Applied Energy 109 (2013) 94–103

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

# Thermal modelling of large scale exploitation of ground source energy in urban aquifers as a resource management tool

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## HIGHLIGHTS

- Electrical heat pumps for building heating and cooling is key for low carbon cities.
- Modern buildings have unbalanced energy demands leading to heat plumes in the aquifer.
- The impact of current ground source energy in London is modelled at the aquifer scale.
- Currently approved schemes are sustainable, but there is evidence of interference.
- Achieving Ground Source Energy targets will need regulation for sustainability.

## ARTICLE INFO

*Article history:*
Received 5 August 2012
Received in revised form 26 February 2013
Accepted 1 March 2013
Available online 27 April 2013

*Keywords:*
Ground source energy
Geothermal
Hydrogeology
Open loop
Renewable energy

## ABSTRACT

As part of its legal commitment to reducing $CO_2$ emissions, the UK has outlined a roadmap for significant increases in the use of ground source heat pumps for heating and cooling buildings. The technology is particularly suitable in new buildings, and in large commercial buildings. Such development is focussed in urban areas of economic growth. This paper presents an aquifer scale model of the impact of the expansion of open loop ground source energy schemes deployed in London. The model predicts the impact for currently operating schemes, and also the potential impact of all open loop schemes that have been licensed in central London. It is concluded that there will be thermal interference between these schemes and that in areas with such a high density of ground source energy schemes, the resulting loss of efficiency will mark an effective limit to the energy available for unbalanced ground source cooling. The current unregulated approach to managing the energy resource of the Chalk aquifer beneath London will not be able to sustain the demands implied by the UK roadmap for ground source energy. A more actively managed approach is needed if these energy demands are to be met, economically, in London and other centres of economic growth.

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## 1. Introduction

Heating and cooling our buildings accounts for a significant proportion of the EU energy use, which has been largely supplied by fossil fuels, but which must increasingly be met by renewable energy sources. The UK government, in common with other EU partners is committed by the European Renewable Energy Directive to ambitious increases in renewable energy, and by the Climate Change Act 2008 to reducing carbon emissions. The UK has outlined a roadmap for achieving national targets of 15% renewable energy by 2020 implies that about 6% of this target will be from non-domestic ground source heat pump installations [1]. This corresponds to a 30-fold increase in installed capacity of heat pumps.

Much of the early development across Europe has been for small scale residential heating systems. In contrast, the IEA [2] identify that the biggest contribution to carbon reduction by heat pumps can be made through use of natural ('sensible') or engineered thermal energy storage systems providing balanced heating and cooling for larger commercial buildings. The IEA roadmap envisages dramatic growth in the use of this technology worldwide.

Where buildings are located above aquifers, as in London and many of Europe's major cities, the most cost effective approach for installing heat pumps in a large commercial building is generally an open loop ground source scheme. Above a heating or cooling capacity of 100 kW, closed loop schemes require large numbers of boreholes and are increasingly uneconomic to develop. In an open loop scheme, groundwater is directly abstracted from a small number of boreholes and reinjected to the ground after

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http://dx.doi.org/10.1016/j.apenergy.2013.03.005

passing through a plate heat exchanger which extracts the energy from the water. The thermal energy load is thus transferred directly to groundwater in the underlying aquifer.

Most of the installed capacity of approximately 0.4 GWth for non-domestic heat pump systems in the UK at the end of 2010 [1], is in new buildings or fitted as part of major redevelopment works. This is because heat pump heating and cooling systems work most efficiently at relatively low temperature differentials and thus are most effective in well insulated modern buildings. It has meant that the deployment of the heat pump technology has been focussed in areas of economic growth, and in particular, in the UK, this has meant that the majority of installations are located in London and the south-east of England. If the country is to achieve its ambitions to make the transition from fossil fuels to electrical heating, and meet its renewable energy and carbon emission targets, the required dramatic growth in installed capacity is most likely to continue to be focussed in this part of the country.

This paper presents a modelling assessment of the potential thermal impact on the Chalk aquifer beneath central London, and estimates physical constraints to the energy that can be derived from this resource.

The model shows that large open loop schemes that are well balanced utilise the energy resource afforded by the Chalk aquifer beneath London as an energy storage system, and are a genuinely long term sustainable solution for building heating and cooling. However, many commercial buildings have unbalanced, cooling dominated demands. These schemes have the potential to develop large heat plumes in the aquifer and can be seen instead as directly 'mining' the energy resource of the aquifer.

