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Cold Water Heat Networks and the Thermal Storage Revolution

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Abstract

This paper will present evidence that rather than build district heating schemes, 'Cold Water Heat Networks' (CWHN) linked with seasonal storage provide a better solution. CWHNs transfer heat at ground temperature and extract it via heat pumps, which allows the integration of diverse energy systems through links to boreholes and other storage, the recovery of low grade waste heat, and the delivery of simultaneous heating and cooling, none of which are possible with conventional heat networks. Some elements of this concept have been used in Northern Europe, but have yet to be demonstrated in the UK.

This paper gives the results of a feasibility study for a development of this technology that has been conducted at London South Bank University and shows the carbon and cost reduction potential of installing such a network in a central urban area. The analysis considers retrofitting a simple network linking two existing buildings. The performance of the network is measured against a business as usual scenario (existing gas boiler systems and roof mounted chillers). The metrics considered include life cycle cost, carbon savings, and return on investment. The paper details the assumptions made for each scenario and shows that the CWHN performs better against every indicator. The paper closes with an analysis of the barriers to scalability based on a workshop that has been held with industry and government stakeholders.

Keywords - component; formatting; style; styling; insert (key words)

1. Introduction

Improving the way we heat and cool buildings is a key part of decarbonising cities. The thermal performance of modern buildings is driving down the demand for space heating per unit [1]. Commercial buildings are already typically cooling led and this trend is accelerating. The UK Department of Energy and Climate Change (DECC) has the stated goal of delivering 15-25% of space and water heating demand through heat networks. Current capacity is estimated at 2% [1]. Developing scalable solutions to heat networks is therefore critical to meeting energy demand, and to reaching the UK's 2050 carbon reduction targets.

Inter-seasonal heat storage can make use of the ground temperature as a heating resource [2]. Combining this principle with high temperature heat pumps, it is possible to link buildings and create a large scale ground source heat pump network: an internet for heat. Some of the principles and technologies behind this type of 'Cold Water Heat Network' (CWHN) have been established in parts of Europe.

This paper will describe the fundamental physics and components of the proposed CWHN for a new variation developed in the UK, and how they compare to conventional heat networks, with examples of these networks in practice. It then gives the results of a feasibility study for the retrofit of a CWHN in central London. Finally the results of a stakeholder workshop will be used to frame the barriers to scalability and shape the further work needed in this area.

2. Literature

This paper brings together two separate but related principles. First is the idea of heat networks, which share the distribution of heat from a central source. Second is the use of the ground itself as 'a temperature resource' for inter-seasonal storage. This literature review will describe each in turn, and explain how they can act together to create a CWHN.

a. Heat Networks

Communal district heating systems are widespread in many cities of the world. The benefits networked heating systems are well acknowledged and form a central component in the UK's efforts to decarbonize heat [1].

The main components of the system are [1][3]:

- Centralised plant for heat generation and circulation
- Distribution pipework circulates hot water at around 80/90ºC
- Building interface plant to provide heat for individual customers
- To achieve a successful business model, the scheme requires sufficient committed long-term customers to justify the cost of installing the heat network and the centralised plant.

b. Inter-Seasonal Thermal Storage

The theory and principles behind seasonal thermal storage are well studied (see e.g. [2][8][9]). This paper specifically focuses on aquifer thermal energy storage (ATES). There are a few examples of ATES systems in the UK, and more in Europe, with 1000 systems already operational in the Netherlands, and calls for 20,000 by 2020 [11].

The stored heat can be utilised in a number of ways. Seasonal storage has been used in Rajput and Moghul buildings in India, using various techniques of ground coupling to provide cooler environments [4]. Recent applications include de-icing road surfaces [10] or the Drakes Landing Solar Community in Okotoks, Alberta [6]. ATES systems are known to provide particular advantages in cooling operation, potentially eliminating the need for conventional cooling plant [13].

c. CWHNs in principle

ATES systems have been applied to single buildings. The idea of linking the load points across multiple buildings, is less common [11][12]. Because heating and cooling energy is being extracted from water circulated at ground temperature, this work has coined the term Cold Water Heat Network (CWHN) to describe such systems. A CWHN is a network distribution system, using water in a pipework circulation, to deliver energy for heating and cooling to users. An example layout is shown in Figure 1.

