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Smart Cities – Thermal Networks

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Abstract

This paper presents a feasibility study of the technical and economic viability of introducing combined heating and cooling networks, referred to collectively in this paper as “thermal networks”. The steps used for this study include the identification of the most viable thermal network configuration, followed by analysis of a number of potential building mix scenarios and estimation of their respective potential impact on energy consumption, carbon emissions and economics. The final step was a discussion of the potential benefits and drawbacks associated with the implementation of the selected thermal network.

This study revealed that by utilising thermal networks, with central energy centres, approximately 1831 tonnes of CO_2 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. It has also been identified that, in conjunction with a marginal shift in policy to encourage an increase in service led economy, thermal networks can become technically and economically viable with around 40-year net present value payback periods and by introducing financial support from governments, such as 9 – 12 pence investment per kWh of cooling, the payback periods could be reduced to around 25 years.

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

1. Introduction

Over the last few decades the building services industry within the UK has seen many shifts in priority, typically being driven by market or legislation changes. The most recent shift was due to the implementation, and continual progression, of EU legislation expressed within the Building Regulations Approved Document Part L: Conservation of Fuel and Power. This has created an energy focused agenda aiming to deliver low carbon buildings, typically with increased capital costs.

One of the key emerging concepts is that of Smart cities. This involves utilisation of building and cluster data, information technology (IT) and internet of things/value to connect the cities services, infrastructure, people and buildings together. The potential benefits of Smart cities are efficient working and reduce energy consumption and CO_2 associated with developments.

To investigate the potential of introducing connected heating and cooling networks in the UK referred to within this document as “thermal networks” and illustrated graphically in Fig. 1, the authors draw on knowledge and experience of successfully designing district heating networks (DHN) complemented by best practice guidance on DHNs [1] and learning captured from researching successful district cooling networks (DCN’s) at other parts of the world such as the Fortum Remote Cooling Network [2, 3 and 4]. The investigation began by studying related topics within previous research. This was followed by detailed exploration of the potential benefits of thermal load sharing between buildings and the potential methods of capturing waste heat for use within local DHN’s. Based on the outcome of the first stage of the investigation into the most technically, financially and economically viable option, the investigation then assessed the potential impacts of implementing thermal networks on a number of cluster scenarios with various mixtures of building type density distribution. Further considerations of thermal networks has be identified and discussed to determine the positive and negative effects these networks may have within the smart city.

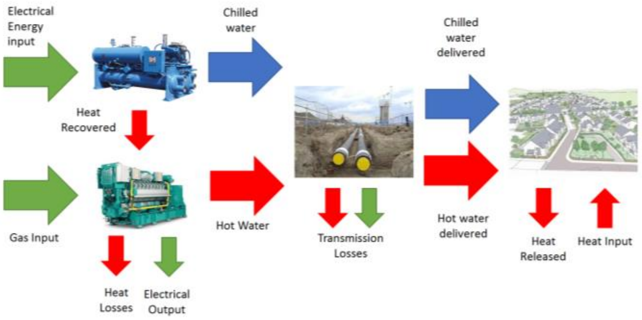

Fig. 1. Configuration of thermal network energy flow

2. Modelling of typical wide scale networks

The heating and cooling loads for the network were estimated based on the building mix rather than assumed fixed annual and peak heat/cooling loads. This was done using dynamic modelling software. The heating and cooling demands for 5 building types (Hotel, Industrial Office, Residential, Retail and Schools) were modelled using Environmental Design Solutions TAS. The internal conditions within the model utilised the NCM templates provided for the respective building types. The outputs from the model have been used to determine a demand per area, by using the demands rather than consumption. The efficiencies of plant were removed from the calculation and as such are able to be applied manually.

The dynamic modelling generated both estimated monthly and hourly demand loads 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.

2.1 Network configuration

The three building mix scenarios were investigated. Those are; service led economy, a industry led economy and retaining the existing building mix. Table 1, illustrate the percentages build-up of each of the scenarios with each building type. While this investigation focuses on 5 building types this has been deemed as a representative sample of the majority of the building types within London. The percentages within scenario 1 have been based on research and analysis of published data [5] regarding the employment in each sector. This has been used to determine what split of the network could attributed to each of the business sectors, residential has been taken as half of the network area due to assumption that the workforce will be living in the local vicinity. Scenario 2 & 3 are based on the current building mix however the mix has been modified to account for an increase in services or industrial requirements respectively.

