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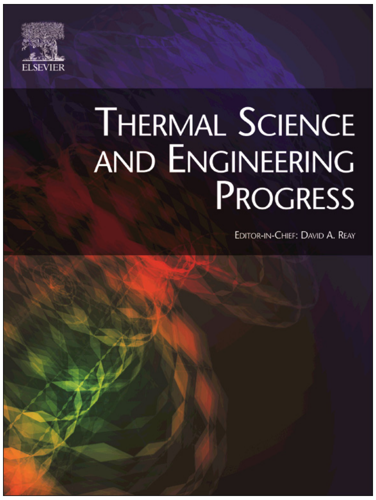

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Smart Cities – Thermal Networks for London

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ABSTRACT

This paper presents a feasibility study of the technical and economic viability of introducing combined heating and cooling networks in London, referred to collectively in this paper as “thermal networks”.

The study begins with a review of the current and potential future demographic and energy trends for London. This is followed with detailed energy analysis of three different thermal network configurations to identify the most viable thermal network configuration for London. Future projection analysis was also carried based on a number of potential building mix scenarios.

The study revealed that by using thermal network with heat recovery produced significant energy savings and subsequent carbon savings by upto 56 %. The majority of the energy saving and equivalent CO_2 emission savings resulted from the reduction of the heating energy required to cater for the loads due the viability of heat recovery from the cooling network into the return of the heating network. The study also revealed that by utilising thermal networks, with central energy centre approximately 1831 tonnes of CO_2 equivalent could be saved per annum compared to traditional supply methods. With a minimum assumed system life of 25 years this equates to approximately 46000 tonnes CO_2.

Keywords: Thermal networks, Combined Energy, *Combined heating and cooling.*

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1. Introduction

The UK has historically been a predominantly heat led environment with approximately 50 % of the energy used in buildings is mainly due to heating and only 2 % of this heat is currently being provided by heat networks [1]. The situation however is progressively changing; District Heat Networks (DHN's) are becoming increasingly popular especially within high density cities like London. However, variation of the climate, considerable improvement in buildings thermal performance and the increase in IT usage are contributing to excess heat in buildings and thus increasing the need for cooling within high-density cities. The majority of the excess heat is currently being wasted or discharged into the atmosphere and resulting in greater influence on the urban heat island. Added to this, the UK is currently assessing the best economic strategy to ensure continued growth throughout the process of leaving the EU and on into the future [2 and 3]. The latest discussions on this subject have proposed a number of strategies in order to continue the growth in key areas. The two key strategy options that are currently being discussed are; service led economy and industry led economy. If adopted, either of the two options would result in a different energy requirement compared to current situation. For example, the service led economy would need more buildings that require cooling due to increased IT usage and more human density per m^2 while the industry led economy would require more buildings that require heating energy.

One of the key emerging concepts is that of Smart cities. This involves the utilisation of building and cluster data, information technology (IT) and the internet of things to connect services, infrastructure, people and buildings together. The target of Smart cities is to enable energy recovery and thus reduced energy consumption and CO_2 emission associated with the development of a growing economy. Thermal network, as illustrated in Figure 1, is one aspect of Smart Cities which combine DHNs with District Cooling Networks (DCNs) to provide heating and cooling to cluster of buildings. This could, if designed and operated correctly, provide overall energy saving and reduction of CO_2 emission.

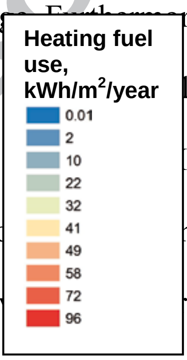
To investigate the potential viability of thermal networks in London, the authors drew on on knowledge and experience gained from researching successful district heating networks (DHN) in the Lonodon area, complemented by best practice guidance on DHNs [4] and learning attained from researching successful district cooling networks (DCN's) in other parts of the world such as the Fortum Remote Cooling Network [5, 6 and 7].

This paper presents a brief summary of the demographic and energy trend for London, followed by the results from an assessment of three different thermal network configurations for use in London. The paper also assess the potential impacts of implementing a thermal network, with water source heat pumps within the main energy centre to reject the heat from the cooling system into the return of the heating system, on a number of cluster scenarios with various mixtures of building type density distribution.

2. London Demographic and Energy Trends

According to the London Plan 2011, London is responsible for 8.4 % of the UK emissions (the latest annual estimate is 44.71 million tonnes of CO_2 equivalent and heat density (relative heat demand based on fuel use $kWh/m^2/year$) for the centre of London currently exceeds 96 kWh/m^2 per year, see Figure 2 for detail [8]. Also according to an energy use survey conducted by URS for the City of London [9] on a selection of the City's businesses. Based on the information provided by the respondents the key emission sources were reported as heating and lighting at 31%, air conditioning at 26% with refrigeration responsible for a further 9%, see Figure 3. This demonstrates that in an urban environment containing many office blocks the cooling energy demand is likely to equal or even exceed the heating energy demand.

Various other studies have been undertaken to assess the current and future cooling demand for London, some within the context of the overall development strategy, others in response to the need to develop a strategy for climate change mitigation and future energy supply. The London Plan [8] presented an overall strategic plan where within the section on climate change and mitigation the report set targets to reduce carbon emissions to 60% of 1990 levels by 2025, requiring all new buildings to be zero carbon by 2019 and promoting increased use of decentralised energy and heating and cooling networks. It also included a cooling hierarchy to be applied when making planning decisions and 'urban greening' objectives to mitigate climate chan re a report on Delivering London's Energy Future by the GLA [10] addresses the l issues in greater depth and set targets to increase the supply of decentralised energy P and Tri-generation systems and associated heating and cooling networks) to 25% c nergy. The report also stressed as sets out in policy 5.6 of the London Plan, "new de required to connect to existing local district heat and cooling networks where feasible, or to use site-wide heat networks and, where appropriate, install CHP systems". These requirements promote a great opportunity to extend existing heat networks and incorporate Thermal Networks that could provide both heating and cooling.



