Vertical Closed Loops
- Case History Research

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‘City-scale geothermal simulation tool’

LONDON

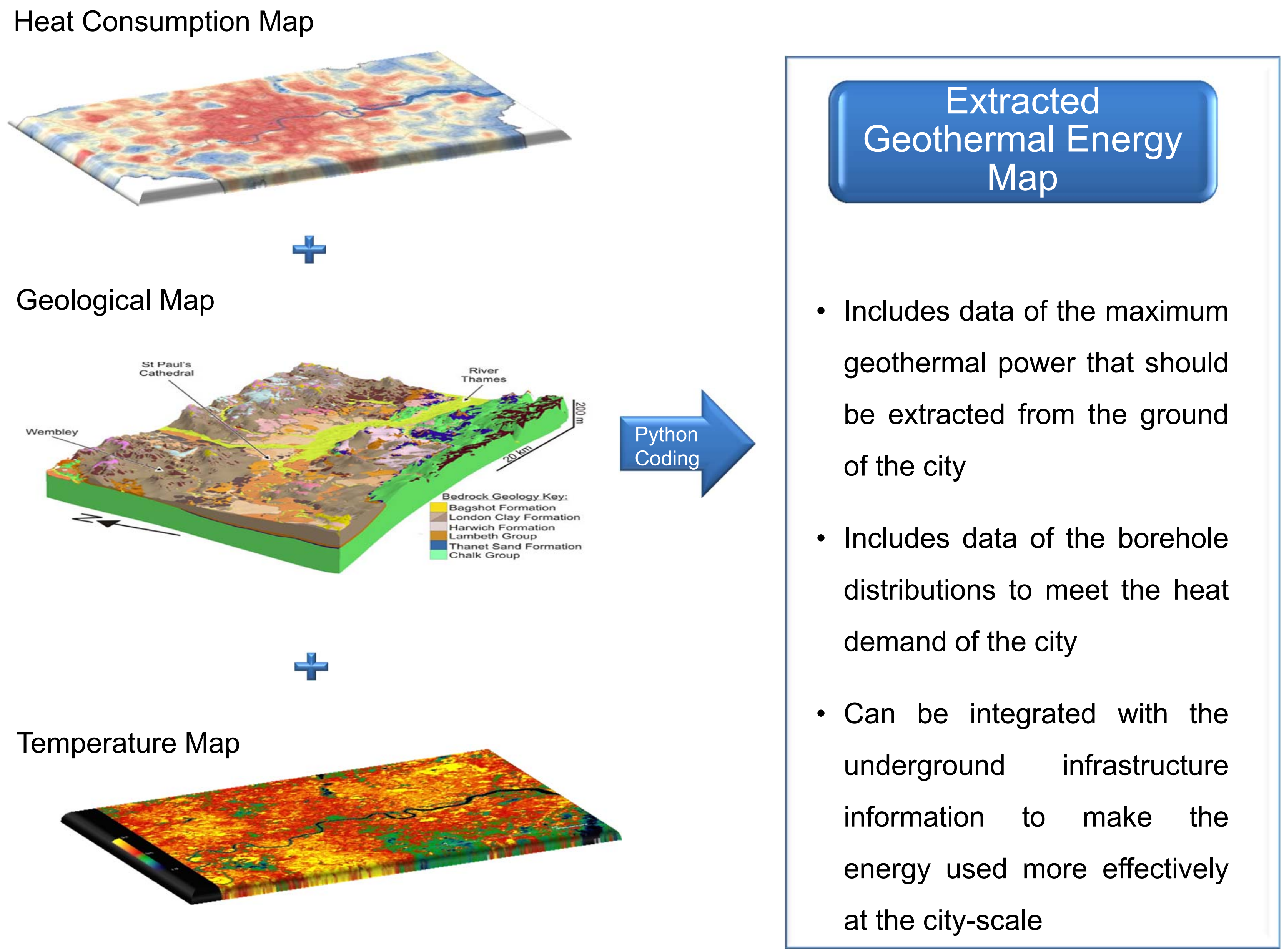
- Examine the geothermal energy potential at city scale
- $Q = (nC_w + (1-n)C_s)V\Delta T$,
  - Q (kJ) is the total heat potential content of the thermal reservoir,
  - V is the volume of the reservoir, n is porosity,
  - Cw and Cs (kJ m-3 K-1) are the volumetric heat capacity of water and solid,
  - ΔT is the temperature reduction or increase of the whole reservoir.

