Industry collaboration to develop and validate design software to model building and air side plant performance with specific heat pump and ground loop performance

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Abstract
Ground source heat pumps are an established technology for providing both heating and cooling to the built environment. Their use is likely to expand further given the requirements of both government and industry to reduce carbon emissions and overall energy use. Although not a 100% renewable source, typically 75% may be offset. For communities that depend substantially on electricity for conditioning in the built environment, this technology offers an opportunity to significantly reduce the environmental impact of electricity generation.

The current paper describes work carried out by EDSLTAS, Mitsubishi and CABR to develop software that will accurately model specific heat pump and ground loop performance, but critically this is then linked to a full building simulation to correctly predict the part load demand and consequent overall energy consumption of the system for each hour through a whole year. The resulting software has then been compared and validated against comprehensive monitored data from the Mitsubishi headquarters in the UK.

Key words
Ground source heat pumps, Monitored performance

Introduction

Ground source heat pump (GSHP) technology is attracting significant interest worldwide due to its potential to offer useful reductions in energy demand in the built environment. Monitored performance of such technologies is an important part of increasing awareness and confidence amongst designers and developers.

Simulation based design tools are useful in developing design strategies for the successful installation of GSHP in new build and retrofit projects. To further develop confidence in designers and developers the simulation based design tools need to benchmarked against monitored performance data.

Monitored data from the UK is presented here for a Mitsubishi Electric PQHY-P200YGM-A water source VRF system (Variable Refrigeration Flow) system combined with a closed loop ground source installation.

Installation data for the GSHP

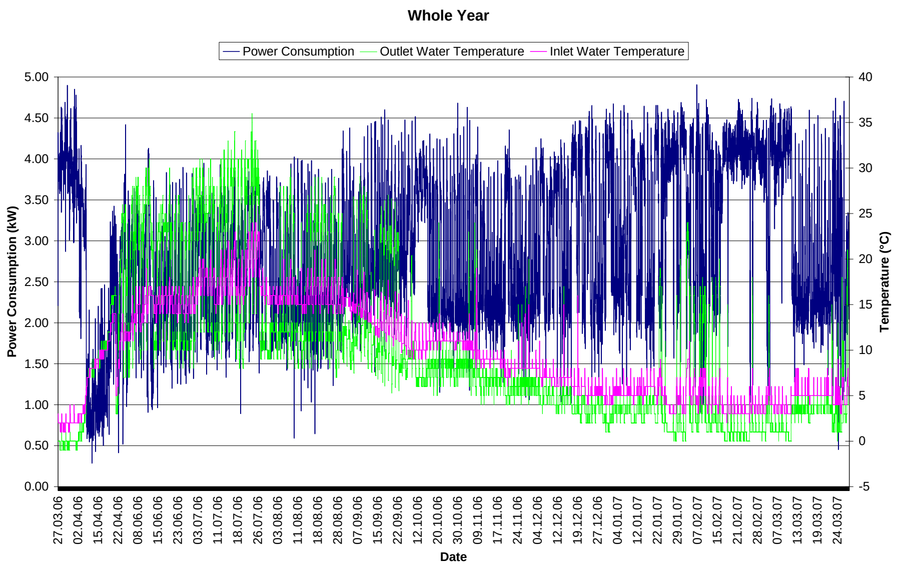
Part of one wing of the Mitsubishi Electric HQ in Hatfield UK was retrofitted with a GSHP system. The VRF equipment installed includes a R410A PQHY-P200YGM-A 8hp unit, capable of delivering a nominal cooling capacity of 22.4 kW and 25kW of heating attached to 4 PEFY-P50VMM-E ceiling concealed fan coils, installed with linear slot diffusers. The four indoor units provide heating and cooling to a total of 165m2 open plan office on the ground floor. The indoor set points were set to auto 21C +/-2C. The building at Hatfield is a 1970's build and is very responsive to the outdoor conditions (low levels of insulation, single pane glazing and poor air tightness).

The ground loop uses the horizontal slinky method. From a central header 5 separate trenches, totalling 50m long, were dug 0.3m wide and 1.8m deep. Plastic pipe was then laid vertically in the trenches with the bottom of the trench lined with 0.1m of sand. Following this the slinky was then covered with sand to achieve the maximum surface area to the maximum surface area to the ground and so give the best heat transfer. Following this the remaining trench was filled in with the soil dug from the trench.

The GSHP installation replaced an original water based fancoil system serviced by a natural gas boiler and water cooled chiller. The original system was not monitored in detail, but a comparison of annual energy use is presented based on the boiler efficiency and seasonal COP of the chiller serving the demand profiles for the monitored period.

Monitoring data for the GSHP

Real time monitoring was set up to record the inlet and outlet temperatures from the slinky to the heat pump, and the compressor power consumption every 10 mins over a period of 12 months. This logging was used to show the full running efficiency of the system over the monitored period. Additional short period tests were undertaken to show the part load efficiency of the system, which was done by running the system with only selected indoor units running.



Part load tests

Comparison of part load efficiencies for original and replacement systems for the short period part load tests.

These tests were conducted before the 12 month monitored period.

