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Field-scale monitoring of a horizontal ground source heat system

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ABSTRACT

The performance and sustainability of ground source heat systems is dependent on the thermal behaviour of the neighbouring ground. This paper presents a field-scale monitoring scheme which has been designed and implemented to inspect the ground behaviour in response to a horizontal ground source heat system providing space heating to a domestic property.

The system comprises of 112 thermistors buried in the ground along with sensors to record the influential climatic variables and system heating loads. Soil properties were also measured throughout the site as part of a wider site investigation. Dataset collected during the first 13 months of research is presented within the scope of this work. The resolution and duration of the collected dataset facilitated an extensive analysis including thorough investigations of ground thermal distributions resulting from heat extraction and recharge.

Findings indicate that the horizontal ground source heat system implemented at the site has provided a sustainable source for space heating during 13 months period of inspection. The unsymmetrical distribution of ground temperatures observed highlighted the importance of climatic variables on ground-loop design and in doing so also highlighted potential avenues for future optimisation. Further to this, the compiled dataset can be considered as a significant contribution to the scientific aspects of ground thermal behaviour due to heat extraction/recharge and provides a comprehensive benchmark for the development and validation of predictive models.

1. Introduction

The scope of this work focuses on closed horizontal ground source heat pump (GSHP) systems which can be used to generate sustainable space/water heating. The systems fundamentally consist of a buried pipe (or ground-loop), within which a circulatory fluid passes, absorbing thermal energy from the surrounding ground. Despite the growing popularity of horizontal GSHP systems, there is limited information available on ground performance within the operating systems (DECC, 2010).

A number of field-scale horizontal GSHP monitoring sites have been globally installed over the past few decades, although a very limited number of them have monitored the ground thermal behaviour. The majority of data collection within the field has focussed on the mechanical aspects of heat pump systems and in particular the so called "Coefficient Of Performance" (COP). In order to investigate the ground response, an array of system measurements is required, namely; ground temperature, climatic variables (known to influence annual and diurnal ground temperature regimes), heating load of the system and the ground thermal properties. Of the salient monitoring sites which exist globally, very few have collected all of the previously listed aspects. Among notable horizontal GSHP investigations which have monitored the ground is the study by Esen et al. (2007) where ground temperature was measured and soil samples were collected. Wu et al. (2010) reported both ground temperature and climatic conditions as part of a horizontal GSHP investigation which also included a ground investigation. Similarly, Phillippe et al. (2010) monitored ground temperatures in response to a horizontal GSHP system under four differing surface conditions. Interactions between the physical soil environment and a horizontal GSHP have been studied by Garcia Gonzalez et al. (2012) for a domestic site in the UK. The effects of heat extraction by the horizontal GSHP, installed at 1 m depth on the soil temperature and moisture have been reported for a period of one year monitoring. The results indicated that the heat extraction has considerably altered the soil temperatures and moisture content to an extent that the performance of the GSHP can be affected (Garcia Gonzalez et al., 2012)

The lack of data within the research field leads to an incomplete understanding of the way ground responds to thermal energy

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extraction from GSHP systems. The work presented within the scope of this paper aims to improve the understanding of ground response in horizontal GSHP systems through the collection and analysis of field-scale ground, climatic and heat pump data.

A field-scale instrumentation of a horizontal GSHP system has been designed and implemented at a site located in Powys, UK. A substantial investigation into the ground thermal behaviour has been undertaken, incorporating a large number of in-situ temperature sensors. In addition, a weather station has been installed at the site to measure the influential climatic processes. A site investigation was also carried out to obtain the physical properties of the soil at the site. Details of the monitoring design are presented in this paper along with the remote communication techniques employed. The logged data has been structured, managed and interrogated with a developed data management tool. Salient data from the first 13 months of collection is presented here in the form of time evolution and contour plots. The results allow ground temperature changes in response to both heat extraction and climatic processes to be inspected.

2. GSHP site and monitoring design and development

The monitoring site is located at Ffynnon Gynydd, Powys, Wales, UK. A horizontal GSHP system was installed for space heating in a large, newly built farm house at the site. The ground source heat system comprises five horizontal ground-loops with a total length of approximately 750 m. These five loops were evenly spread across a 40 m wide by approximately 80 m long area. The loops were installed at an approximate depth of 2 m, employing a parallel pipe arrangement. A polyethylene pipe with an external diameter of 40 mm and wall thickness of 2.4 mm was used for all ground-loops. The fluid circulating within the closed-loops comprised of a solution, 75% water and 25% ethylene-glycol. The heat pump system is a 16 kW Dimplex heat pump, which was installed within a plant room in the house. Fig. 1 presents a schematic diagram of the GSHP system as installed at the site.

