METERING MEASUREMENT CHALLENGES & MONITORING OF A LARGE SCALE GROUND SOURCE HEAT PUMP (GSHP) SYSTEM

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ABSTRACT

Ground Source Heat Pump (GSHP) systems have significant potential to reduce carbon emissions. The performance of GSHPs is highly dependent on their interaction with the ground and specifically the extraction and injection of the heat. A number of literature reviews has shown how the performance of GSHP systems vary in practice when compared to the theoretical aspects. This paper provides detailed investigative work on heat metering installation difficulties and associated errors which affect the long term practical performance of GSHP systems. Particularly, incorrect installation of heat meters is a sensitive issue for a heat metering scheme designed to evaluate the performance of any heating technology since it's likely that they will bias the readings. The findings obtained from this work confirm a range of generic installation problems that the refrigeration, air condition and heat pump (RACHP) industry is currently facing. The findings obtained from this study provide useful information for design and implementation of future GSHP systems in terms of improving energy efficiency as well as reducing costs. This study has identified a range of installation errors which include (i) temperature sensors being incorrectly positioned and/or installed (ii) incorrect selection of heat meters (iii) type of thermocouple pockets and (iv) poorly insulated sensors, all of which have contributed to an uncertainty error of ± 25 % of the system performance.

INTRODUCTION

It is widely accepted that global climate change is predominantly due to the emissions of greenhouse gases (GHG), 75 % of which are attributable to CO_2 (Pachauri and Reisinger, 2007). In the UK, 47 % of CO_2 emissions are due to the production of heat with a significant contributor to the total emissions from heat generation in the domestic sector (Karl, 2008; UK Office of Climate Change, 2007).

GSHP systems have significant potential to provide low carbon heating and cooling and produce large scale emission reductions. In theory, GSHPs can work efficiently if properly designed. However, in practice the performance of these systems is dependent on a range of different parameters and issues such as how well the system and the ground loop is actually designed, installed, maintained, operated and subsequently controlled in the field. The UK heat pump (HP) stock in 2013 contributed to 20 Mt of greenhouse gas emission savings. The current European installed base of HP produces 147 TWh of renewable energy from the air, water and the ground and is responsible for the abatement of 24 Mt of CO_2 per annum (European Heat Pump Association and Delta Energy and Environment, 2013). Until recently, there has been very little published data on the performance of installed HPs in the UK. However, in 2010 and 2013 the Energy Saving Trust (EST) published results on the first and second phases of the most comprehensive field trial of the technologies ever undertaken in the UK, which studied HPs at 83 sites (54 ground source and 29 air source). The results of the EST studies have suggested that over-complicated system designs and poor understanding of heating controls by both installers and householders contributed to the inadequate performance reported in phase 1 (Energy Saving Trust, 2010, 2013).

This paper describes the range of installation challenges relating to the flow meters, temperature sensors and calculator

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units. It also describes the process taken to overcome the difficulties and quantifies the associated errors. It identifies a number of problems in relation to the heat meters installation and the measurement of temperatures.

DESCRIPTION OF K2 AND ITS GSHP SYSTEM

There are small numbers of existing renewable energy centres in the UK. However, these are generally in rural settings where there is plenty space, flexibility and opportunity for the installation of renewable technologies which offer significant space requirements. K2 is located one mile from the centre of London and is set in an urban context on a tight London South Bank University (LSBU) campus. As shown in Figure 1 below the K2 building (8500 m^2 floor area) is the newest development on campus completed in June 2009. CEREB is part of K2 and is a new £3m research and teaching energy technology centre at LSBU, funded by Higher Education Funding Council for England (HEFCE) and the London Development Agency (LDA).

