School of Engineering and Sustainable Development
Institute of Energy and Sustainable Development

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DE MONTFORT UNIVERSITY
LEICESTER

PERFORMANCE MONITORING OF A LARGE UNIVERSITY GSHP SYSTEM

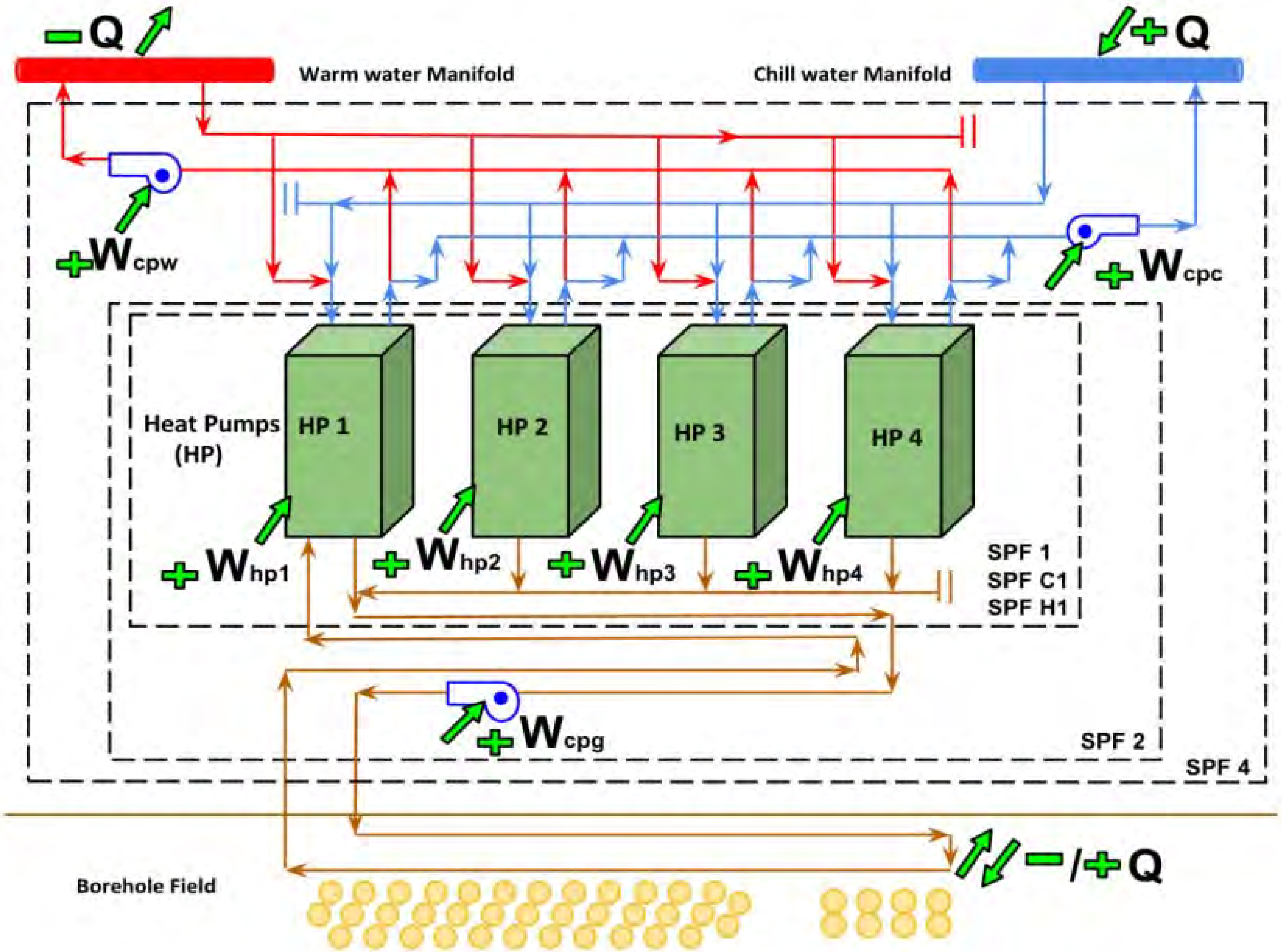
Dr Simon Rees

Selvaraj Naicker

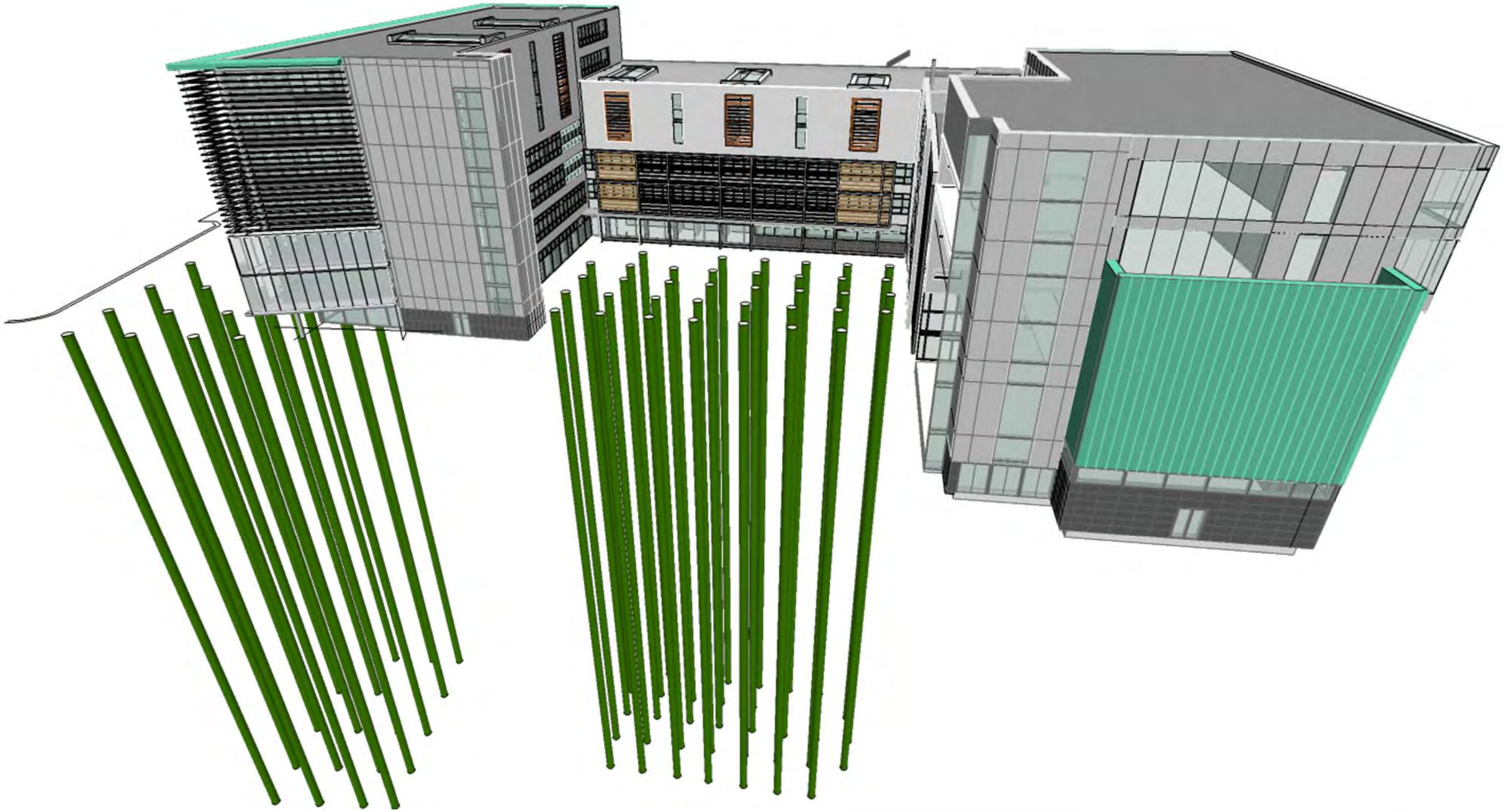
THE HUGH ASTON BUILDING

- A multi-use building (15,607 m^{2})
- Monitored since opening in Jan 2010
- GSHP system provides all AHU and FCU cooling (360 kW peak) and all underfloor heating (330 kW peak capacity)
- Has Four Water Furnace 2-stage reversible heat pumps
- 56 x 100m deep borehole heat exchangers, 125mm diameter. 30 l/s peak flow

SYSTEM SCHEMATIC



BOREHOLE ARRAY DESIGN

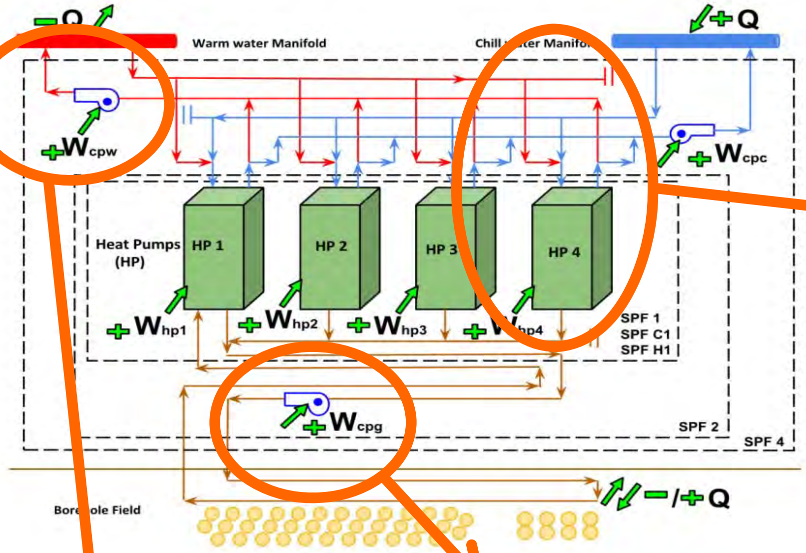


19 + 37 arrays

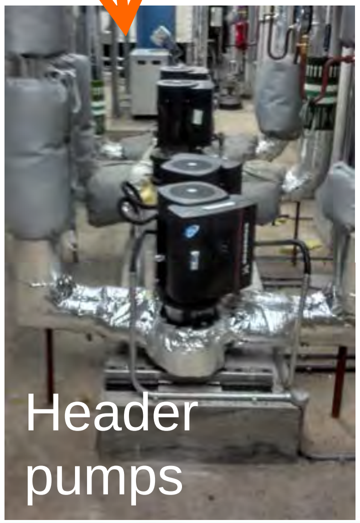
The Heat Pump Installation

2-stage design with scroll compressors and plate heat exchangers. Any HP can be used for heating or cooling