3. Comparison of Different Thermal Network Configurations

This section describes some of the potential arrangements available for thermal networks and explores modifications to the heating and cooling system configurations which could help the load balancing of thermal Networks. The riding factor has been the integration of the two systems in order to allow for a proportion of heat recovery. Three configurations have been assesed in this research;

Configuration 1 – Thermal networks which utilise district networks to serve the connected buildings with the required heating and cooling. These networks use water source heat pumps within the main energy centre to reject the heat from the cooling system into the return of the heating system; , therefore, resulting in a reduction of the main heating plant capacity.

- **Configuration 2** - Local balanced network which uses a local water source heat pump and DHN connection. The individual heat pumps within each building use the return of the DHN network as the heat sink. This increases the return temperature of the DHN network resulting in reduced main heating plant capacity.
- **Configuration 3** - A traditional configuration using an independent local chiller in the building and DHN connection.

The impact of the three configurations has been investigated in terms of energy reduction, carbon savings and cost performance. Table 1, provides a summary of the inputs used including any assumptions made as part of the assessment.

3.1 Calculation Steps

Five rigorous calculation steps were developed to assess each configuration, further detail could be found in [11] and are summarised below:

Step 1 – Pipework sizing

To determine the pipework size required for the heating and cooling network in each of the scenarios, the flow rate for a given peak capacity was calculated. This was done based on the system capacity, specific heat capacity and the temperature difference between the flow and return runs. Based on the calculated flow rates, the required cross-sectional pipe area and resultant diameter for the pipes were determined for both the heating and cooling circuits.

Step 2 - Heat Losses

With the pipework details established as set out in step 1, the heat losses/gains associated with the thermal network distribution were then estimated for each run, based on the pipe surface area, the heat loss coefficient and the temperature difference between fluid and the ground.

Step 3 - Friction Losses

Friction losses associated with the district network distribution were estimated using the Darcy-Weisbach equation. This, in turn, enabled the determination of the pump power and pump input power.

Step 4 – Energy Consumption

The system heat recovery (MWh/Annum) was calculated by multiplying the cooling consumption (MWh/Annum) by the Heat recovery efficiency.

Step 5 – Costs

To estimate the costs associated with each of the configuration, the plant and pumping station cost were estimated based on manufacturers' data. The cost of the pipework materials has been extrapolated from manufacturers data. The installation costs were estimated based on rules of thumps (£/MW and £/m) backed with previous knowledge gained from designing and installing DHN's in London.

The running cost for each configuration was calculated based on the gas and electricity tariffs and kWh used from each source plus maintenance cost. While the revenue is the income generated from heat and coolth sale at the standards rates listed in Table 1.

3.2 Results of System Configurations

Using the method detailed in Section 3.1 the energy consumption associated with the three system configurations were established and are summarised in Table 2. This in turn were used to determine the equivalent carbon emissions as demonstrated in Table 3. As could be seen from Tables 2 and 3, both configurations consisting of heat recovery produced similar energy savings and subsequent carbon savings between 53.6 and 56.5 % for configurations 2 and 1, respectively. The majority of the energy saving and equivalent CO2 emission savings were due to the reduction of the heating energy required to cater for the loads, please see Figure 4.

While this section has assumed that both the heating and cooling systems are balanced, in the UK, this is unlikely to occur due to the predominantly heating led climate. Section 4 develops the analysis to take into account potential load profiles which are likely to be present within thermal networks in the UK.

4. Modelling of Typical Thermal Network

Five building types (Hotel, Industrial Office, Residential, Retail and Schools) were modelled and used with different mix to simulate clusters with district thermal (cooling and heating) network. The model enabled the prediction of the heating and cooling loads for the network based on the building mix rather than assumed fixed annual and peak heat/cooling loads. This was done by using dynamic modelling software (Environmental Design Solutions TAS) to model the heating and cooling demands for the 5 building types based on London Weather data. The internal conditions within the model utilised the NCM templates provided for the respective building types. The dynamic model generated both monthly and hourly loads profiles for each of the 5 building types. From this, typical winter and summer days were selected based on their peak heating and cooling demand respectively. Also, the annual heating and cooling energy profiles per m^2 for the 5 modelled buildings were obtained.

4.1 Network configuration

Three potential building mix scenarios were investigated. These are defined below and explained in Table 4 as percentages;

i) Scenario 1 Current- For this scenario the current building mix of a typical London cluster, with a total network area of 25 km^2 and an associated building area of 150 km^2, was estimated. The building mix percentages for this scenario were been based on analysis of published data relating to employment in each sector [5,12]. This in turn was used to determine what split of the network could be attributed to each of the business sectors.

Residential has been taken as half of the network area due to the assumption that the workforce will be living in the local vicinity.

ii) Scenario 2 Service led economy –for this scenario the building mix modified to accommodate for service-led economy. This was based on the assumption that services led economy would lead to an increase in the percentage of office spaces from its current parentage of 30 % to 48 %.

iii) Scenario 3 Industrial: building mix modified to accommodate for industry-led economy. This was based on the assumption that a service led economy would lead to a significant increase in the percentage of industrial space.

While this investigation focused on 5 building types, this has been deemed as a representative sample of the majority of the building types within London.