The magnitude of the available resource available from an aquifer beneath a city depends on the scale of the aquifer from which the energy is extracted, but also on how balanced heating and cooling demands are. If energy demands are balanced over an annual cycle, the aquifer can provide a long term sustainable resource. If however, unbalanced cooling loads are developed in a small area, there is an increasing risk of schemes interfering with each other leading to loss of efficiency, or even schemes failing to deliver the required performance. The exploitation of thermal energy from groundwater is not directly regulated in the UK, introducing heat to a groundwater body is not introducing a contaminant and the temperatures over which heat pumps are permitted to discharge water back to the aquifer does not constitute pollution. The consequential uncertainty and risk of reduced efficiency, acts as a significant barrier to greater uptake of the technology. Indeed, the investment in a ground source energy scheme has no value unless the scheme operates more efficiently than alternative energy sources with lower capital costs. Whilst heat pumps can, in principle, continue to operate when thermal interference occurs, the scheme is no longer viable when its efficiency falls to uneconomic levels. This makes it difficult to specify the absolute size of the energy resource of an aquifer, but it is clearly no longer available when interference between open loop schemes is likely.

This paper concludes with a discussion of issues for the management or regulation of the thermal resource of aquifers, and a tool that can be used to identify risks to the sustainable large-scale exploitation of the resource. The model developed here successfully represents the cumulative impact of schemes implemented in London to date and shows that there is little risk of interference compromising their performance. However a scenario predicting the impact of all schemes for which abstraction licences have been agreed shows that these schemes, if implemented, would lead to thermal plumes extending over 10% of the aquifer beneath central London. Several schemes are predicted to lead to interference and it is clear that the renewable energy targets set out in the UK roadmap for renewable energy would not be able to be met by extending the implementation of ground source energy for cooling taken from the Chalk aquifer beneath central London.

## 2. Background

There has been increasing global interest in ground source energy (GSE) systems for heating and cooling in recent years, with much recent work to assess the most efficient and economic approach to this low carbon energy source. For domestic and smaller installations, closed loop (i.e. ground coupled) GSE utilising heat transfer from a sealed U-tube in vertical boreholes is most economic. These systems benefit from low capital costs and good efficiency for heating and cooling [3]. The latter is increasingly important as the technology spreads from cold regions, where the technology was initially most widely adopted for heating; to warmer climatic regions and for buildings with modern insulation standards where the building energy demand is increasingly dominated by cooling requirements. For example, Man et al. [4,5] assess the performance of GSE for cooling in warm and temperate regions of China. It is generally found that the cooling performance of such systems is less efficient than heating. To overcome this, hybrid schemes incorporating supplemental cooling (e.g. cooling tower) can be used to improve overall system efficiency [4,6]. One concern with closed loop, or ground coupled GSE schemes is the heating effect on the ground around the borehole leading to loss of efficiency. Michopoulis et al. [6] and Zhang and Wei [7] identify this concern for Greek urban residential buildings and for a large project in Nanjing respectively. This will reduce the efficiency of the GSE making it uneconomic unless larger borehole arrays are installed or hybrid schemes developed. In densely populated areas, the footprint required to supply large unbalanced cooling loads is likely to be increasingly prohibitive for larger schemes.

The development of a thermally affected zone (TAZ) is an important consideration in planning a sustainable GSE scheme and requires a clear understanding of the building energy demand profile, but also requires an understanding of the hydrogeological setting of the ground coupling. For example aquifer properties will affect the rate of ground heating and regional groundwater flow may dissipate or reduce the impact of the TAZ on system performance (see for example Fujii et al. [8]). The suitability of the local hydrogeological setting and the extent to which hydrogeological conditions will support the performance of GSE schemes can be mapped using regional scale groundwater models [9],

An alternative approach that allows the scheme to benefit from a larger ground volume for heat rejection or energy storage is to use an open loop (i.e. groundwater coupled) GSE scheme. This can lead to benefits in small single well schemes where the dipole flow developed between two wells or intervals of a single well leads to a larger volume of ground being utilised for heat rejection and correspondingly lower temperature in the TAZ [10]. However the main economic is realised for larger systems where the capital costs are reduced by only needing two boreholes and by correspondingly reducing the ground footprint required. Options for heating and cooling are discussed by, for example, Self et al. for heating in Canada [11], and Liu et al. for cooling in Singapore [12]. Abessor [13] and Fry [14] discuss the development of open loop GSE in the UK, and in particular in the Central London where much recent UK development is centred. In the right setting such an approach will often be the most sustainable and economic approach, but as with closed loop schemes, there are constraints on the suitability of the local hydrogeology which will determine the most appropriate GSE approach. For example Nam et al. [15–17] consider the most appropriate options for a similar region in Tokyo where limits on the amount of groundwater abstraction,

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