THE HEAT PUMP INSTALLATION




Header pipes and valves


Header pumps


Ground loop pumps

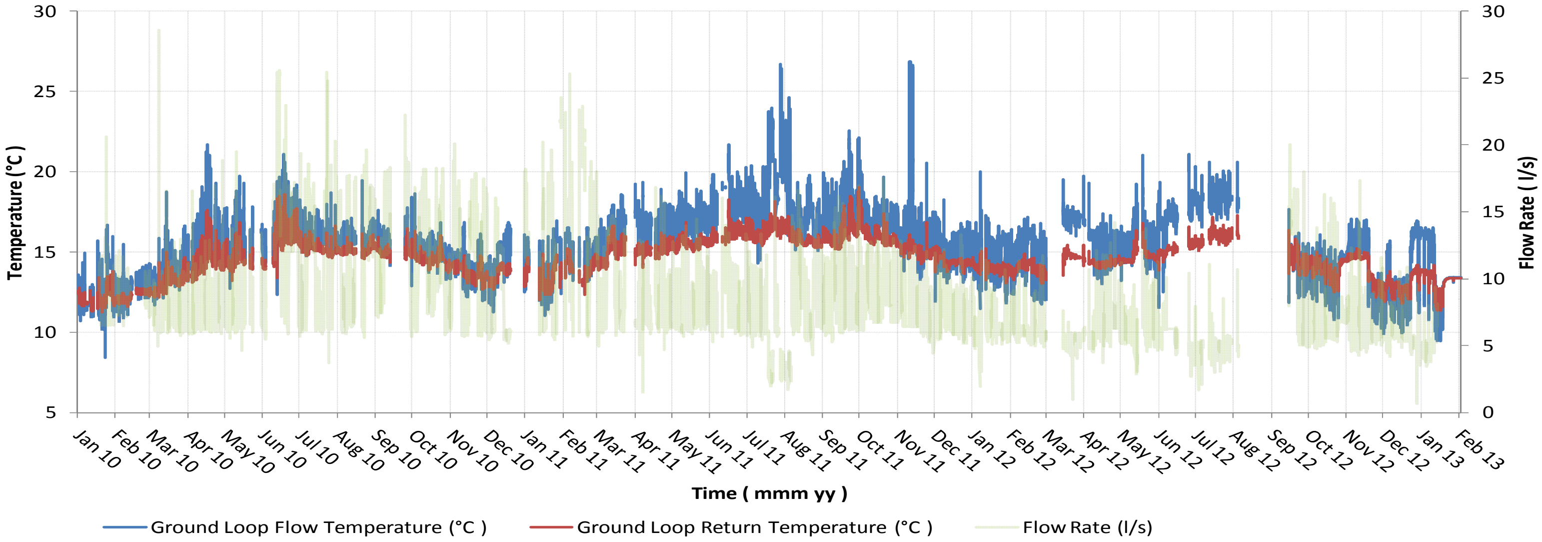
MONITORING

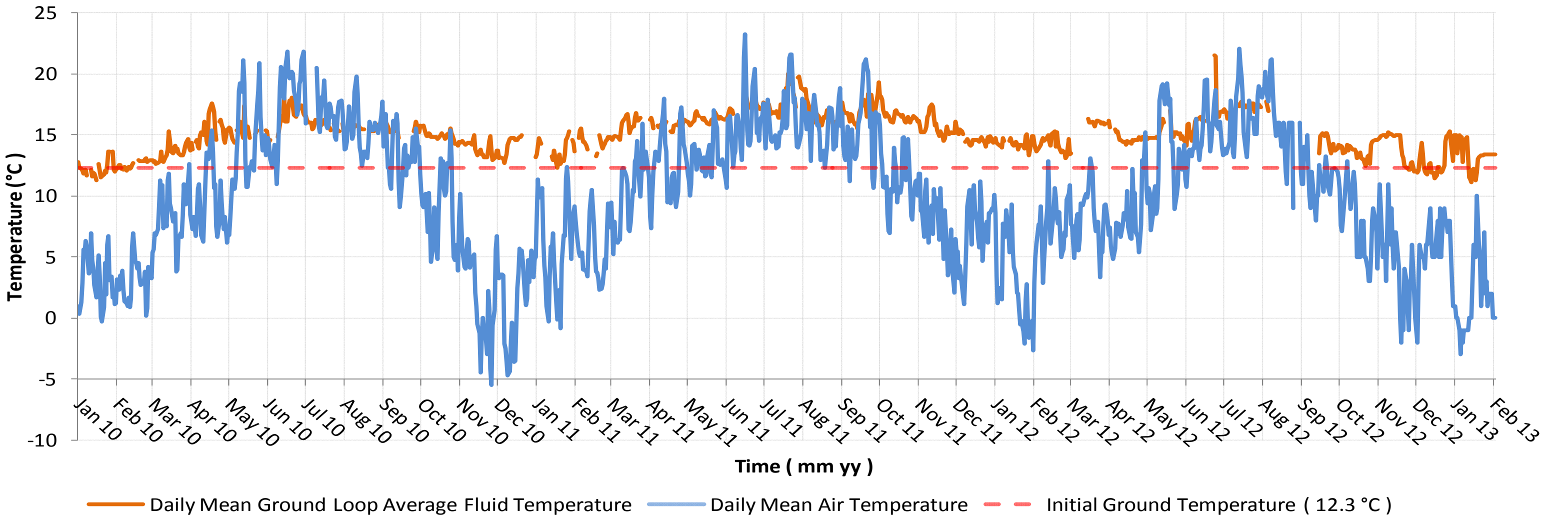
- Aims
  - Performance analysis
  - Reference data sets for model development
- Measurements
  - Ground TRT test analysis
  - Heat pump electrical demand (sub-meters)
  - Ground loop and heating/cooling temperatures and flow rates at 1 minute intervals
  - Borehole temperatures
  - Flow and source/load temperatures for one heat pump
  - BMS Data: compressor operation
- Careful calibration means SPF calculated to +/- 2.7%

MONITORING OUTPUTS

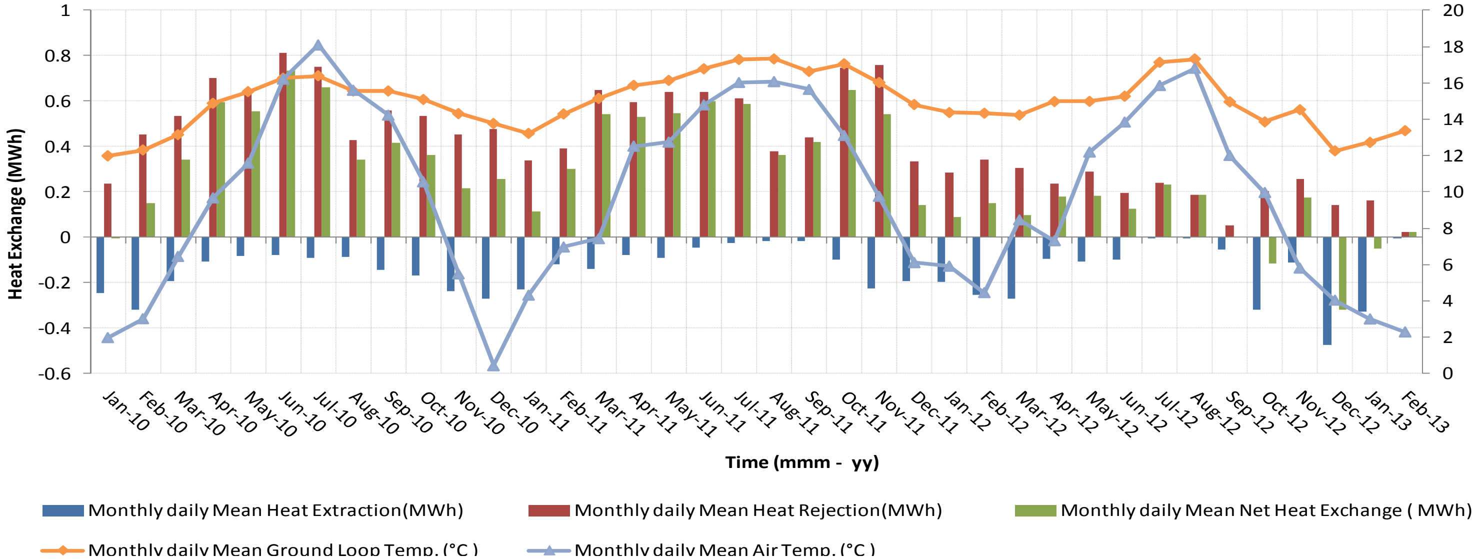
- Seasonal performance factors (various timescales): SPF1, SPF2, SPF4 for heating/cooling modes
- Ground loop temperature and flow reference data
- Analysis: reasons for heat pump and overall system good/poor performance