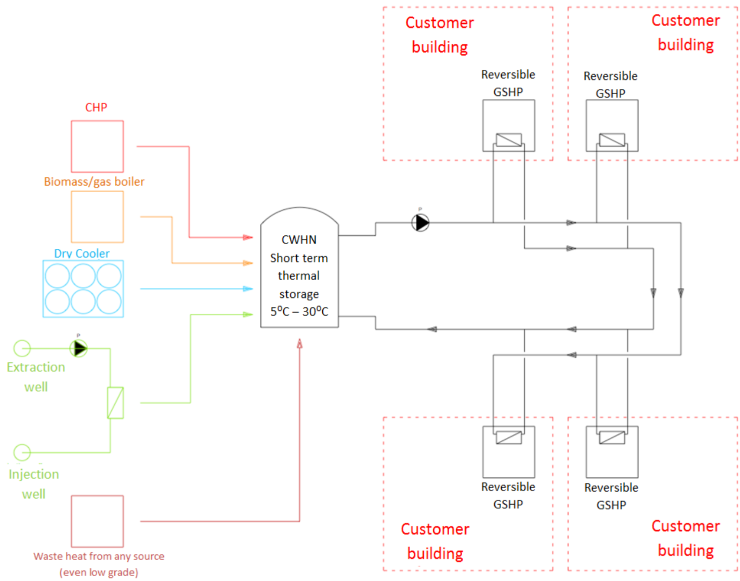

Figure1: CWHN example layout.© Copyright ICAX

In a CWHN system, the main components are as follows:

- Distribution pipework for the circulation of water at between 5ºC and 20ºC, suitable as an energy source for heat exchange using heat pumps for both heating and cooling.
- Interface plant to link the buildings to the CWHN network
- Localised plant (in each building) to provide heating and cooling energy at the building level. (A heat exchanger takes

heat from the circuit into the building, where it is upgraded to useful heat via the heat pump. The amount of heat extracted depends on design details unique to each project.)

- The system can create balance over short, medium, and long term measures (instantaneous, diurnal, and seasonal).

Because plant is local to the building and doesn't require central sizing and planning, it can be implemented incrementally, reflecting the actual development pattern in the UK: the CWHN network can be built from the bottom up, rather than the top down.

The capacity of networks to store heat helps address energy system balancing issues, and diverse heat sources can reduce pressure on peak grid performance. Modelling suggests that heat networks are cost effective for decarbonising heating in older buildings and in dense urban areas [1][7], but retrofitting a heat network to a dense urban area faces many practical challenges. Table 1 summarises the differences between conventional heat networks and CWHN systems based on the literature cited thus far.

Table 1: Comparison matrix between Conventional District Heat and CWHNs

Cost Impact	Conventional District Heating Network	Cold Water Heat Network (CWHN)
Planning, legal permissions for project	High up front development costs and long term permissions needed.	CWHN can be created in incremental steps,
Installation of pipework	Heavy duty insulated flow and return pipework.	Uninsulated single pipe.
Construction, operation and maintenance	Sized and planned at project outset. Adjusting to changes in load profiles is not straightforward.	Plant is in each CWHN user building, operating costs are significantly reduced.
Services	Heating only. Cooling requires separate pipework circuit.	Heating and cooling through single pipework circuit.

d. CWHN Examples

There are examples of systems in Europe that meet this basic description of CWHNs. The Oostelijke Handelskade project in Amsterdam called for 8.2 MW of heating and 8.3 MW of cooling across a passenger terminal, office buildings, hotel, arts centre, and apartments. The design balanced supply and demand within and between buildings, and used two hot and two cold ATES wells, saving 50% of its energy use compared to conventional systems [14]. A highly relevant precedent to the current feasibility study is the 20MW campus-wide CWHN at Eindhoven University [15].