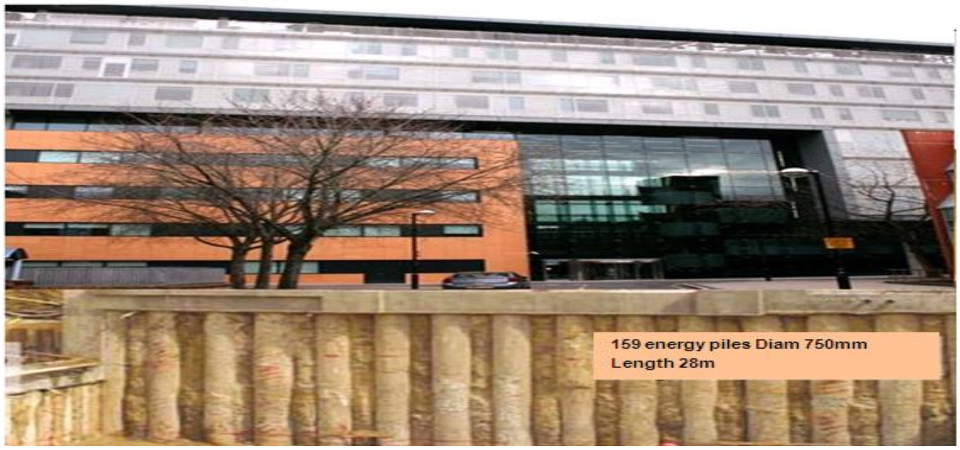

Figure 1 K2 building with its thermopile foundation

The building K2 is eight storeys high with a central atrium that rises to the fourth floor level. The southern wing of the building, which comprises around a quarter of the building footprint area is five storeys high and has a roof level terrace. Most of the building's services are located in the plant room on the roof however some of the plant is on the ground floor. The building consists mainly of offices and laboratories, and some teaching space.

The building was designed with carbon emissions of 55 % lower than the prevailing UK building regulations. It includes a range of features to reduce carbon emissions including technologies such as solar thermal cooling, phase change materials with night time ventilation, solar fibre-optic lighting, solar photovoltaics and GSHP system for heating and cooling.

GSHP System and Its Operation

The GSHP system within the K2 building at LSBU uses four WaterFurnace EKW130 reversible HP units. Each has a nominal capacity of 120 kW for heating and 125 kW for cooling. The heat is transferred from and to the ground through a closed loop system with the aid of 159 vertical energy piles which are built into the foundations of the structure and bored into the London clay. The building's heating and cooling generation is fully provided for by the GSHP system. The source-side of the system consists of energy piles and header pipes to which the GSHP system add or extract heat using a heat transfer fluid which is pumped and exchanges energy between the building and the ground as shown in Figure 2.

The GSHP system utilises a dry air cooler (DAC) designed to operate when the heat sink temperatures were either too high or too low. The DAC was therefore employed as a safety device to protect the GSHP system from operating outside its safe envelope.