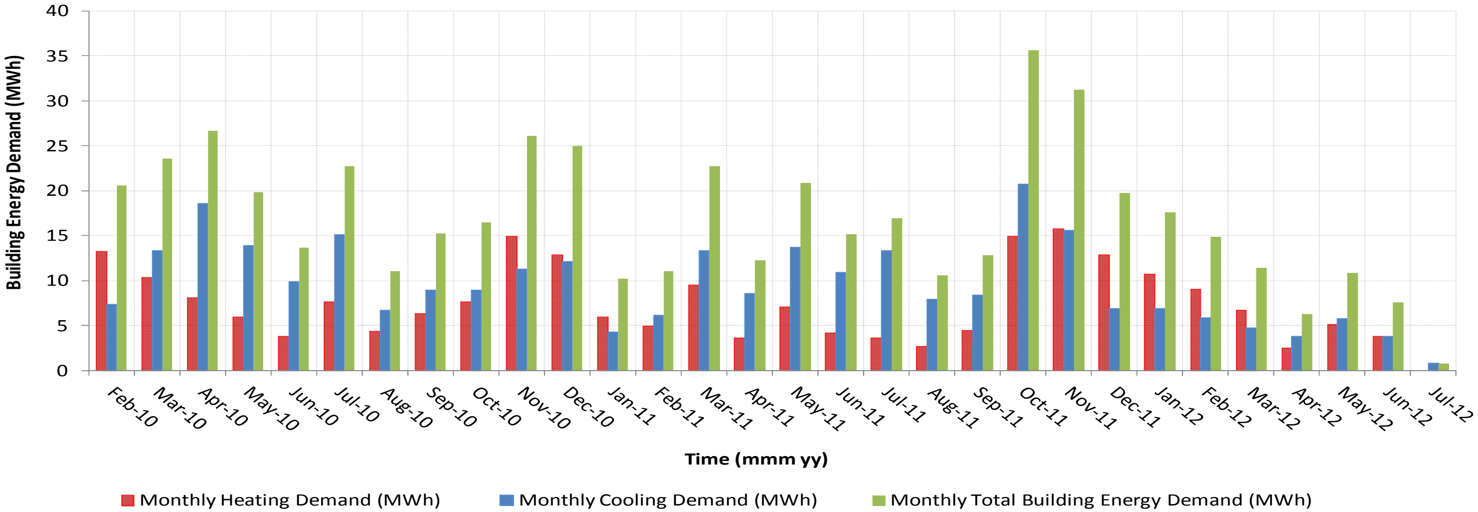
Ground Heat Exchanger Performance



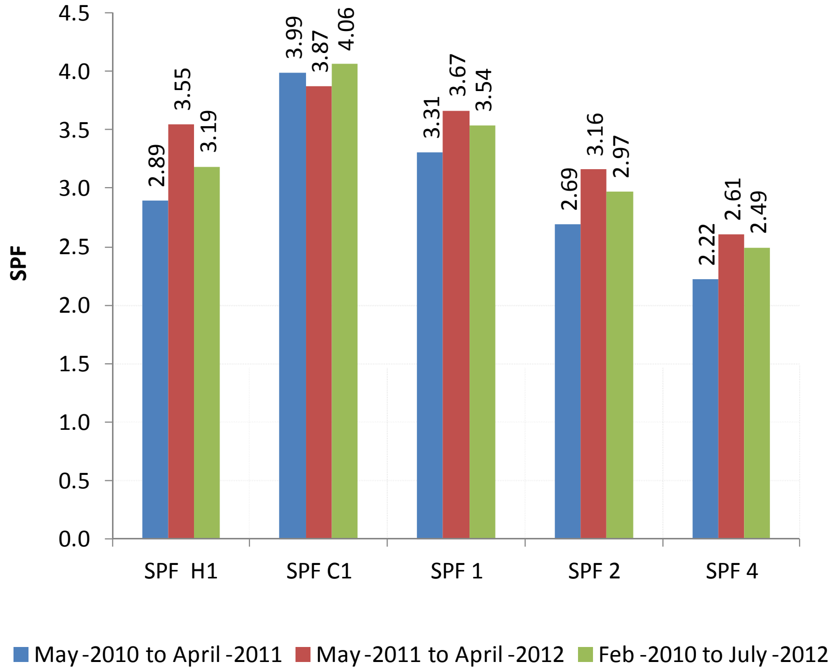


MONTHLY HEAT BALANCES





SYSTEM EFFICIENCIES



- Seasonal performance Factors:
  - SPF1 is heat pump alone
  - SPF2 includes the ground loop pump demand
  - SPF 4 includes the heating/cooling header pumps
- RES Directive requires SPFH2 > 2.5

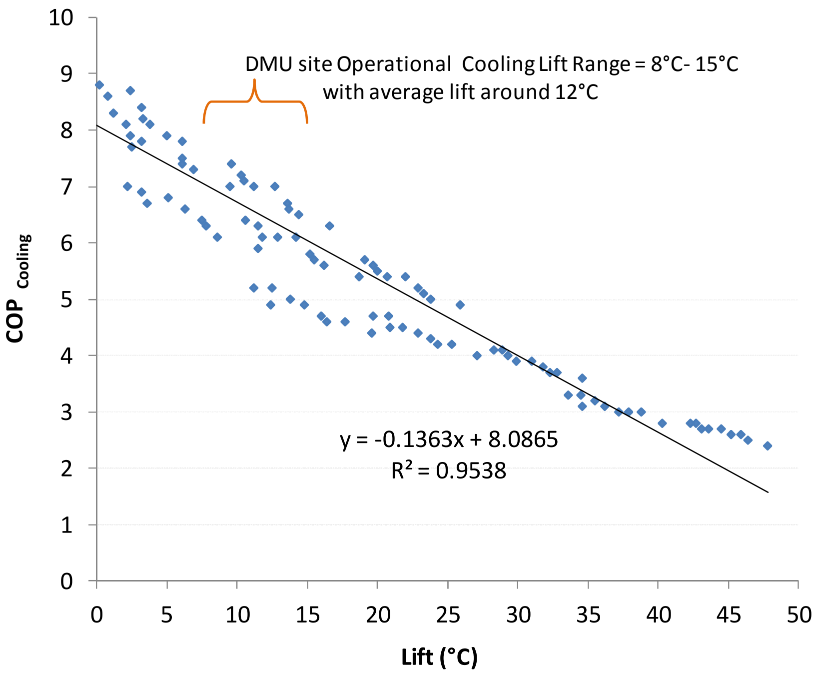
Year (Season)	SPF_{H1}	SPF_{C1}	SPF_1	SPF_2	SPF_4
May -2010 to April -2011	2.89	3.99	3.31	2.69	2.22
May -2011 to April -2012	3.55	3.87	3.67	3.16	2.61
Feb -2010 to July -2012	3.19	4.06	3.54	2.97	2.49