Table 1. 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

For each scenario, the equivalent area of each building-type was evaluated based on the mix percentages shown in table 1. and total network area of 25 km^2 and an associated building area of 150 km^2.

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.

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

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

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

3. Network Energy Analysis Results

3.1 Scenario 1 – current mix

The annual network demand profile is highlighted within Fig. 2, for the heating and cooling systems for 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.

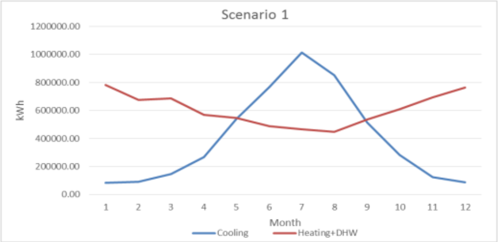

Fig. 2. Annual hot water and cooling load profile

3.1 Scenario 2 – Services led

The annual network demand profile for scenario 1 is highlighted within Fig. 3, for both heating and cooling systems. It can be seen that the cooling demand is below the heating requirement for the majority of the year until peak summer months.

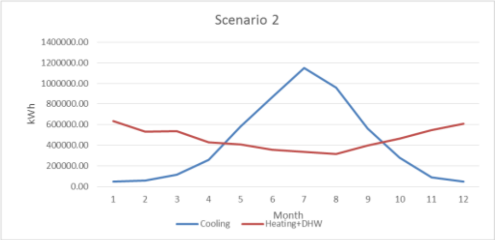

Fig. 3. Scenario 2- Annual hot water and cooling load profile

3.3 Scenario 3 – Industry led

The annual network demand profile is highlighted within Fig.4. It can be seen that the cooling demand is below the heating requirement for the majority of the year until peak summer months.

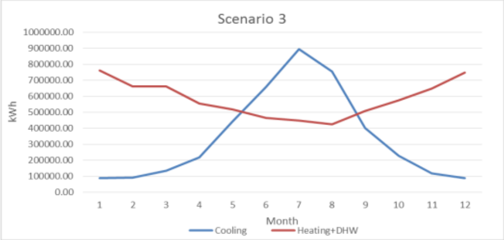

Fig. 4. Scenario 3- Annual hot water and cooling load profile

Typical winter and summer day were also plotted and revealed as with the annual profile, the winter months the heating and DHW demand are greater than the cooling demand. However, on the typical summer day this is reversed with only around a third of the day having a greater hot water demand then cooling.

4. Discussion

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 2. Presents the maximum utilisation of heat recovery based on the annual load profiles

Table 2 System Heat utilisation using annual figures

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

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 cooling demand not correlating with the heating on an hourly basis. Table 3., 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.

Table 3 System Heat utilisation using daily figures

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

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.

4.1 Environmental evaluation

The carbon emissions associated with each scenario has been estimate. Figure 5, 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.

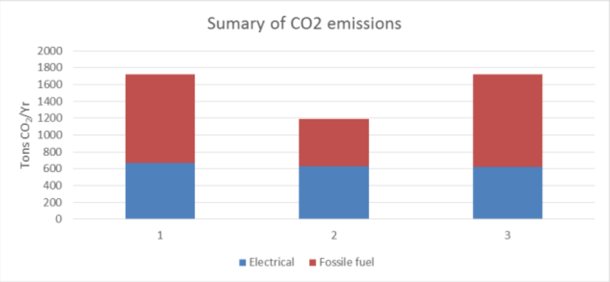

Fig. 5. Summary of CO$_2$ emissions for each scenario

5.2 Economic evaluation

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 6, 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 have payback periods of 41 and 56 years respectively.

References

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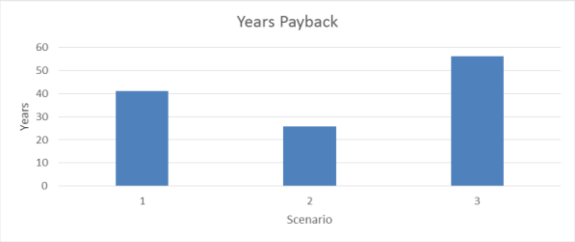

Fig. 6. Simple Payback Period for each scenario

The 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 4 below 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 is 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.

Table 4 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

5. Conclusions

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. 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.

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