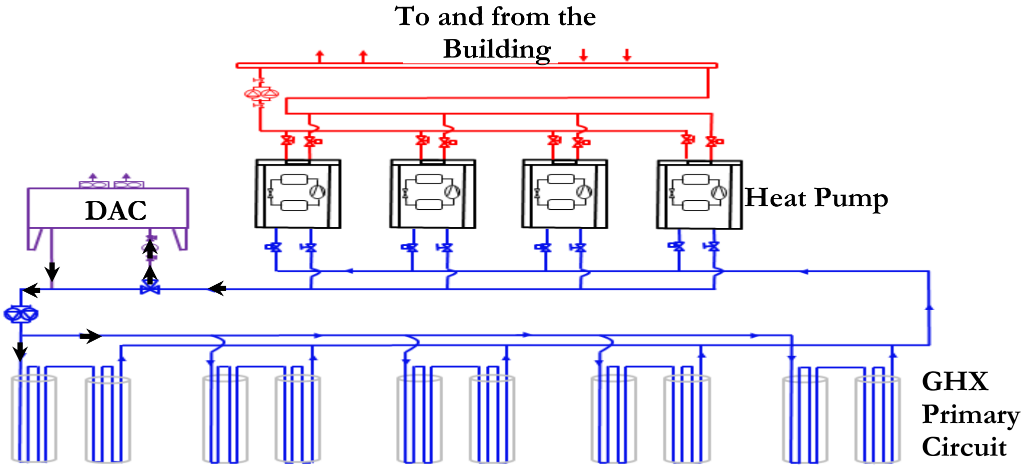

Figure 2 Concept layout of the GSHP System

INITIAL RESULTS AND COMMISSIONING

Figure 3 shows the initial results from the installation for load and source energy output from the GSHP system. As shown in Figure 3 it was noticed that when the load and source side energy were compared, the source side is much higher than the load side and this is impossible especially when the HP is running in heating mode. This anomaly had therefore led to an in-depth investigation of the different components of the heat metering system and these are discussed below in detail.
This section covers the detailed work carried out to investigate the range of installation errors within the complex heat metering and monitoring system in order to establish the long term practical performance of the GSHP installation. Incorrectly installed heat meters are a particularly important issue for a heat metering scheme designed to evaluate the performance of any heating technology since it's likely that they will bias the results.

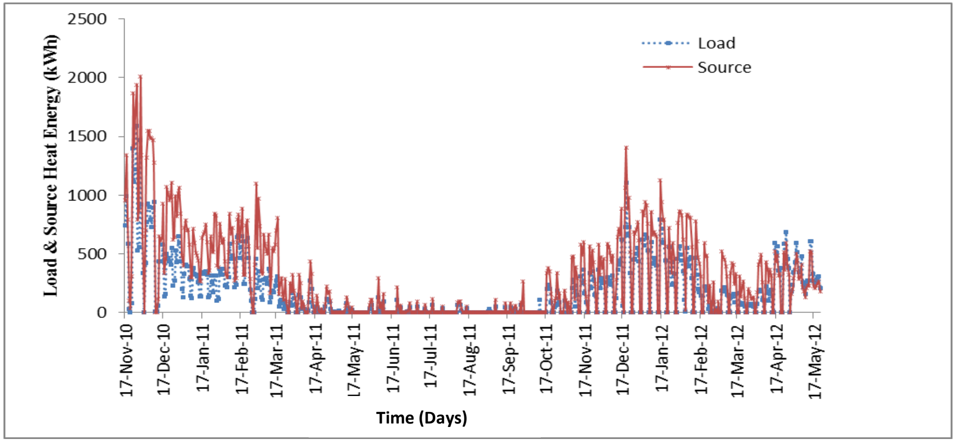

Figure 3 Comparison of load and source side heat energy

Wrong Types of Heat Meter

At the beginning of the design stage of the GSHP system the installers had specified and installed 5 of Metrima MF4 type heat meters on the source side and another 5 of SVM F4HC type heat meters on the load side. At a later stage it was identified that the heat meters installed on the source side can only register heating data but not cooling data, ultimately giving an accumulated false heat data reading. Consequently this required the re-commissioning of the system and the adding of another additional 5 of new Landis Gyr T550 Ultraheat meters on the source side. However this intervention did not resolve the error associated with the source side being higher than the load side. Figure 4 illustrates the type of heat meters used in the installation.

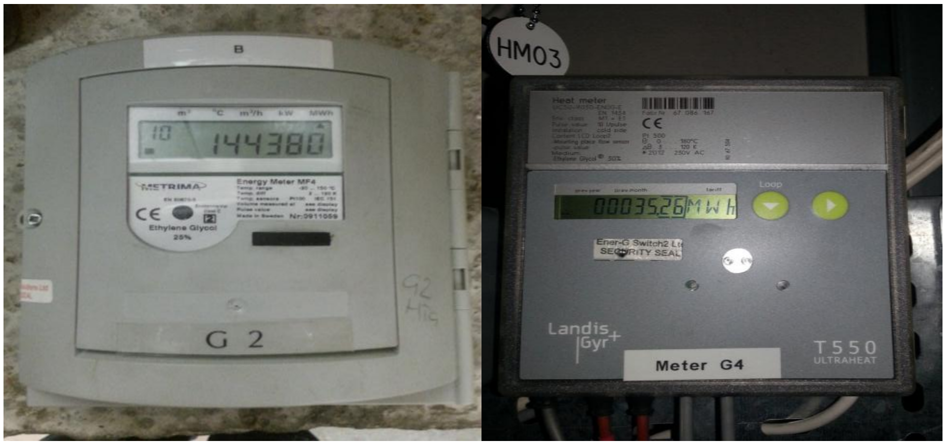

Figure 4 Old and new types of heat meters used at K2

Heating Fluid Properties

The physical properties of the heating fluid are important for accurate measurement as they can affect flow meter measurements directly and also the calculation of measured heat consumption.