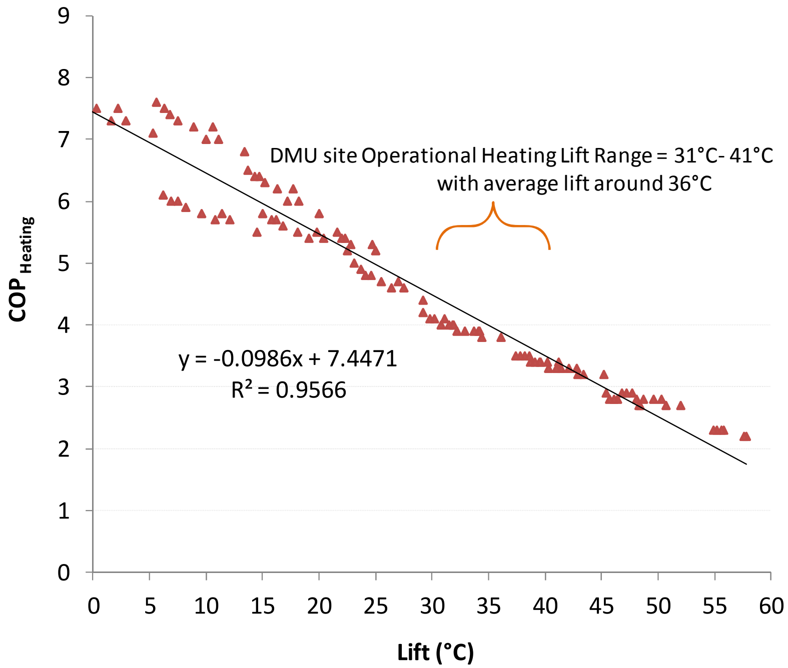
SYSTEM EFFICIENCIES

- Questions:
  - Are the heat pumps performing as the manufacturers stated?
  - What are the main contributors to differences between heat pump and overall system performance?
  - What could be done to improve performance?
- Approach:
  - Compare individual heat pump performance and catalogue data
  - Evaluate circulating pump energies
  - Examine dynamic operation and control

HEAT PUMP EFFICIENCIES

Heat pump performance varies according to flow rates and inlet temperatures at both load and source-side heat exchangers. Also glycol properties.



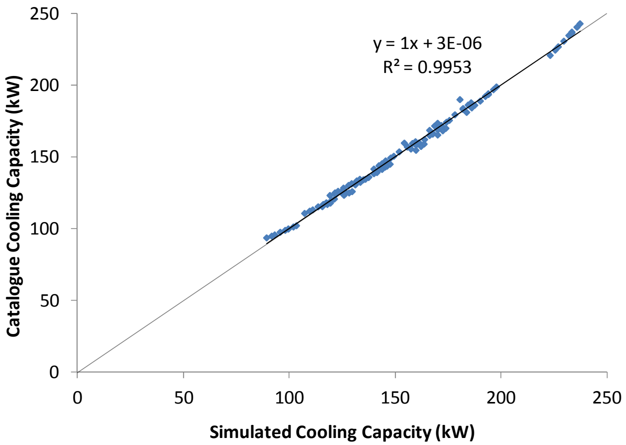


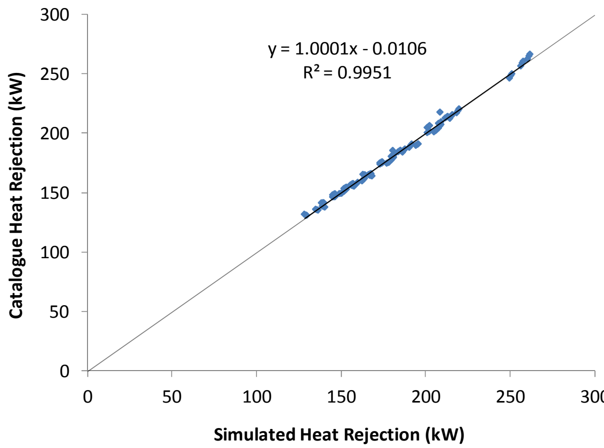
Heat Pump Performance

- Most catalogue data shows performance with water. 20% polypropylene glycol reduces heat transfer by 9% for cooling and 4% for heating in our case.
- We can construct a ‘curve fit’ model using the corrected catalogue data and predict outputs based on measured fluid temperatures and flow rates.

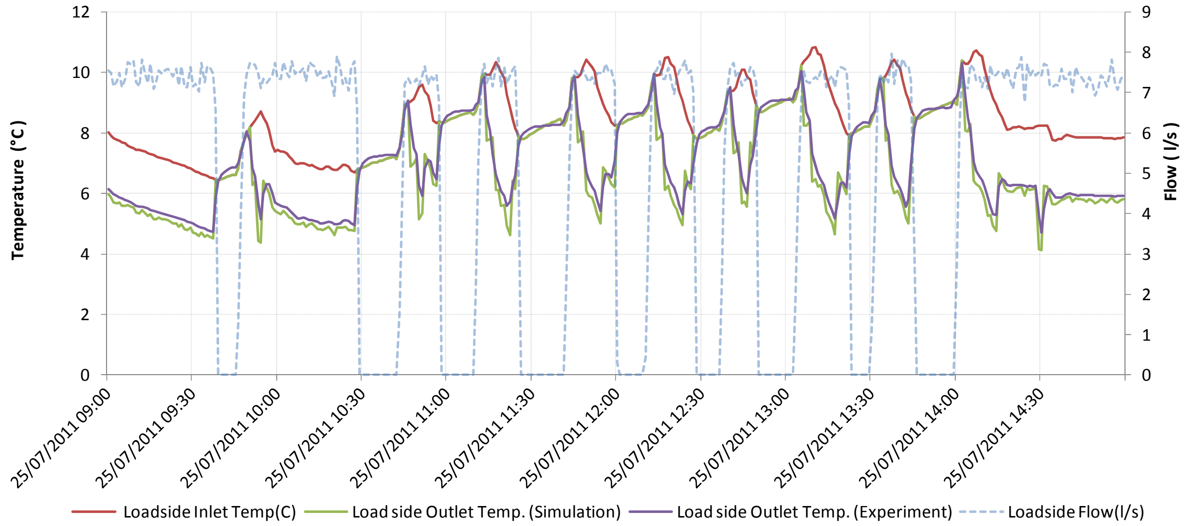
$$\frac{Q_L}{Q_{L,ref}} = A1 + A2\left[\frac{T_{L,in}}{T_{ref}}\right] + A3\left[\frac{T_{S,in}}{T_{ref}}\right] + A4\left[\frac{V_L}{V_{L,ref}}\right] + A5\left[\frac{V_S}{V_{S,ref}}\right]$$

