps addressed?
2. How did the design evolve in response to new information throughout the project?
3. What information would be useful for building owners/managers in retrofitting low carbon heat in the future?

These questions were addressed using a qualitative approach. A researcher shadowed the design team for one year, attended meetings, conducted one to one interviews, and supplemented this data with plant room surveys and direct observations. This process and timeline are detailed here:

Data Type	Description	Dates
Literature review	Rapid evidence assessment of publicly available documents on low carbon heat and heat network design. This was used to describe the research questions stated above.	Oct 2016 – Dec 2016
Document review	Review of design documents including schematics, drawings, and reports. These are protected intellectual property for the various partners and suitably anonymised for this paper. This was used to define the initial design intent for the BEN system.	Dec 2016 – Feb 2017
Weekly site meetings	Weekly meetings held in the site office, regularly attended by LSBU, ICAX, and TFGI to monitor and deliver the CWHN and borehole work packages. Attending these meetings allowed real time observations of the design evolution in response to site conditions.	Dec 2016 – June 2017
Monthly partner meetings	Monthly summary meetings attended by all project partners. Attended quarterly by the paymaster's project monitoring officer. Observing these meetings allowed insight into broader project decision making across all work packages.	Dec 2016 – Oct 2017
One-to-one interviews	Design leads from each project partner were interviewed at least once throughout the project. Interviews were semi-structured in nature centring on the three research questions above. Interviews were conducted face to face and were typically 30 minutes in length.	Dec 2016 – August 2017
Surveys and first hand observations	Finally, in addition to attending meetings, the researcher conducted direct observations of the design and installation process throughout. The researcher had specialist knowledge in plant room surveys and energy management which allowed the meeting discussions to be measured against actual activities on site, and therefore a critical engagement with the information collected and suitable follow on questions for the one-to-one interviews.	Dec 2016 – Oct 2017

Table 2: Data gathering and interviews

The quantitative data collected via the process described in Table 2 was analysed using mathematical equations and existing benchmarking schemes. The qualitative data was distilled and found that project design changes emerged in response to either timeline delays or budget constraints. The analysis section will describe several such examples and the discussion section will describe how these affected the research questions stated above.

5. Analysis

The BEN project was preceded by a three-month scoping study (Gillich, et al., 2016) that identified suitable buildings for a CWHN based on heating profiles and available plant space. This scoping study set out much of the framing information upon which early design decisions were based. However, there were a number of knowns and unknowns which were outside the scope of that study, as well as a number of unidentified-unknowns which the scoping study had no way to anticipate. These two types of unknowns combined to cause a number of changes to the initial design.

Typically, there were two drivers for design changes in this project: timeline delays, and cost overruns. These are interconnected issues, as inevitably a cost overrun required a delay to the work program while a solution was found. In both cases, the BEN project is subject to pressures as an Innovate UK funded research project that would not exist for a typical commercial project. Throughout this analysis the impacts of this distinction will be noted.

5.1 Permissions issues and surveys:

Early in the project, there were delays caused by permission issues - attaining suitable permissions for drilling the boreholes in the desired locations, and locating the CWHN district heating network. This was directly caused by a lack of project run up time. In a commercial project, typically permissions and other essential enabling works could be initialised before activity was mobilised on site.

The initial design for the CWHN work package called for the pipework to be laid in a $1m^2$ underground trench. Shallow services surveys were carried out, discovering a complex network of cables, gas pipes, and water services directly beneath the surface of the road. Despite this, a possible route for the trenching was designed, and hand digging was used to create a set of exploratory pilot holes. This hand digging revealed a number of further services including gas and electricity cables crossing the intended trenching route that hadn’t been picked up in prior surveys. It also came across a substantial underground wall of a former building which was not detected initially.

It was decided that there was no feasible underground route to connect the two boreholes and the trenching route was abandoned altogether. A series of design options was considered, including running the CWHN through the basement plant rooms of intervening buildings or running the pipework over the building rooftops. Finally, it was decided to run the three CWHN pipes along the side of the buildings as shown in Figure 4. This was deemed to blend in with other services works and did not interfere with the aesthetic of the building it was also rapid and significantly less disruptive than any underground solution.

Figure 4 – CWHN pipe work installation

The surveys for the plant rooms also took considerably longer, and cost considerably more than anticipated. This was due to the rather unusual lack of detailed site information of the existing plant and servicing arrangements. The design called for integrating the heat pumps into the building's existing distribution network. The pre-existing configuration was a series of gas boilers operating in a cascade system. The new BEN linked heat pumps needed to match the distribution temperatures and link to the common header. Finding suitable intervention points in the plant room required detailed 3-D surveys that included the heights of all objects in the plant room. Time and effort were expended attempting to assemble this information from existing plant room drawings and surveys but ultimately newer surveys needed to be commissioned specifically for the BEN project.

The interface package design also depended on a detailed understanding of the building control systems, much of which lay in hand written manuals and sometimes was simply remembered by senior estates engineers.

The expense and time delays caused in gathering the needed information for the plant room interface packages was not a symptom of the innovative nature of this project and will likely be common for buildings across the UK.

5.2 Interface Package Cost Overruns

Once the BEN interface package had been specified, the tenders returned at a higher price than the budget allocation. While this overrun was likely within the total contingency of many construction projects, for a research project with an inflexible budget this was a prohibitive cost. An extensive value engineering exercise was undertaken to reduce the costs of the building interface packages. This had a number of significant implications, two of which will be discussed in detail.

Firstly, the reversibility of the wells was removed. This was a “nice to have” that had evolved during the design phase of the project. Plant and equipment associated with the reversibility was removed. However, this meant that the functionality of either wells acting as a discharge or injection well is no longer available. The final BEN installation allows flow only in one direction, with the TB well abstracting water and rejecting it to the JB well.