It was decided to run some more diagnostics to try and resolve the problems of lower load heat energy relative to the source heat energy. Having examined the schematic of the system thoroughly it was spotted that a temperature sensor had become dislodged from its designed position so that it is no longer correctly sensing the target temperature of the system. The temperature sensors were changed to the right location, however the problems of higher source side than the load side persisted. After conducting further investigation and speaking with the HP installers and heat meter suppliers it was established that the heat meters used in the installation were configured for a 25 % of ethylene glycol solution; however our system was designed / installed for a 32 % glycol content solution. The heat meters calculate the energy transfer by measuring the fluid flow and the difference between the supply and return temperature. In order to compensate for the change of density and specific heat with change of temperature the meters are pre-configured with built in heat coefficient factors and these heat coefficient factors are different according to the glycol type and content in the system. Incorrect concentration levels of the glycol on the system can lead to calculation errors.

Originally it was believed that the type of glycol substance used on the system was ethylene glycol hence all of the heat meters were specified for an ethylene glycol solution. However the type of glycol used in the system was neither ethylene nor propylene but a substance called CoolFlow FXC2 which is based on a proprietary blend of refined vegetable extracts and has a very low oral toxicity. The physical and thermal property of this substance is different to ethylene and propylene glycol.

The addition of glycol will affect the physical properties of the heating fluid, including the specific heat capacity, density and viscosity. Theoretically, specific heat capacity and density affects all types of heat meters, with viscosity affecting vortex and turbine types of heat meters. Additional testing has also been carried out on glycol/water mixes to gauge the potential errors associated with using a heat meter calibrated for the wrong heat transfer fluid.

Temperature Sensors

Furthermore, a number of installation errors related to the temperature sensors have been discovered. It is a good practice when installing temperature sensors to give good thermal contact between the sensor and the pipe carrying the working fluid. A study by DECC (2014) has shown that a significant number of sites have heat meters with temperature sensors that are cable tied or taped to the outside of pipes or fitted using custom plumbing arrangements, rather than fitted inside the pipes to ensure the temperature sensor pocket is surrounded by flow. It was identified that some of the temperature sensors were strapped to the outside of the pipe wall. This leaves the sensors exposed to the outside air temperature fluctuations;

poor contact modifies the measured temperature relative to the actual heat carrier fluid temperature. The interference could be minimised by insulating the pipe properly however it is difficult to completely eliminate its effect and therefore it may still contribute some error to the fluid temperature measurement and therefore to the heat energy output. Measurement Point A in Figure 5 shows the temperature sensors strapped horizontally in line with the pipes. Measurement Point B shows a temperature sensor inserted inside a sensor pocket which is the preferred way of measurement.