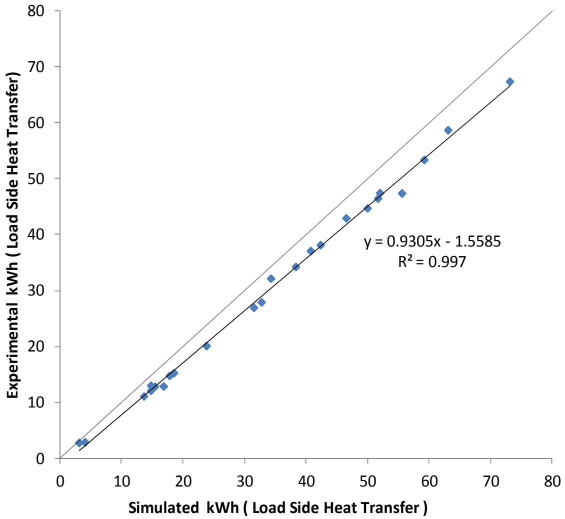
$$\frac{P}{P_{ref}} = B1 + B2\left[\frac{T_{L,in}}{T_{ref}}\right] + B3\left[\frac{T_{S,in}}{T_{ref}}\right] + B4\left[\frac{V_L}{V_{L,ref}}\right] + B5\left[\frac{V_S}{V_{S,ref}}\right]$$