Cooling

LOAD %	PQHY	CHILLER
100	5.15	2.5
75	6.08	2.25
50	6.51	2
Average	5.91	2.25

COP for chiller from the 2006 energy technology list
GSHP is 262% more efficient than the chiller.

Heating

LOAD %	PQHY	BOILER
100	4.63	0.95
75	5.43	0.95
50	4.62	0.95
Average	4.89	0.95

Efficiency of boilers any brand top spec unit
GSHP is 515% more efficient than the boiler

Spring & summer

LOAD %	PQHY	BOILER/ CHILLER
100	4.89	1.725
75	5.755	1.6
50	5.565	1.475
Average	5.4	1.6

GSHP is 338% more efficient than the chiller and boiler

Comparison of annual power consumption and CO2 emissions over the12 month period.

WINTER	kWh consumption	kg CO2 emissions
PQHY	1186.1	510.01
BOILER	6108.3	1160.57

SUMMER	kWh consumption	kg CO2 emissions
PQHY	1133.3	487.31
CHILLER	2969.2	1276.75
AUTUMN	kWh consumption	kg CO2 emissions
PQHY	1272	546.96
CHILLER/BOILER	3981.4	1234.22

SPRING	kWh consumption	kg CO2 emissions
PQHY	1550.4	666.67
CHILLER/BOILER	4852.8	1504.35

ANNUAL	kWh consumption	kg CO2 emissions
PQHY	5141.0	2211.0
CHILLER/BOILER	17910	5176

Calibration of the GSHP system

As part of the Hatfield monitoring a number of steady state cases were run for both heating and cooling. Three tests were run at three different demand levels. The first test was cooling, the second test was for heating and the final test was a period of heating followed by a period of cooling. This final condition occurs quite frequently at mid-season where the building needs heat at the start of the day, but then cooling is required as the occupants and equipment warm the space. For each of these runs a 100%, 75% and 50% demand level was set by utilising 4, 3 or 2 of the indoor units working at nominal capacity. A model of the equipment and ground loop was prepared and calibrated against the results of these 9 steady state runs.

To ensure the simulation was as accurate as possible, equipment performance data was obtained from the appropriate Mitsubishi catalogue [Ref 1,2 & 3]. For the heat pump (PQHY-P200YGMA-A) nominal heating and cooling capacities as well as nominal power consumptions were entered first. For heating and cooling capacity, corrections were applied for; inlet water temperature, water flow rate, intake air wet bulb temperature at the indoor unit, total indoor unit demand and refrigerant piping length. For input power (consumption), corrections were applied for; inlet water temperature, water flow rate, intake air wet bulb temperature at the indoor unit, and total indoor unit demand.

For the indoor units, PEFY-P50-VMM-E, a similar procedure was followed [Ref 3]. Once nominal capacities for heating and cooling were specified, corrections were applied for intake water temperature at the outdoor unit along with corrections for indoor air wet and dry bulb temperatures.

From measurements taken during the steady state runs the average pressure drop across the ground loop was found to be 22.58kPa at the design flow rate. The pressure drop across the heat pump was specified as 16.5kPa. To ensure peak efficiency at design flow rate for the pump, a peak head value of 58.62kPa was selected, this gave the electrical pump power consumption predictions to within a few per cent of those measured.

The following table summarises the results of the steady state runs, comparing consumption and average COP for measured and simulated data.

Run	% Loading	Capacity	Power consumption measured	Average COP measured	Power consumption simulated	Average COP simulated
Heating	50%	9.14	1.98	4.62	1.89	4.84
	75%	14.1	2.6	5.43	2.46	5.73
	100%	18.28	3.94	4.63	3.83	4.77
Cooling	50%	8	1.4	5.73	1.33	6.02
	75%	12	2.57	4.67	2.41	4.98
	100%	16	3.87	4.13	3.74	4.28
Cooling after Heating	50%	8	1.1	7.27	0.99	8.08
	75%	12	1.61	7.48	1.58	7.59
	100%	16	2.59	6.17	2.49	6.43

As you can see close agreement was found, with the simulated results being slightly higher in general, but well within tolerances for engineering use and energy consumption prediction. The close agreement is to be expected given the completeness of the manufacturer performance data and known internal conditions during the steady state runs. The one significant unknown variable was the returning water temperature from the ground loop. The simulation results were consistently slighter lower in temperature than the measured values, which, counter intuitively, leads to better performance for both heating and cooling in general. One possible reason for this could be the assumption of a far field ground temperature of 10C (based on analysis of typical weather for the region), it’s quite possible this could be 11C or 11.5C, which would more closely align the results.

Unfortunately no external climate data was recorded during the test which makes a quantitative comparison impossible. Instead a simulation was run using typical weather for the region and a qualitative comparison made.

The figure below shows the power consumed by the heat pump alongside the temperatures entering and exiting the ground loop. This format was chosen to aid comparison with the monitored data.