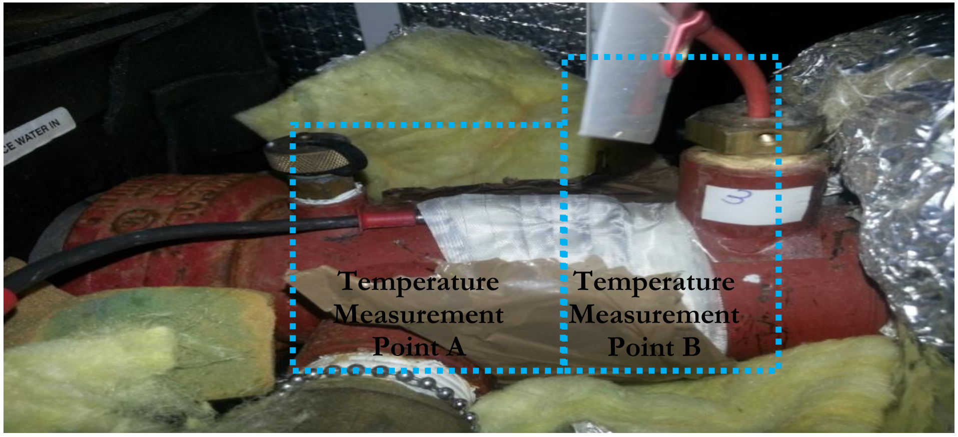

Figure 5 Inserted and strapped temperature sensors

The correct installation method for thermocouples is with the probes inserted inside sensor pockets with suitable thermal grease. Further investigation on the temperature sensors showed that the thermocouple sensor pockets were not deep enough within the pipes to ensure good thermal contact between the sensor and the heat carrier fluid. This introduces a gap between the fluid and the temperature sensor which creates a barrier for heat transfer and an accurate reading of the fluid temperature. As can be seen in Figure 6, with Measurement Point C there is a very noticeable gap between the liquid circulating inside the pipe and the thermocouple's head. This consequently creates a delay and error between the actual fluid temperature value and the thermocouple's reading that are seen by the heat meter. A comparison has been made between a properly inserted thermocouple and one inserted in to a short thermocouple pocket, to identify the potential errors associated with this anomaly and the results are provided in section 4.

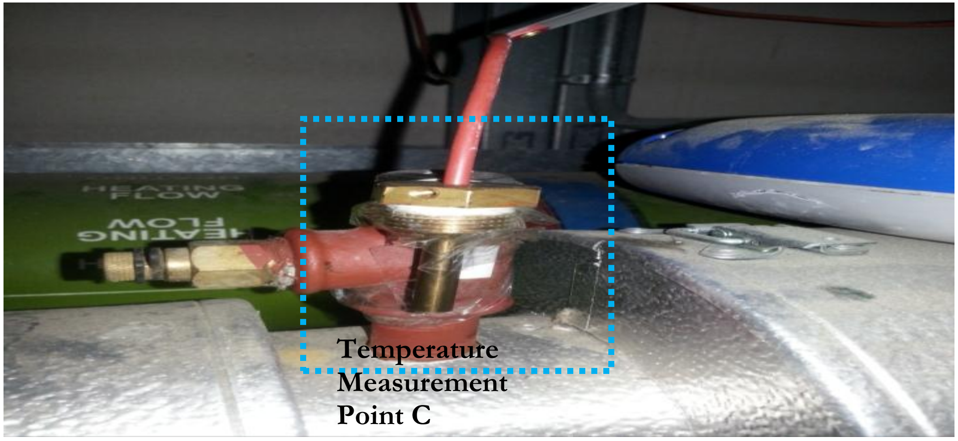

Figure 6 Short thermocouple pocket

QUANTIFICATION OF IDENTIFIED ERRORS

This section provides the quantification of measurement errors resulting from the measurement difficulties and installation errors identified in the previous section.

Calculated Theoretical Error

An estimate of the effect of heat transfer fluid properties on the measurement of heat can be made based on standard heat transfer equations and the known properties of typical heat transfer fluids. The following example illustrates the theoretical error in measuring heat transfer resulting from a heat meter set up to measure a 25 % propylene glycol, 32 % glycol/water mix and a 32 % Thermox FXC2 water mix. Table 1 gives the properties of propylene glycol / water mix and 32 % Thermox FXC2 water mix.