To determine the overall load for each scenario Equation 1 was used to estimate the overall area of the building type within the district network. The area was then used within Equation 2 in conjunction with the building profiles to determine the equivalent heating and cooling loads.

$$\text{Building Area} = \%\,\text{Mix in Scenario} \times \text{total network coverage} \quad (1)$$

$$\text{Estimented load/ building type} = \text{Building Area}\,(m^2)\ x\ \text{profile}\,(kWh/m^2) \quad (2)$$

These have used to generate a total system demand profile on which the analysis has been based on.

4.2 Energy Analysis Results

4.2.1 Scenario 1 – Current mix

The annual network demand profiles for the heating and cooling systems for scenario 1 are highlighted in Figure 5. As can be seen from the figure, the cooling profile is below the hot water profile from September to May and rise above the hot water profile from May to September, peeking by almost 10 folds in July.

4.2.2 Scenario 2 – Services led

The annual network demand profile for scenario 2 is highlighted in Figure 6, for both heating and cooling systems. Similar to Scenario 1 it can be seen that the cooling demand is below the heating requirement for the majority of the year until peak summer months.

4.2.3 Scenario 3 – Industry led

The annual network demand profile is highlighted in Figure 7. It can be seen that the cooling demand is below the heating requirement for the majority of the year until peak summer months.

4.3 Discussion of Energy Analysis Results

All the scenarios demonstrate that an element of heat recovery is viable between the two systems. The quantity of heat recovery, however,, is variable between the scenarios due to the altering load profiles causing the heat or coolth demands occurring at different periods. Table 5, presents the maximum utilisation of heat recovery based on the annual load profiles.

Based on this it appears that the current mix allows for the greatest heat recovery. However, when looking at the daily load profiles, it is apparent that these figures are inflated due to cooling demand not correlating with the heating on an hourly basis. Table 6, below demonstrates the resulting utilisation rates when looking at the daily profiles. These assume that thermal stores are used to allow all heat recovery to be achieved throughout the day.

It can be seen that the profiles associated with scenarios 1 & 3 produce a reduction in utilisation while scenario 2 remains at 64% utilisation of potential recoverable heat from the cooling system.

5. Economic and Environmental evaluations

Using the energy demands and network configurations detailed above an estimation of the associated capital costs has been taken and potential running costs identified. With estimated revenue for hot and chilled water based on traditional generation techniques, a financial appraisal of the three scenarios has been undertaken. Figure 8, illustrates that the most cost-effective scenario utilising a service led economy which has a simple payback of around 26 years while the current and industry-led scenarios to have payback periods of 41 and 56 years respectively.

The carbon emissions associated with each scenario has been estimated. Figure 9, illustrates that results of the calculation. As can be seen from the figure, the carbon emissions associated with scenario 2 is approximately 30% lower than the current scenarios while the industrial led scenario is equivalent to the current condition.

The above economic assessment has been based on a system using low carbon technologies to provide the remaining required heat rather than traditional boilers or CHP units. Table 7, demonstrates the simple and NPV payback periods associated with using traditional low-cost boilers and a CHP compared to the base case. The low-cost boilers result in a reduced capital cost and as such a lower payback period of 35 years. The system with integrated CHP has a similar capital cost to the base case. However, the running cost and revenue value has increased due to the increased use of gas and the potential to sell electricity to the grid. This has produced a payback period of 23 years which is a more viable investment time frame.

6. Conclusions

Current trends suggest that heating demand is likely to reduce while cooling demand is likely to increase. Additionally, the increased use of IT and increased use and insulation of buildings are likely to increase demand for cooling load in the London area. However, with the increased use of DHN's within high density areas such as London, this research has identified an opportunity to incorporate cooling networks with existing DHNs to provide full thermal networks that could supply heating and cooling provisions and future proof energy use through heat balance and recovery opportunities.

The analysis in this paper has demonstrated that the use of a central energy centre with integrated water-cooled heat pumps can be used to effectively supply low carbon & cost heating and cooling via connected thermal networks. Furthermore, it has been shown that by following a service led economic plan there is greater opportunity to utilise the recovered waste heat. This is a result of the balance of the building profiles leading to favourable heating and cooling loads. This scenario has been shown to have a payback period of between 23-40 years depending on the technology integrated into the system and have a carbon reduction of around 30% over a traditional method.

References

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[1] DECC, Assessment of the costs, performance, and Characteristics of UK heat Networks- URN 15D/022, 2015.

[2] PCW, UK Economic Outlook, Report published by PricewaterhouseCoopers LLP, March 2018.

[3] CM 9417, The United Kingdom's exit from and new partnership with the European Union, February 2017. www.gov.uk/government/publications, Web ISBN 9781474140669, ID 01021701 02/17 5230.

[4] CIBSE, The Chartered Institution of Building Services Engineers Heat Networks: Code of Practice for the UK. London, 2015.

[5]F Fortum Varme, A Brief Introduction to District Heating and District Cooling, 2017. https://stockholmdataparks.com/wp-content/uploads/a-brief-introduction-to-district-heating-and-district-cooling_jan-2017.pdf.

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[6] F Fortum Värme, Remote Cooling Networks, 2017. https://www.fortum.com/countries/se/foretag/fjarrkyla/sa-fungerar-fjarrkyla/pages/default.aspx.

[7] S. Werner, District Heating and Cooling in Sweden. Energy, 2017, pp. 419-429.

[8] GLA The London plan: spatial development strategy for Greater London, 2011. https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/LP2011%20Chapter%205.pdf [Accessed 30th May 2018].