Critically, these projects demonstrate the ability for heat networks to match load profiles by using the ground and water to turn the network itself into a storage system. UK versions of a CWHN have been advanced [17], but despite successful Northern European examples there is no comparable system in the UK. Standalone ATES solutions have been installed, but none have been linked together via heat networks.

Heat networks themselves face slow deployment due in large part to non-technical barriers [1]. The purpose of this study was therefore to explore not only the technical potential of retrofitting a CWHN in central London, but also the non-technical barriers present and whether any of these barriers are better addressed using CWHNs. The following section will describe how this study was conducted.

3. Method

Heat networks and inter-seasonal storage represent two proven solutions capable of reducing carbon emissions. This feasibility study assessed the potential to create a simple demonstration network linking two buildings in central London to each other and to ATES. The methodology was as follows:

- Select site and suitable network size
- Engineering analysis of costs, and energy and CO_2 savings
- Conduct workshop with key stakeholders on barriers to implementation and scalability.

4. Site selection

The London South Bank University (LSBU) campus offers an ideal location in South London to demonstrate and test CWHN technology in a dense urban area. The decision of which two buildings to connect for the demonstration project was based on the following criteria:

- **Physical location:** the buildings had to be separated by a sufficient distance that the ground temperature of one would not affect the other. The separation should also not be too large so as to minimise disturbance and installation costs.
- **Building access and space requirements:** the buildings plant rooms must be accessible to machinery in order to install new heat pumps that can be connected to existing building systems.
- **Building load profiles:** the buildings will ideally have large, but differing load profiles so that there is potential to move energy between them in useful ways.

In order to address these three criteria, the LSBU & Academic Environment (EAE) provided energy performance data for all of the buildings in their portfolio. Cooling load data is not recorded as a standalone item, but rather is captured in the overall building electrical loads. Most cooling on LSBU campus is provided by local air conditioning units. Based on interviews with LSBU EAE team, the highest cooling loads occur in buildings that were not suitable for a demonstration project due to plant room restrictions.

On 13/07/2015 a site visit was carried out in which ICAX engineers visited shortlisted buildings along with representatives from LSBU EAE team. Following from this, the proposal is to provide a CWHN linking the Tower Building and M Block, J.L. Building, & Ext. Block as shown in Figure 2. These buildings represent the optimal combination of the three criteria listed above. A summary of the heating profiles for each building are given in Table 2. Note that two buildings have very similar annual heating profiles, and thus the potential to move heat between them in the demonstration will be limited. Rather they will add and remove heat from the aquifer thermal storage.

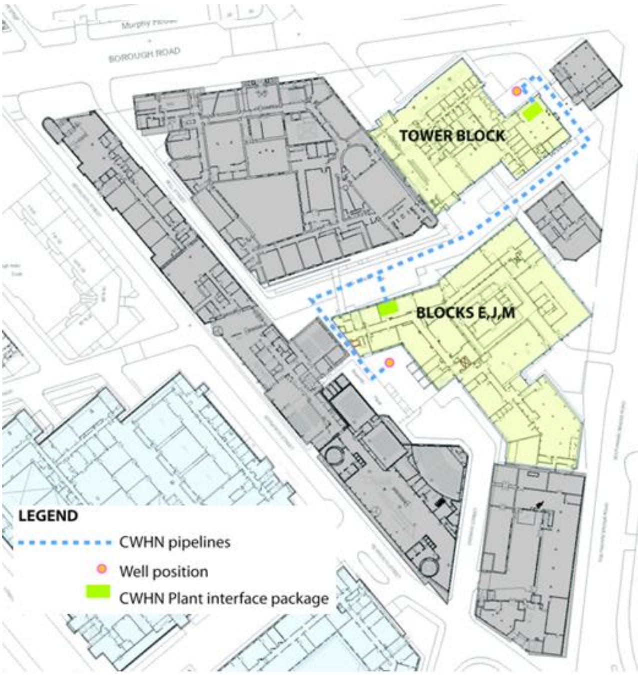

Figure 2: Proposed layout for CWHN demonstration.