Table 1 Properties of Propylene Glycol and Thermox FXC2

Temp (°C)	25 % Propylene Glycol		32 % Propylene Glycol		32 % Thermox FXC2		Error Comparing 25 % Propylene & 32 % FXC2	Error Comparing 32 % Propylene & 32 % FXC2
	ϱ (kg/m^3)	C_p (kJ/kg.K)	ϱ (kg/m^3)	C_p (kJ/kg.K)	ϱ (kg/m^3)	C_p (kJ/kg.K)		
0	1028	3.91	1030	3.83	1040	3.81	1.4 %	0.4 %
10	1021	3.92	1028	3.83	1036	3.83	0.9 %	0.8 %
20	1019	3.93	1024	3.85	1031	3.85	0.9 %	0.7 %
40	1012	3.95	1015	3.9	1020	3.89	0.7 %	0.2 %
60	995	3.97	1005	3.91	1007	3.94	-0.4 %	1 %
80	980	3.98	995	3.92	993	3.98	-1.3 %	1.3 %

The effect of measuring pure water with a meter set up to measure a 32 % propylene glycol / water mix can be estimated based on the equation for heat:

$Q = V \varrho C_p \Delta T$

Assumptions:

Heat flow measured for 1 hour

$V = 0.0068$ m^3/s

$\Delta T = 10$ K at an average temperature of 45 ˚C

From Table 1

$\varrho.C_p$ 25 % = 1012 x 3.95 = 3,997 kJ/m^3.K

$\varrho.C_p$ 32 % glycol = 1015 x 3.9 = 3,959 kJ/m^3.K

$\varrho.C_p$ 32 % Thermox FXC2 =1020 x 3.89 = 3,968 kJ/m^3.K

Assuming 25 % propylene glycol in the system the total heat consumption therefore is calculated to be 3,997 kWh. The GSHP system at LSBU was designed for 32 % Thermox FXC2. Using the characteristics for this fluid the total heat consumption is calculated to be 3,968 kWh. However, if the meters were set up for 32 % propylene glycol the actual consumption would be 3,959 kWh. Comparing the 25 % propylene glycol with 32 % propylene and 32 % FXC2 glycol mix there would be an approximate error between approximately -1.3 % and 1.4 % in the system.

Temperature Sensors Installation

A further test was carried out on the installation of temperature probes to quantify the level of errors attributed from the wrong installation of temperature sensors. Figure 7 illustrates the temperatures measured during the experiment (i) on the outside surface, (ii) with the temperature probes inserted correctly inside the thermocouple pocket with thermal grease and (iii) with the temperature probes half inserted inside the thermocouple pocket. Pipework and fittings were insulated with 100 mm thick Rockwool insulation to minimise effects of the environment.

It can be seen that both half inserted and surface strapped probes do not replicate the fully inserted probe well. This is particularly apparent under fluctuating conditions. Typically the surface probe over estimates by around 1K, whereas the half inserted probe over estimates by approximately 2.5K. A temperature difference of 2.5K is equivalent to approximately 25 % error in the heating output. The reason why the half inserted probe is performing much worse than the strapped probe is because the strapped probe is well insulated and the connection path to the ambient environment is around 300 mm. In contrast the connection path between the top of the pocket on the half inserted probe is around 100 mm.