[9] URS, Carbon Footprint of the City of London Carbon Footprint- A Study to Determine the Carbon Footprint of the City of London - Project No: 49353207, 2009 http://www.cityoflondon.gov.uk/services/environment-and-planning/planning/planning-policy/local-development-framework/Documents/City%20of%20London%20Carbon%20Footprint%20Report.pdf [Accessed 30th May 2018]

[10] GLA, Delivering London's energy future: the Mayor's climate change mitigation and energy strategy. Greater London Authority, October 2011. https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/Energy-future-oct11.pdf

[11] Pope, Ian, Smart Cities – Thermal Networks, MSc dissertation, London South Bank University, 2017,.

[12] Mayor of London, Work Force Jobs By Sector, 2016. https://data.london.gov.uk/dataset/workforce-jobs-by-sectors/resource/d33a73d4-fcb4-4140-89b8-b049badfa896.

Figures

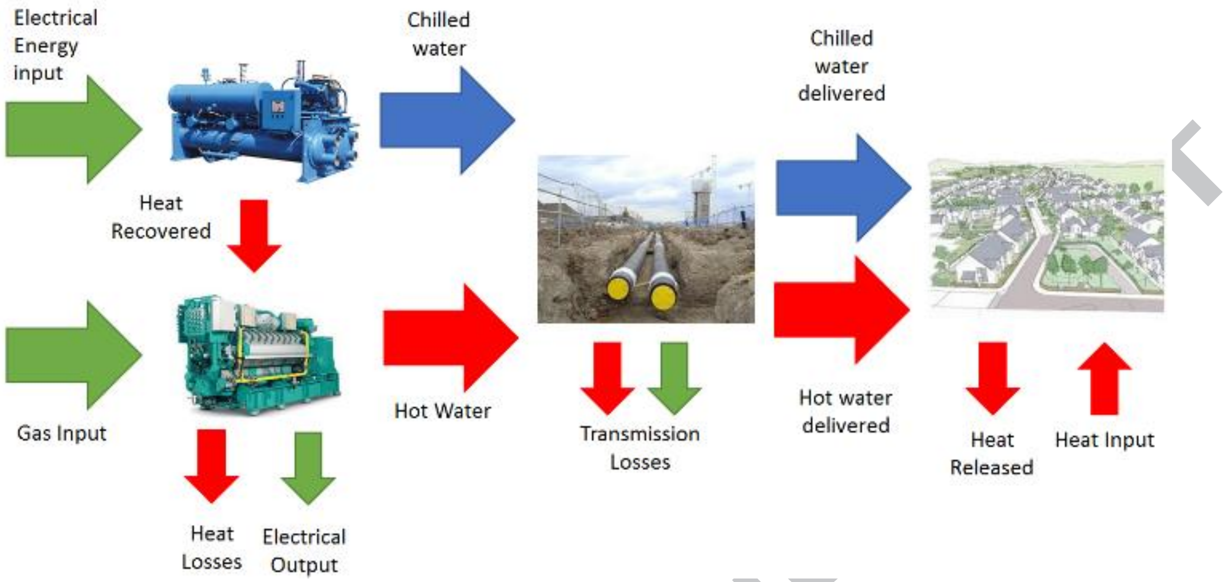

Figure 1. *Configuration of thermal network energy flow*

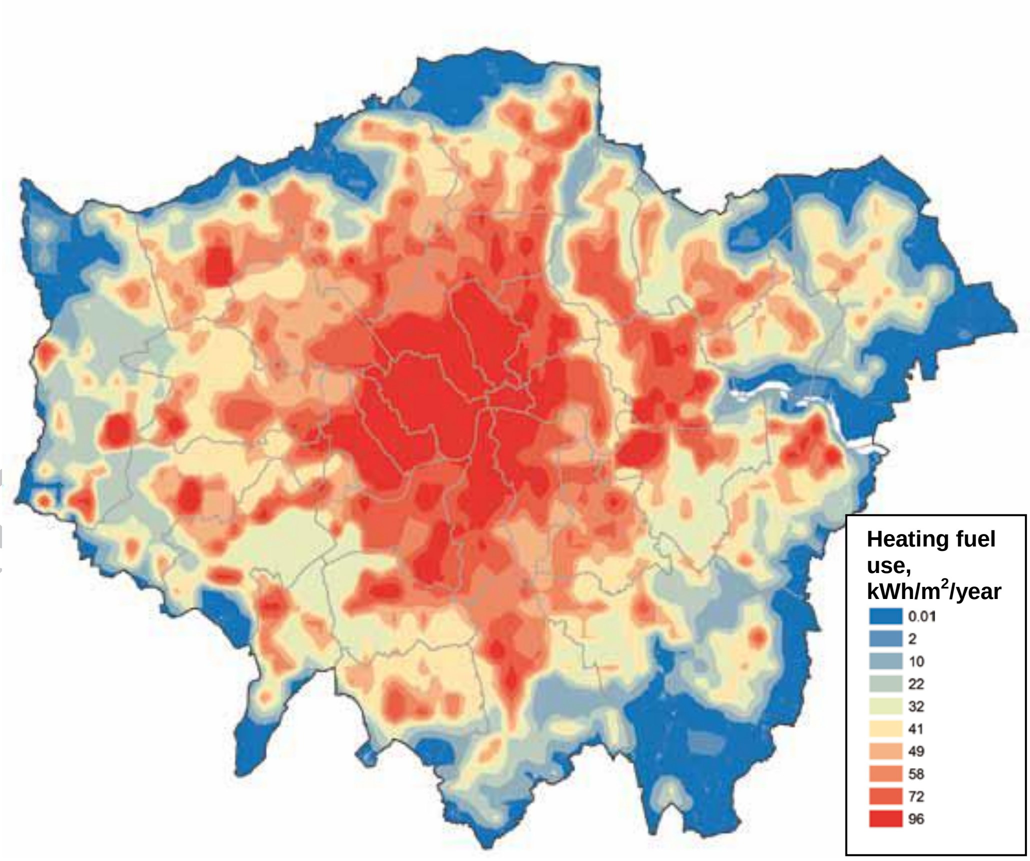

Figure 2. Heat density in London (relative heat demand based on fuel use kWh/m^2/year), [9]