Table 2: Energy performance data for LSBU buildings from 01/08/2014 to 09/06/2015.

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

5. Engineering analysis

In order to conduct a high level engineering analysis on both the likely costs and sizing for the system, a number of assumptions were made based on current fuel prices and energy policies. A summary of these assumptions is given in Table 3. The heat pumps will be sized to meet 100% of the building heating load and provide a complete replacement for the existing boilers. The boilers will remain as redundancy.

Table 3: Cost benefit analysis assumptions.

Gas standard tariff	0.04 £/kWh
Electricity standard tariff	0.11 £/kWh
Gas price increase	5% per annum
Electricity price increase	4% per annum
Inflation	3% per annum
RHI GSHP- Tier 1	0.087 £/kWh delivered
RHI GSHP- Tier 2	0.026 £/kWh delivered

Based on the assumptions listed in Table 3 and the sizing data of Table 2, the CWHN installation was compared to a business as usual scenario with the two buildings continuing to operate on independent gas boiler systems. The scenario was projected for 20 years, giving the results in Table 4.

Table 4: Preliminary cost benefit analysis – Business as Usual (Gas Boiler) versus CWHN.

Lifetime benefit over 20 years compared to business as usual (BAU) gas boiler (£)	£4,651,038
CWHN Capital Investment (£)	£1,950,000
Payback (years)	10.2
IRR (%)	8.8%

Estimating the carbon savings associated with CWHNs is not straightforward. Because it is a foundational technology, the true carbon savings will depend greatly on its implementation. For example, a building with a high cooling load could reject heat to a building with a high heating load. Or it could make use of rejected waste heat from a nearby data storage facility. With CWHNs, it is possible for the only carbon emissions associated with building services to be in the heat pumps themselves. A simple calculation for the proposed demonstration project estimates a 35% savings for the CWHN compared to a typical gas boiler. The benefits of electrified heat also improve with the decarbonisation of the UK grid..

Table 5: Potential carbon savings – University campus retrofit.

	BAU (Gas boiler)	CWHN
Heating (MWh/pa)	2356	2356

Cooling (MWh/pa)	600	600
Gas boiler efficiency	0.8	3
Chiller SEER	2.5	5.4
Heating emission ($kgCO_2/kWh$)	0.184 (gas)	0.445 (elec)
Cooling emission ($kgCO_2/kWh$)	0.445 (elec)	0.445 (elec)
Heating emissions (tonnes CO_2e/pa)	542.0	349.9
Cooling emissions (tonnes CO_2e/pa)	106.9	49.5
Total emissions (tonnes CO_2e/pa)	648.9	399.3
Heating emissions savings	(tonnes CO_2e/pa)	192.1 (35%)
Total emissions savings (w cooling)	(tonnes CO_2e/pa)	249.6 (38%)

This is likely to be a low-end estimation of the carbon savings for several reasons. Firstly it does not fully capture the potential to recover waste heat or use thermal storage. Secondly, the buildings for the proposed demonstration do not have very high cooling loads. As shown in Table 5, for typical SEERs the carbon savings increase as the cooling load increases.

Finally, the true carbon savings of a CWHN will increase with time as more buildings, heat sources, and storage become connected to the network and more sophisticated algorithms are developed to distribute that heat accordingly. The £1,950,000 initial capital expense is a sizing estimate that was created through discussions with potential contractors as part of the feasibility study. In practice, both the capital and operating costs of the CWHN are expected to decrease over time as more networks are installed. The Renewable Heat Incentive (RHI) is a mechanism to compensate for this technology lag and are thus included in the financials. The RHI also recognizes that ground source energy is a private cost but a public benefit.