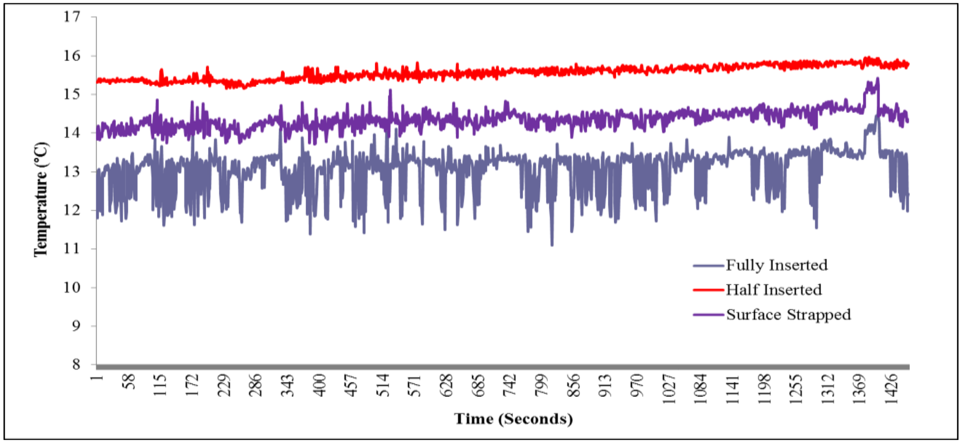

Figure 7 Temperature measurement at different points of pipe

Assuming that the fully inserted pocket measurement is correct, Figure 8 shows the errors in temperature difference recorded in experiment tests for two different temperature probe installations. Figure 8 shows that when the temperature probes are strapped on the outside surface of the pipe or half inserted into a pocket, a large temperature difference error of between +15 % to -40 % occurs compared to a fully inserted probe. AECOM (2013) has conducted a similar study to establish heat meter measurement errors and the result shows similar values to the above findings. The potential for this error is much greater on the load side because the temperature difference between load and ambient is much greater. This therefore is one of the key factors in which the results being incorrect. As a result long pockets were installed throughout and this corrected the source and sink load inversion shown in Figure 3.

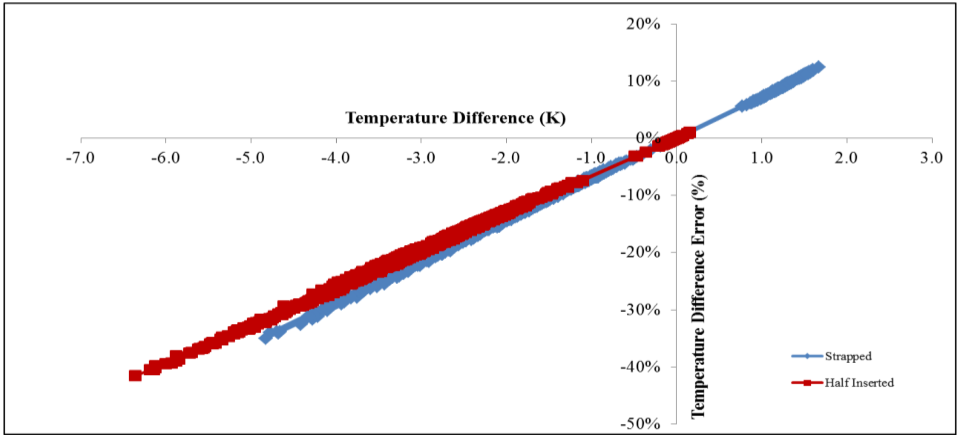

Figure 8 Errors due to incorrectly installed temperature probes compared to fully inserted

CONCLUSION

Specifically, this paper presented a detailed description of the K2 building and the GSHP system and its operation. This paper has shown that the K2 building has an extensive heat and electricity sub-metering to enable performance monitoring and evaluation at the individual zone levels.

Incorrectly installed heat meters are a particularly important issue for a heat metering scheme designed to evaluate the performance of any heating technology since it's likely that they will bias the results. The findings from this study have shown that many of the temperature sensors were positioned and installed incorrectly.

Significant amount of time has been spent analysing and interpreting the data from the complex heat metering system and have been able to identify some generic problems with some of the control system and approaches that are routinely used for GSHPs. This has provided new practical insights into the operation of the GSHP system and a real contribution to knowledge. This work has specifically involved the investigation of the complex heat metering and monitoring system to establish system performance measurement of the installation.

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NOMENCLATURE

Q = Heat output (kW)
V = Volumetric flow rate of heat transferring fluid (m^3/s)
ϱ = Density of heat transfer fluid (kg/m^3)
C_p = Specific heat capacity of heat transferring fluid (kJ/kg.K)
ΔT = temperature difference between the flow and return (K)

ABBREVIATIONS

ASHP	Air source heat pump
BMS	Building management system
COP	Coefficient of performance
EST	Energy Saving Trust
GSHP	Ground source heat pump
kWh	kilo Watt hour
RHI	Renewable heat incentives

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Learning objectives

Provide an overview of heat metering measurement difficulties.

Identify the implications of incorrectly installed heat meters to the performance of heat pump installation.