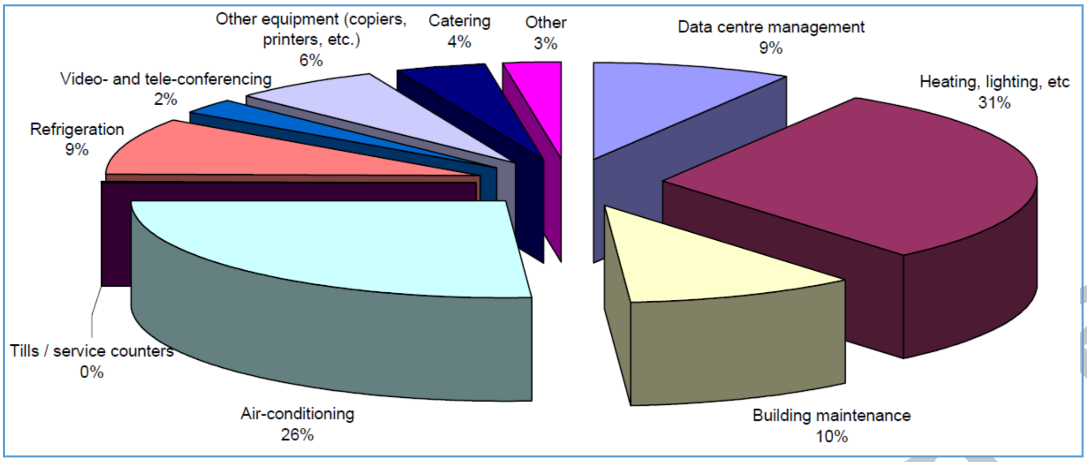

Figure 3. Proportion of Energy Use By Activity Type in the City of London [10]

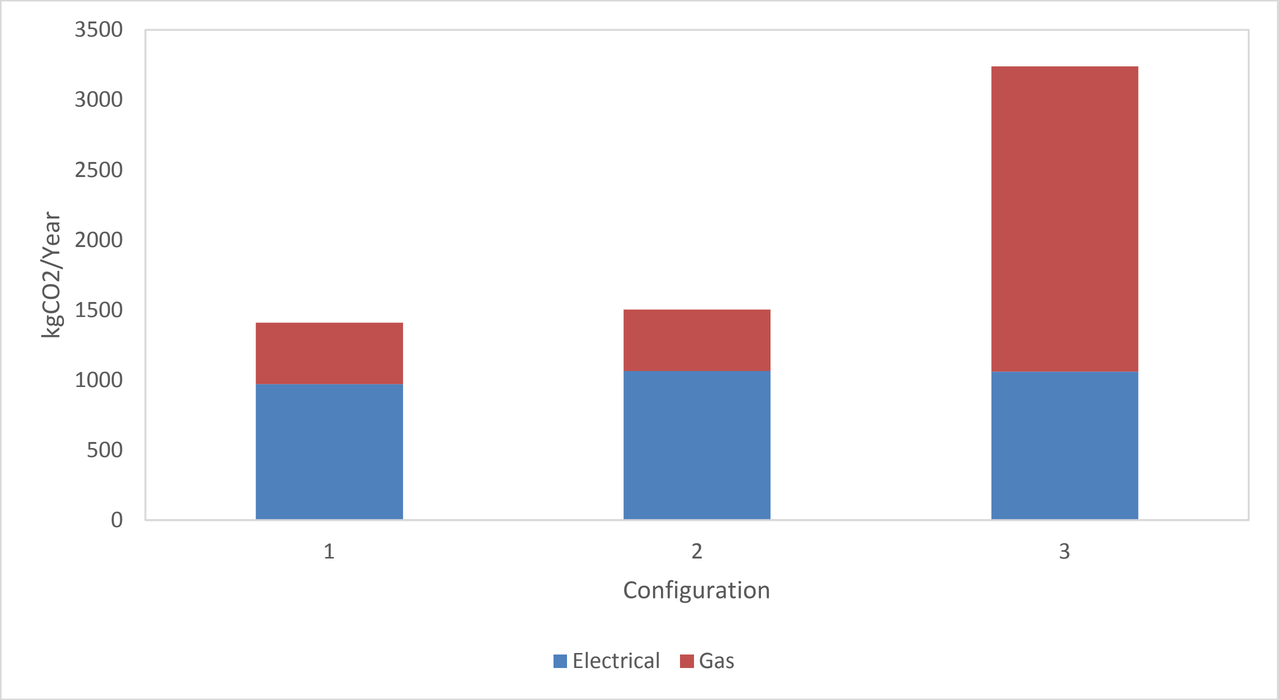

Figure 4, a summary of CO_2 emissions associated with the different configurations.