A second significant change was reducing the electrical load to the water storage tanks. These serve as buffer vessels that respond to DSR events and provide flexibility for BEN to manage peak loads. However, the electrical cabling and panel upgrades required to fit both water storage cylinders were prohibitively expensive. The value engineering exercise dropped the immersion heater from one of the two water storage tanks. This cylinder can still be charged via the heat pump, but it does not currently have capacity to offer DSR balancing services from the immersion coil. The cylinder is, however fully equipped to allow this functionality to be provided if power is brought on.

The initial scoping for the electrical loads ensured that there was capacity available from UK Power Networks, but underestimated the costs of upgrading the building electrical systems to make use of this capacity.

6. Discussion

The analysis above highlights a number of lessons for retrofitting low carbon heat and enable the three research questions to be addressed:

What information was available for early stage design decisions and how were information gaps addressed?

The project used an initial scoping study to identify suitable buildings and outline key design criteria. This scoping study included surveys of the plant rooms, but the surveys were primarily for determining the high level suitability of the building and overall space requirements. Detailed design of the BEN system required more detailed surveys, which are commonly held as part of the portfolio information held by Facilities Departments, but which were not available here. These had to be commissioned.

There was no information available about the shallow services such as cables, gas and water network, which ultimately prevented any trenching for the heat network pipework.

The project attempted to address information gaps through internal means such as finding existing plant room drawings and operating schedules.

This caused a number of stresses on resource constrained estates staff, and often still resulted in incomplete information and necessitating further surveys to be undertaken. Note that it is important not to overgeneralise based on a single study as the portfolio of information available will vary by project.

How did the design evolve in response to new information throughout the project?

The BEN system underwent several major design changes including moving the principle CWHN pipework from below to above ground. The fact that the design could accommodate this change cost speaks to the flexibility of the overall approach. Had this been a more conventional 80℃ heat network with high grade steel pipework, the options would have been considerably limited.

In response to the larger than expected cost of delivering the interface packages several design simplifications were necessary. BEN had to forfeit the ability to reverse the flow of the borehole loop, which reduces the ability of the network to exploit the aquifer as a thermal store. At its core this does not affect the functionality of the network itself, but reduces the range of operating configurations and research possibilities for the network.

The network also had to reduce the electrical upgrades to the buildings, which limited the ability of the hot water cylinders to provide DSR services. This will likely reduce the DSR revenue generated by the system, but the connections are still in place if the university decides that electrical upgrades to fully exploit this resource are deemed financially worthwhile in the future.

What information would be useful for building owners/managers in retrofitting low carbon heat in the future?

Future projects should commission a complete range of surveys at an early design stage. These should include not only services and plant room surveys but also electrical surveys to determine available capacity and the cost of any upgrades needed to exploit that capacity, as well as below ground services where trenching is envisaged.

Retrofitting existing buildings requires careful design. This is particularly true when linking a new heat source into an existing distribution system. There were a number of major changes noted in this paper such as moving pipework above ground, but also a number of smaller changes and refinements. These often included rerouting pipes to accommodate existing services or adjusting design set points to accommodate an existing control setup. Scrupulous, up to date record keeping of all service and plant room information (including for controls), will ensure that this process is simpler. Recording building performance and historic heating profiles is particularly useful information for designing a low carbon retrofit.

As explained above, although there is currently no cooling demand in both the JB and TB, it is a possibility that parts of these two buildings or any other building in close vicinity may require cooling. Waste heat from a third building which requires cooling can be added to the circuit to assist in providing heating for both the JB and TB. After transmitting its heat, the circulating fluid will lower in its temperature and can be retuned back to its building to absorb more heat again to provide continuous cooling.

There is an opportunity across London to increase the use of geothermal systems for heating. At the present time, the majority of existing open loop systems tend to be used for cooling demand for the purpose of air-conditioning. Therefore, there is a need to balance the overall heat gains and losses to the aquifer by using an open loop system for the generation of heat using the BEN system.

This indicates that the Environmental Agency will be keen on assisting the BEN system to maintain the ground source water temperature balance and aquifer warming (Maidment, 2013).

7. Conclusions

The BEN system is specifically designed to provide heating (and potentially cooling) energy using a cost-effective CWHN, high temperature heat pump functioning in combination with ground source water and a DSR control process. The demonstrator is intended to test and prove its practicality and commercial viability.

Major challenges observed during the implementation of this project were highlighted, primarily under the themes of time and cost overruns. Contingency planning was also mentioned as a key issue and this should always be considered in a projects, and included in the budgeting.

The implications were discussed for future efforts in retrofitting low carbon heat. The fact that heat pumps raise peak electrical loads and the implications for DNOs has been noted. At the detailed planning stage, attention should be paid to the specific site electrical capacity.

The transition to low carbon heating systems is likely to occur at the point of failure of an existing system or when natural maintenance cycles determine a system to no longer be worth maintaining. At these times considerable care should be given to which parts of the heating system should be replaced. Building owners are very likely to take a varied approach to this and designers must create suitably flexible systems to accommodate this variation.

The fact that BEN was able to accommodate such a wide range of changes and be installed and commissioned is a credit to the flexibility of the underlying design. Suitably incorporating some of these lessons in future low carbon heat retrofits can help better anticipate, and thus reduce the cost of delivering that flexibility.

One final note is necessary to caution against overgeneralisation of these findings. There are many buildings for which BEN forms a relevant precedent, but a far greater number of detailed case studies such as this will be needed to define the range of building archetypes and contractual arrangements to guide the delivery of low carbon heat across the stock.

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