Prior to the installation, the field was covered with short grass. Post installation, the field returned to the same condition and use. Additional details regarding the ground characteristics are provided in Section 3. A series of thermistor strings were installed to monitor the ground temperature surrounding the horizontal GSHP system and the surrounding ground. The installed thermistor strings focus on one of the five ground loops (loop No. 1). A schematic showing the longitudinal spacing of the thermistors is provided in Fig. 1a.

Thermistors measuring the ground temperature were installed in eight cross-sections. The cross-sections were evenly spaced at 10 m intervals along the loop length (see Fig. 1b). Two types of configurations have been adopted in arranging the thermistors. These include (i) a “detailed” arrangement utilised in cross-sections AA and BB and (ii) an “intermediate” arrangement utilised in cross-sections A, B, C, D, E and F. As Fig. 2 shows, the detailed thermistor arrangement incorporated a larger number of thermistors thereby allowing for a more detailed examination of the ground behaviour at the cross-sections.

Based on the expected in-situ ground and climatic conditions, an RST Instruments Thermistor String was selected which has a temperature reading accuracy of ±0.1 K within the anticipated operational range and conditions at the site.

In addition to the ground monitoring, climatic parameters capable of influencing the thermal behaviour of the soil were identified and monitored at the site. A weather station was installed at the location specified in Fig. 1. The ambient air temperature, solar radiation, relative humidity, wind speed and rainfall have all been monitored at the station. The sensors were selected based upon the operational ranges, durability and manufacturer specified accuracy, similar to the process previously highlighted with regards to the ground thermistors.

Table 1
Average soil properties measured/calculated from the site investigation.

Soil property	Average value	Standard deviation
Density, kg m^{-3}	1830	250
Moisture content (gravimetric), %	13.1	4.3
Porosity, dimensionless	0.31	0.1
Thermal conductivity, Wm^{-1} K^{-1}	2.3	0.44
Specific heat capacity, Jkg^{-1} K^{-1}	1172	108.7
Saturated hydraulic conductivity, m s^{-1}	2.83×10^{-10}	–

Appropriate facilities to monitor the system flow rate and fluid temperature differential across the heat pump were also installed. The thermal energy extracted by the GSHP system can be calculated using these two system parameters in conjunction with the fluid’s specific heat capacity. The system flow rate was measured at a single point located close to the heat pump unit. Two fluid temperature sensors were located immediately either side of the heat pump unit in order to measure the temperature differential across it, thereby allowing the transient heat extraction to be calculated. It is noted that unlike previous studies, this site aimed to collect data necessary to investigate the ground behaviour in response to horizontal GSHP systems and not the COP.

Further information regarding the site development and monitoring can be found in Hepburn (2014).

2.1. Data monitoring and transmission

Sensor readings from the ground, climatic and system sensors have been logged every 15 min. A multiplexer unit was used in combination with a data-logger in order to simultaneously collect the outputs of all 120 sensors implemented at the site (112 for ground temperature, 3 for heat pump system and 5 for climatic variables). The multiplexer unit was located above the manifold chamber, while the data-logger was located in the plant room (see Fig. 1). The multiplexer unit was positioned at the base of the monitored ground-loop to reduce the required wiring. The connecting wire between the multiplexer and data-logger units was housed in a conduit approximately 1 m beneath the ground.

The monitoring system was designed to incorporate remote communication techniques which allow for live communication and remote data downloading off-site. This communication capability is an important system specification due to the distance between the monitoring site and University campus. The logger was connected to a GPRS (General Packet Radio Service) modem, allowing the system to be contacted via the mobile phone network.

3. Soil properties

Investigations into the soil properties and characteristics at the monitoring site were undertaken in conjunction with sensor installations. Samples were retrieved throughout the site between depths of 0.5 and 2.2 m. The soil density, moisture content (gravimetric), particle size distribution, mineral content and saturated hydraulic conductivity were measured in accordance with the relevant British Standard procedures (British Standards Institution, 2002a,b). In-situ measurements of thermal conductivity and specific heat capacity were measured using a thermal probe. The measurements for thermal conductivity and heat capacity have been carried out for approximately 50 locations at the site at different depths. The averages of these properties alongside the standard deviations are reported in Table 1. It is noted that thermal conductivity and heat capacity can vary with the moisture content and during the monitoring programme these values might have