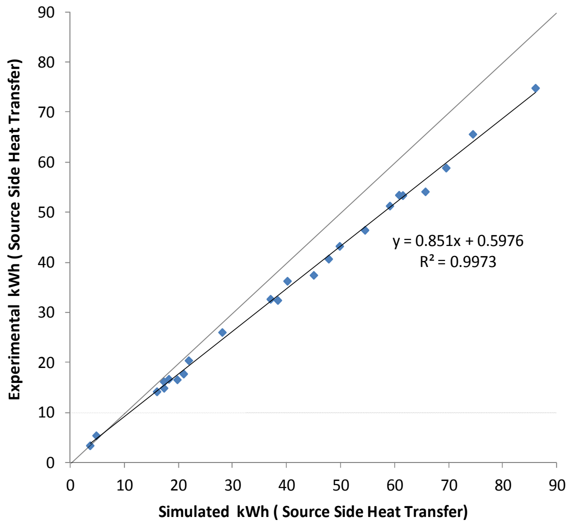


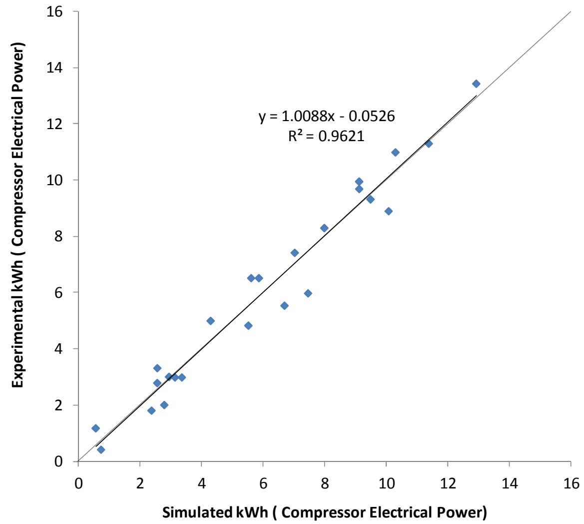


HEAT PUMP PERFORMANCE



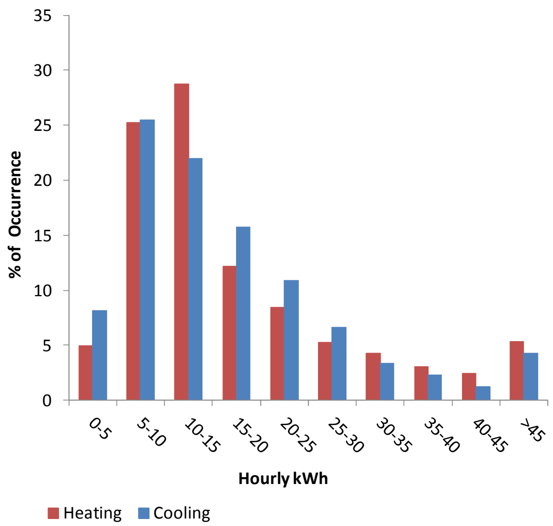


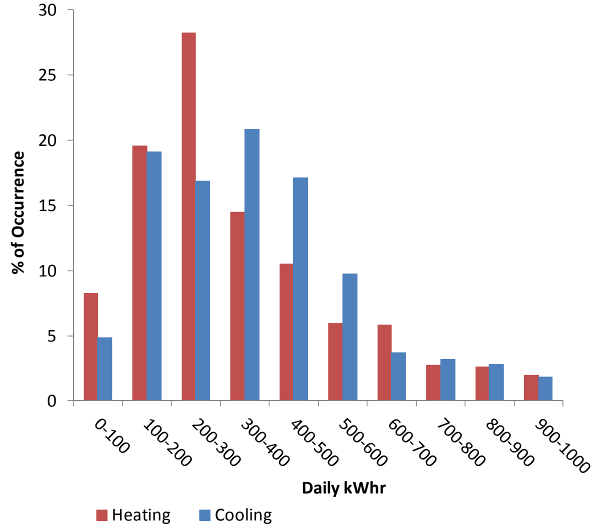


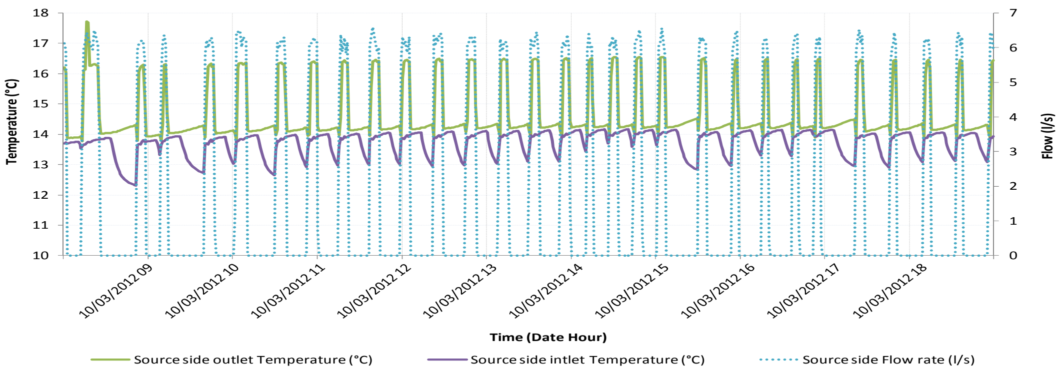


DYNAMIC OPERATION

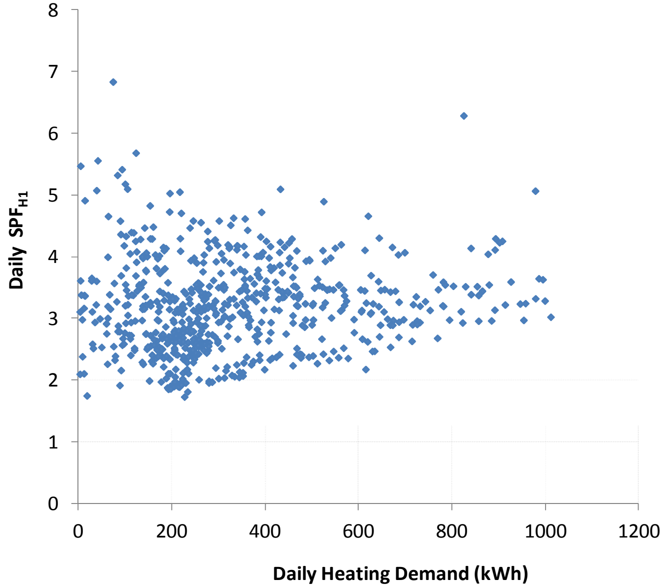
Only one compressor stage is needed for much of the time.
On/off control leads to short cycle times.