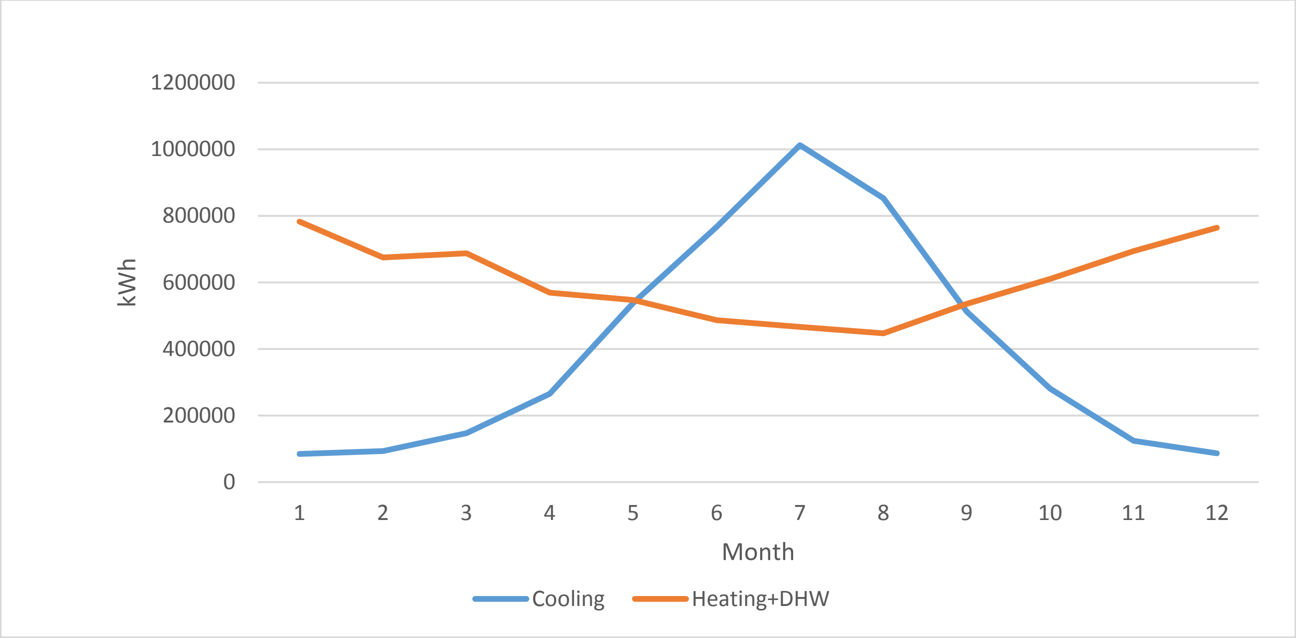

Figure 5. *Annual hot water and cooling load profile*

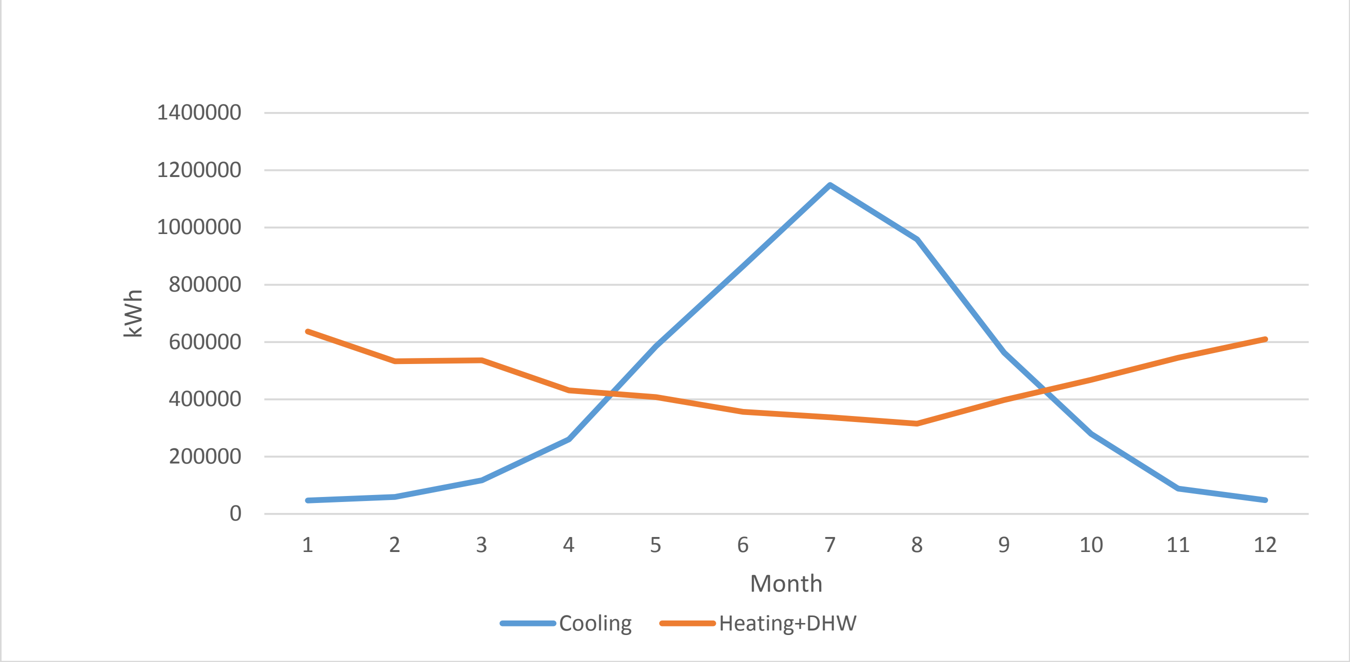

Figure 6. *Scenario 2- Annual hot water and cooling load profile*

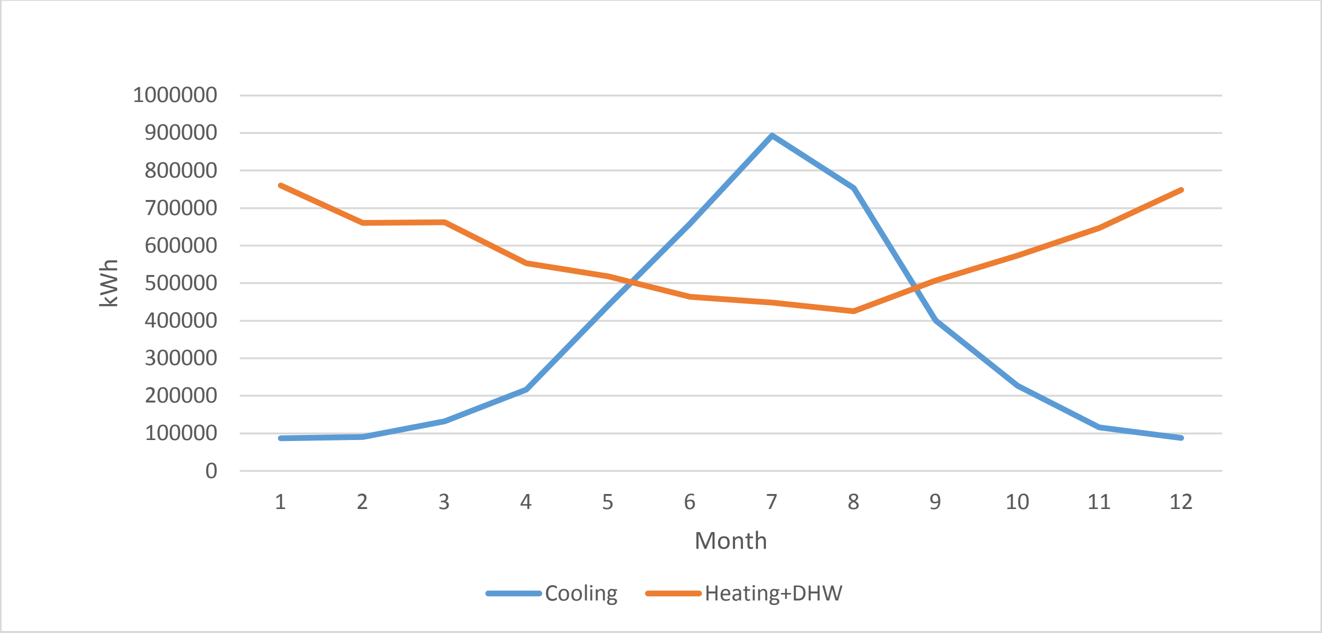

Figure 7. *Scenario 3- Annual hot water and cooling load profile*

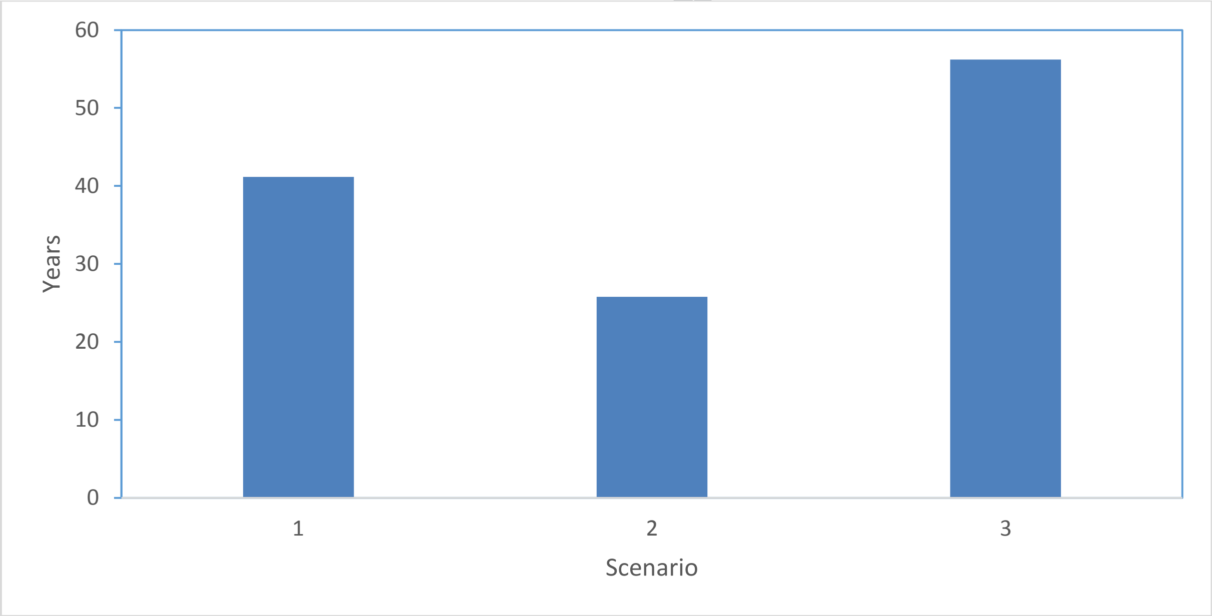

Figure 8. *Simple Payback Period for each scenario*

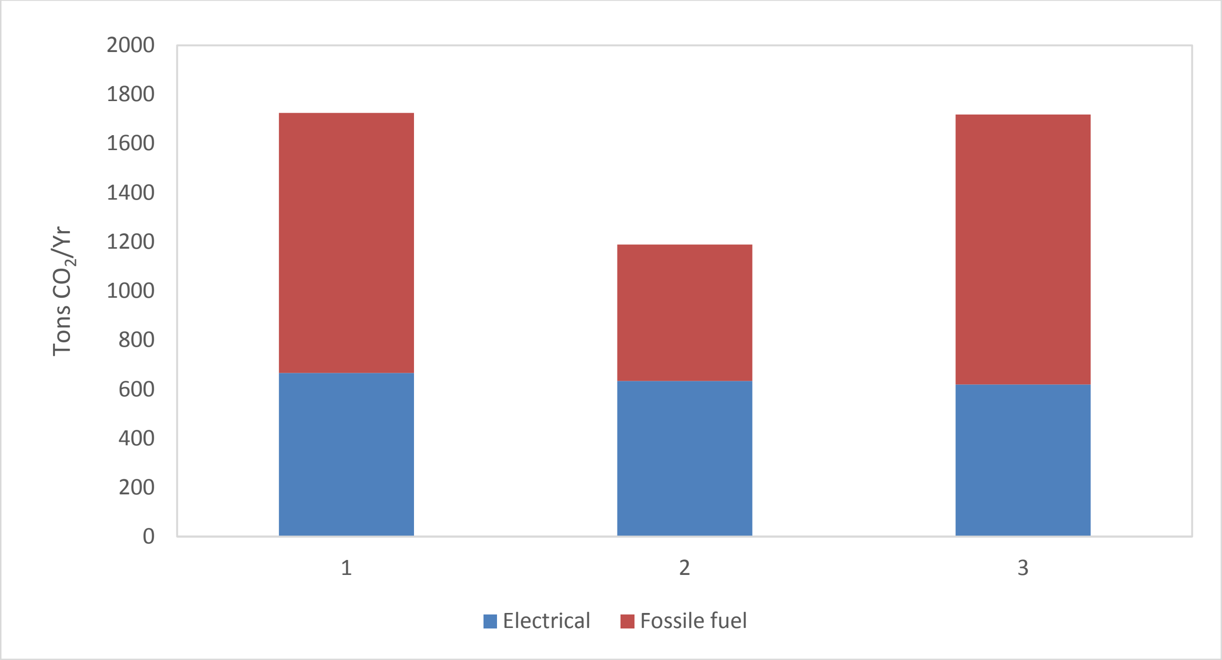

Figure 9. *Summary of CO2 emissions for each scenario*

Table 1. *System Configuration details*

System Details	Value	Units
Peak Heating/Cooling Capacity	1.5	MW
Annual Generation	10,512	MWh
Network Length	1.5	km
Cooling COP Unit Central/Local	4.5/4	
Heating Flow Temperature	80	°C
Heating return temperature	40	°C
Cooling Flow Temperature	5	°C
Cooling Return Temperature	15	°C
Average Ground Temperature	5	°C
Pumping Efficiency	90	%
Pump Motor Efficiency	80	%
System no. Running hours	7008	Hours per annum
Pipework Details		
Heating thermal conductivity	0.013	$W/m^2.K$ (with insulation)
Cooling thermal conductivity	0.06	$W/m^2.K$ (without insulation)
Friction coefficient	0.015	For Steel Pipe
Pipework Usage Factor	0.9	
Cost		
Cooling Plant Capital	350	£/kWp
Heating Plant Capital	800	£/kWp
Maintenance	0.25	£/kW
Electrical cost	0.075	£/kWh