6. Results of Stakeholder Workshop

A stakeholder workshop was held on 07/07/2015. Delegates included decision makers from both the developer and client side, as well as from local government in order to cover the range of stakeholder perspectives. The purpose of this workshop was to discuss how the factors in Table 1 are relevant in the context of a demonstration project in a dense urban environment, specifically central London. The agenda covered barriers to heat networks overall, the benefits of cold versus hot water networks, the choice of demonstration venue at LSBU, and scalability and adoptability issues. The following headline points were raised by stakeholders:

Emissions: Air quality is a serious issue in many cities as urban district heating schemes, particularly from CHP and biomass sources increase the level of nitrogen oxides and particulates in the air. Delegates noted that CWHNs offer considerable benefits to air quality compared to conventional heat networks by removing the need for an energy centre and the associated on-site combustion. A switch to electrical heat energy sources is also consistent with current Local Authority level thinking.

Investment continuity: The issue of compatibility was raised as delegates were curious whether current heat networks could later be converted into Cold Water networks. The study found no reason that existing, conventional heat network pipework currently being installed could not converted or upgraded for CWHN use.

Load diversity: As CWHNs grow, the benefits of diversity across the network increase. Users in one part of the network may require cooling – and therefore reject heat can be which can be delivered to users who are demanding heat. Exploiting this type of load diversity in small systems is challenging due to the risk of changes in the load profile of any one building. However, as the network grows, this risk is reduced.

Opt-in versus Opt out: Conventional district heating networks require a critical mass of users to be bought in and legally bound in order to be viable. This is a significant hurdle to the rapid growth of networks, since it places constraints on operators and users of networks, sometimes beyond the natural use pattern of urban buildings. Major urban leaseholders, will normally be subletting urban office buildings in 5 year lease periods, and will tend to budget in relatively short timetables. To make it as easy as possible for the market to migrate towards heating and cooling networks, it is helpful to provide more bite-sized infrastructure investments. CWHNs achieve this by allowing a network as small as two buildings to be viable. These small-scale networks can later be joined together incrementally.

As well as being more accommodating at the "opt-in" stage, the CWHN is more flexible at the point where the user may choose or need to "opt-out". Opting out of a conventional district heating scheme is highly problematic. The schemes rely on a certain economy of scale in order to functional viably. Removing users upsets the economy. This opt-in, opt-out flexibility is a crucial asset for CWHNs and reduces a major barrier to uptake compared to conventional heat networks.

7. Conclusions

There is considerable potential to reduce carbon emissions through the provision of heat networks. Inter-seasonal storage captures waste energy but is limited in scope unless it is suitably connected to infrastructure. Combining these two ideas via a CWHN has the potential to share heat between stores and buildings. This feasibility study considered a demonstration case in central London. It showed the project is not only technically feasible, it outperforms a business as usual scenario in terms of lifecycle cost and carbon emissions.

A stakeholder workshop explored qualitatively the practical implications and limitations of CWHN technology, specifically comparing the feasibility to conventional heat networks in central London. This highlighted numerous benefits and points of consideration in addition to those outlined in the literature review. These include air quality issues in dense urban areas, and the way in which opt-in/opt-out flexibility reduces a major barrier to heat network deployment.

This work shows the promise for an effective demonstration of CWHN technology in central London. However, it only scratches the surface of the potential for heat networks to create an arterial system of distributed thermal energy storage. Desmedt [16] for example considers how a district heating network can increase the profitability of a CHP system using distributed thermal storage. Using a CWHN only increases this potential by enabling the recovery of low grade heat from virtually any low carbon energy source. This would revolutionise heat transfer and storage for buildings. Building services will no longer be about creating heat, but about moving heat away from places that need cooling towards places that need heating. Less heating and cooling generation, more thermal storage and management. CWHNs can open a new frontier of innovation in technologies to add, move, and remove energy from a network.

Acknowledgment

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