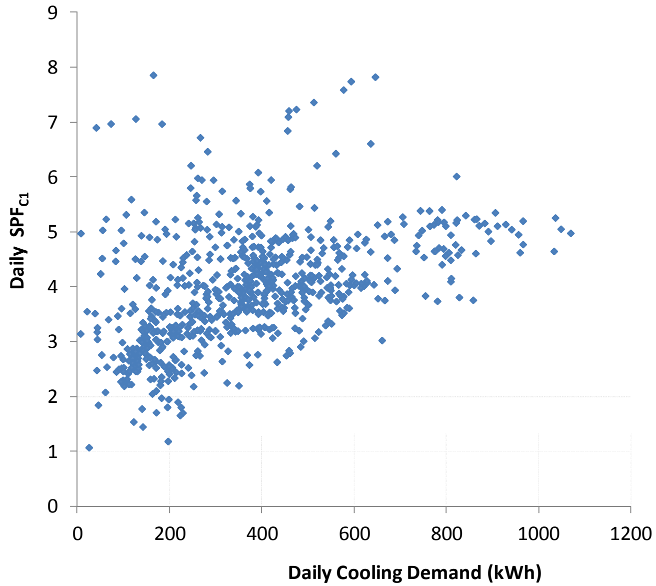


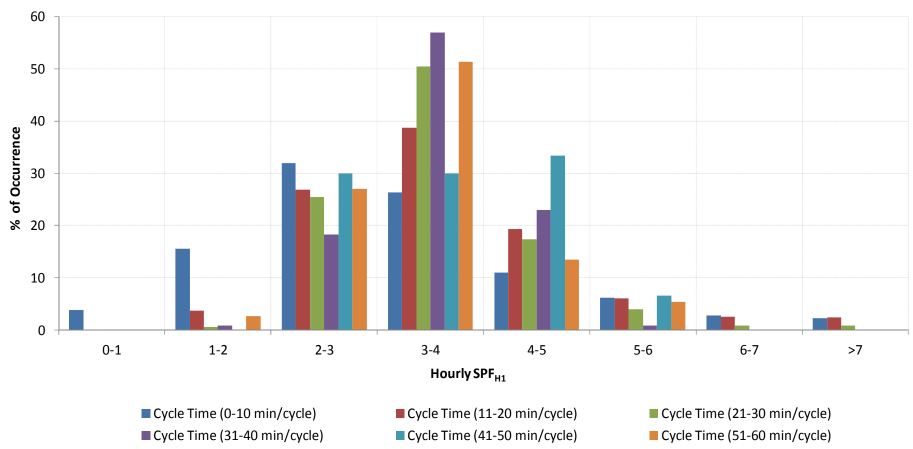


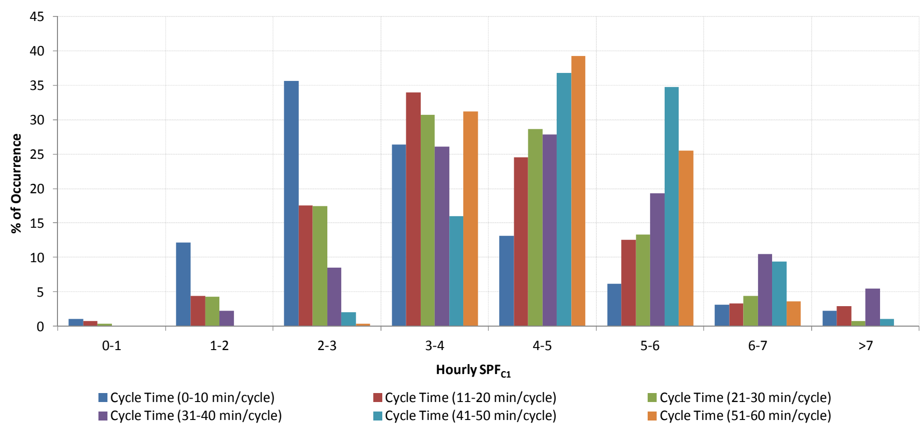


DYNAMIC OPERATION



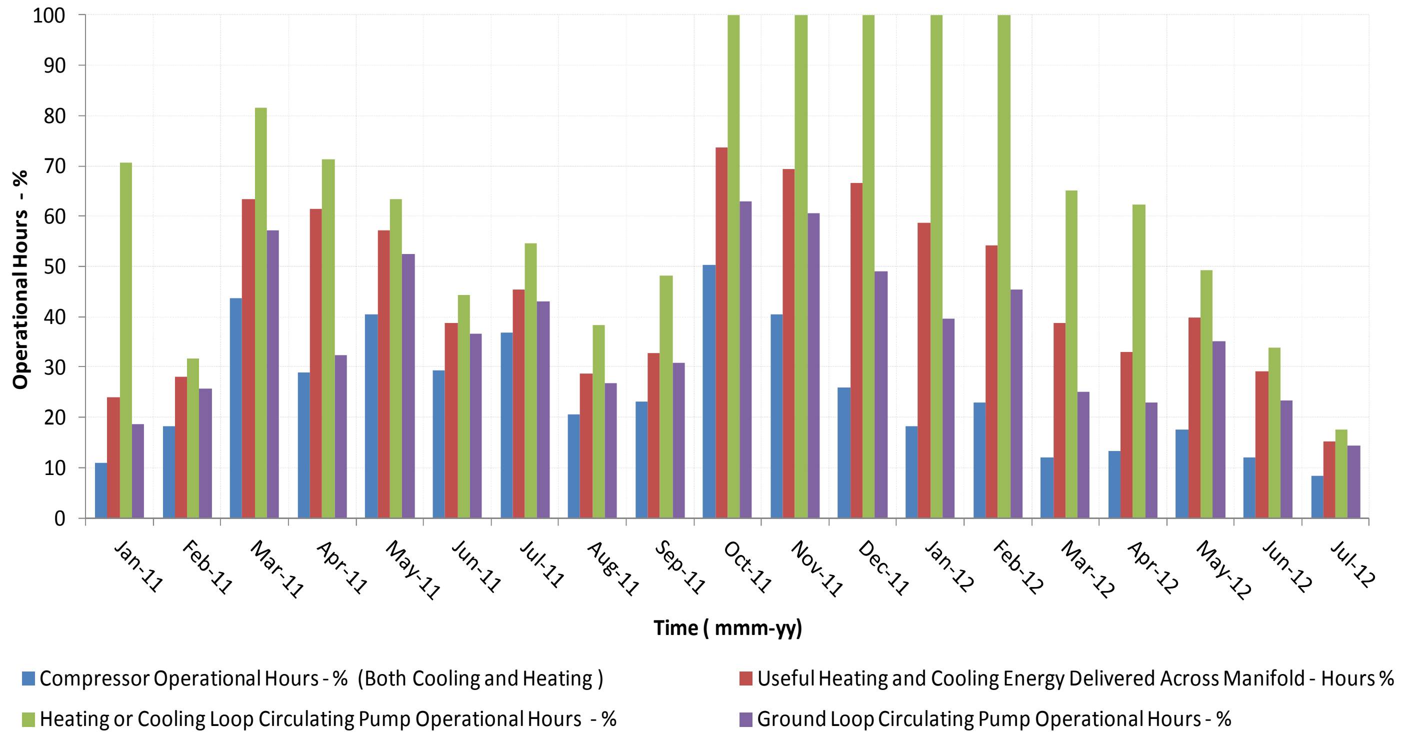






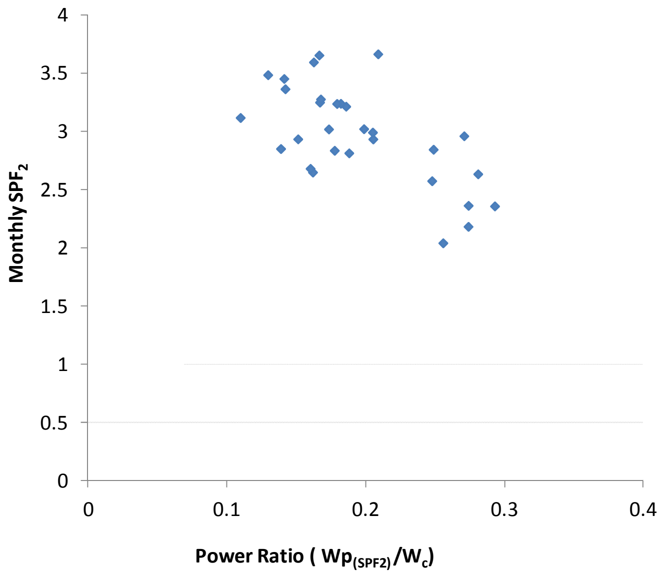
CIRCULATING PUMP OPERATION

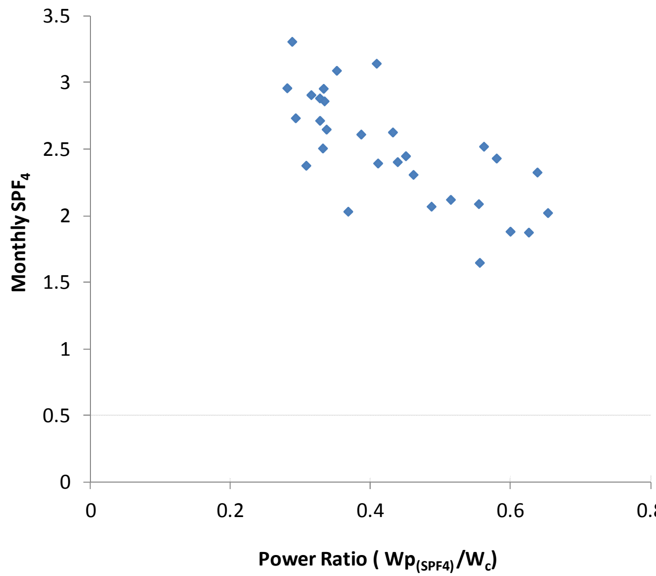
- Pump sizes are large relative to compressor sizes
- Pumps also operate unnecessarily – valve, flow switch and control faults



CIRCULATING PUMP ENERGY DEMANDS

Pump demands have a big effect on SPF_2 and SPF_4





Monthly Pump to Compressor Power Ratio *Vs* Monthly SPF_2, SPF_4

IMPROVING PERFORMANCE

- Cycle times would be improved by
  - Smaller lead machine
  - Variable compressor speed
  - Buffer tanks
- Lift could be reduced by heating temperature tuning/reduction
- Pump energy demands could be reduced by:
  - Better hydraulic design
  - More robust control (fault detection/correction)
  - Reduced start-up/shut-down running
  - Ground loop demand control

CONCLUSIONS

- Overall performance – satisfactory
- Good ground heat exchanger performance
- Potential improvement:
  - Longer cycle times
  - More resilient control
  - Heating temperature optimization
  - Lower glycol levels
- General lessons:
  - Pump energy, heating temperatures and controls are issues limiting efficiency: as in domestic systems
  - Short timescale dynamics are important
  - Better control integration (design/contract stages) and post installation care are needed