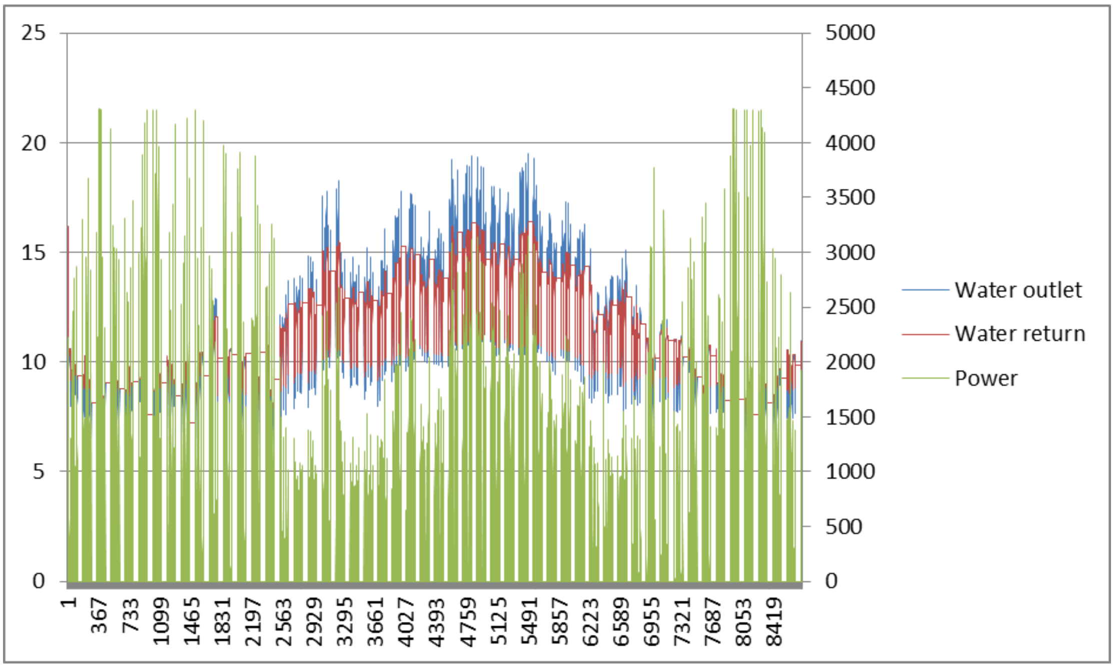


Fig 5 Simulated annual GSHP system performance

It's clear from the figure that the typical weather year that's been used demands far less cooling than the monitored period. A similar amount of power is used during the winter with similar performance generally. However, during the summer, a significant reduction is seen, rarely reaching 3kW, whereas the monitored data shows cooling requirements over 4kW from time to time, with 3.5kW being typical.

The next figure shows the COP for heating and cooling hour by hour through the year from the simulation. Sadly this is not possible to extract from the monitored data so no comparison is possible. It's noticeable how the heating COP degrades as the cooling requirement in summer pre-warms the ground, but the early morning heating continues to help boost the cooling COP.

Integration of the GSHP model into the building simulation model

The monitored data did not provide detailed building performance. The building loads being calculated from the compressor energy use and the inlet and outlet water temperatures hourly. To provide a fuller picture of the building performance and demonstrate refurbishment design analysis, the GSHP model has been integrated into a building simulation model. This analysis will demonstrate the simulation based difference in energy use and CO_2 emissions when based on the UK Building Regulations Part L2 compliance procedures for refurbishment of existing stock.

The building simulation model

Calibrated model comparison with GSHP serviced monitored data

An office area of 165m2 on the ground floor of the simulation model has been created to represent the monitored area. Assumptions have been made, based on occupation records, about how this office area would have been used in 2006. Occupation was on a 10 hour day Mondays to Fridays. Lighting and equipment energy use have been based on the 2006 building use of 20W/m2 and 35W/m2 respectively. Occupancy densities were one person per 7.5m2.

Very little detailed weather data was monitored, so a typical CIBSE design year was chosen to drive the model.

The previously installed fancoil system was modelled to the standards expected of the period of installation. The same period standards were applied to the definition of the efficiencies of the natural gas boiler and chiller. The boiler was assumed to be 95% efficient and the chiller assumed to have a COP of 2.25.

The simulated annual space demand for heating and cooling was 16636kWh and 8244kWh respectively.

Simulated energy consumption and CO2 emissions

ANNUAL	kWh consumption	kg CO2 emissions
PQHY	4976	2011
CHILLER/BOILER	21175	6119

ANNUAL	kWh consumption	kg CO2 emissions
PQHY	5141.0	2211.0
CHILLER/BOILER	17910	5176

When compared with the monitored data the chiller/boiler energy use for the simulated performance is higher by about 20%.

This would intricate that there is more heating in the simulated results than the monitored. The boiler is far less efficient than the chiller, but for the GSHP the COPs for heating and cooling are similar.

Conclusions

This paper illustrates an attempt to use, often limited, monitored performance data for innovative plant and control strategies to help advice the design decision making process in building refurbishment projects as well as new design. The GSHP system was calibrated in the simulation software with good levels of practical correlations. The use of these calibrated models within a total building/plant simulation model showed good correlation with the actual performance witnessed on site.