Gas Cost	0.025	£/kWh
Coolth Revenue	0.035	£/kWh
Heat Revenue	0.035	£/kWh
Carbon		
Carbon emissions associated with electricity	0.398	kg CO_2/kWh
Carbon emissions associated with Gas	0.207	kg CO_2/kWh

Table 2. *Energy Consumption summary table for each configuration*

Configuration	**1**	**2**	**3**	**Units**
Cooling Electrical Consumption	2437.9	2673.3	2663.8	MWh/Annum
Heat Recovered	8,409	8,409	0.0	MWh/Annum
Gas Consumption	2117.0	2123.3	10526.6	MWh/Annum
Cooling network heat loss	2.0	0.0	0.0	MWh/Annum
Heating network heat loss	14.6	20.9	14.6	MWh/Annum
Pumping Losses	99.9	45.3	35.8	MWh/Annum
Total Electrical Consumption	2437.9	2673.3	2663.8	MWh/Annum
Total Gas Consumption	2,117	2,123	10,526	MWh/Annum

Table 3 *CO2 Emission summary for each configuration*

Configuration	1	2	3	Units
Emissions associated with electrical consumption	970	1064	1060	Tons CO_2/Annum
Emissions associated with gas consumption	438	440	2179	Tons CO_2/Annum
Total emissions	1409	1504	3239	Tons CO_2/Annum
Reduction over traditional	56.5	53.6	0	%

Table 4 *Variation of building type mix for each scenario*

	Scenario 1 Current	Scenario 2 Service	Scenario 3 Industrial
Building Type	%	%	%
Residential	50	40	4
Office	30	48	18
Industrial	2	6	24
School	5.5	6	6
Retail	6.5	2.4	6
Hotel/Food	5.5	3	6

Table 5. *System Heat utilisation using annual figures*

	Scenario 1	*Scenario 2*	*Scenario 3*
Utilisation(Annual)	71%	64%	67%

Table 6 *System Heat utilisation using daily figures*

	Scenario 1	*Scenario 2*	*Scenario 3*
Utilisation(Daily)	58%	64%	57%

Table 7. *Scenario 2 Financial Payback Summary*

	Scenario 2	Scenario 2 Low cost heating plant	Scenario 2 integrated CHP
Simple Payback	26 years	24 years	17 years
NPV Payback	40 years	35 years	23 years

HIGHLIGHTS

- London demographic and energy trends have been researched and presented.
- Comparison of three thermal network configurations has been conducted based on energy analysis.
- Typical thermal network based on five building types (hotel, industrial office, residential, retail and schools) were modelled and used with different mix to simulate clusters with district thermal (cooling and heating) network.
- Using the energy demands and network configurations an estimation of the energy saving and associated economic and environmental savings for different cluster mix were evaluated and compared.
- The analysis has demonstrated that the use of a central energy centre with integrated water-cooled heat pumps can be used to effectively supply low carbon & cost heating and cooling via connected thermal networks.