- If the magnitude of temperature reduction/increase is set as ΔT = 10°C, the heat potential of the London clay strata at depth = 30 m is approximately 5.52×10^{10} kJ per sq. km area

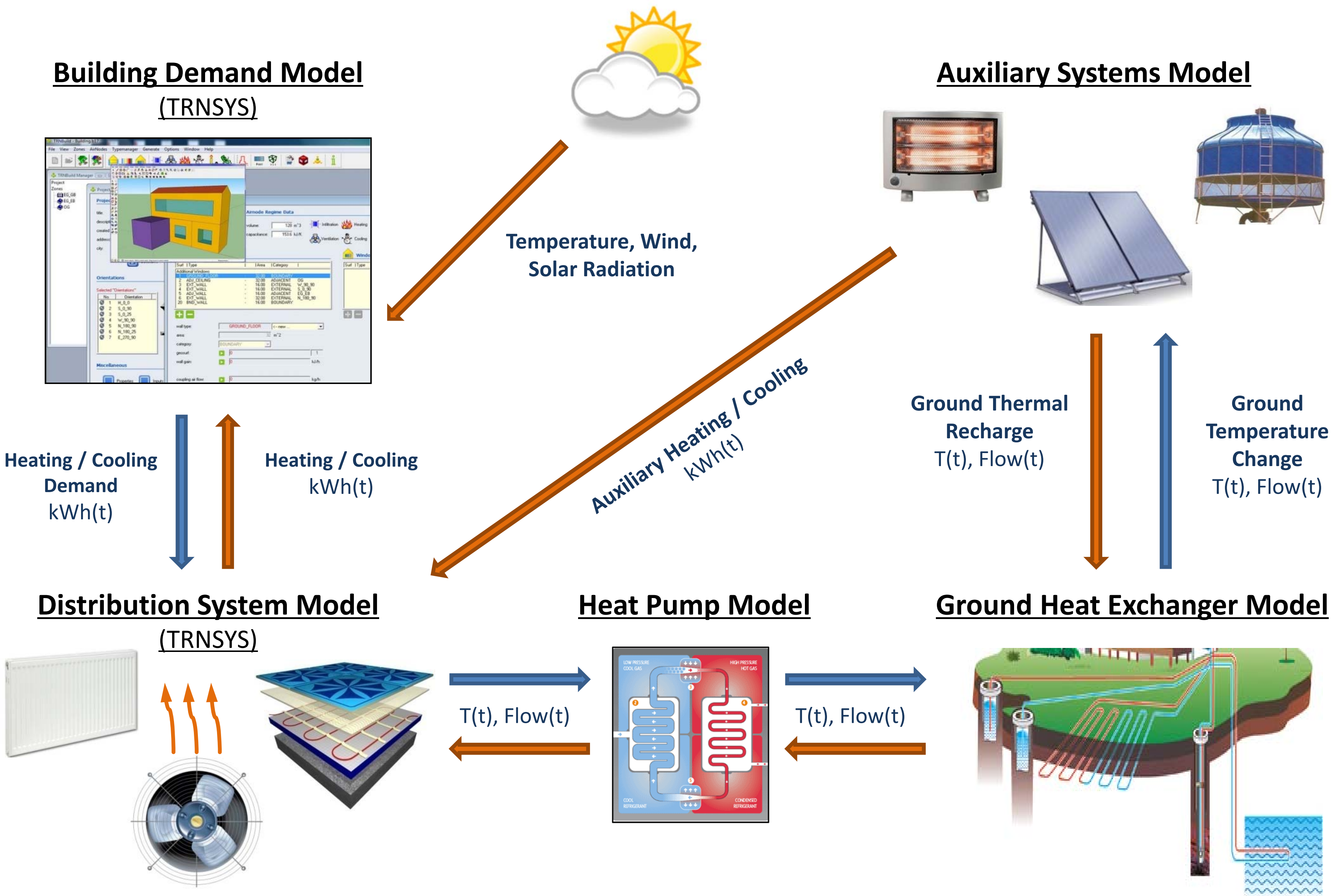
- The annual gas consumption for space and water heating is roughly 5.5×10^{10} KJ per sq. km of all land area in London (UK annual energy statistics, DECC, 2008).

- This is equivalent to the heat capacity of the London clay strata evaluated earlier (5.52×10^{10} kJ per sq. km area)

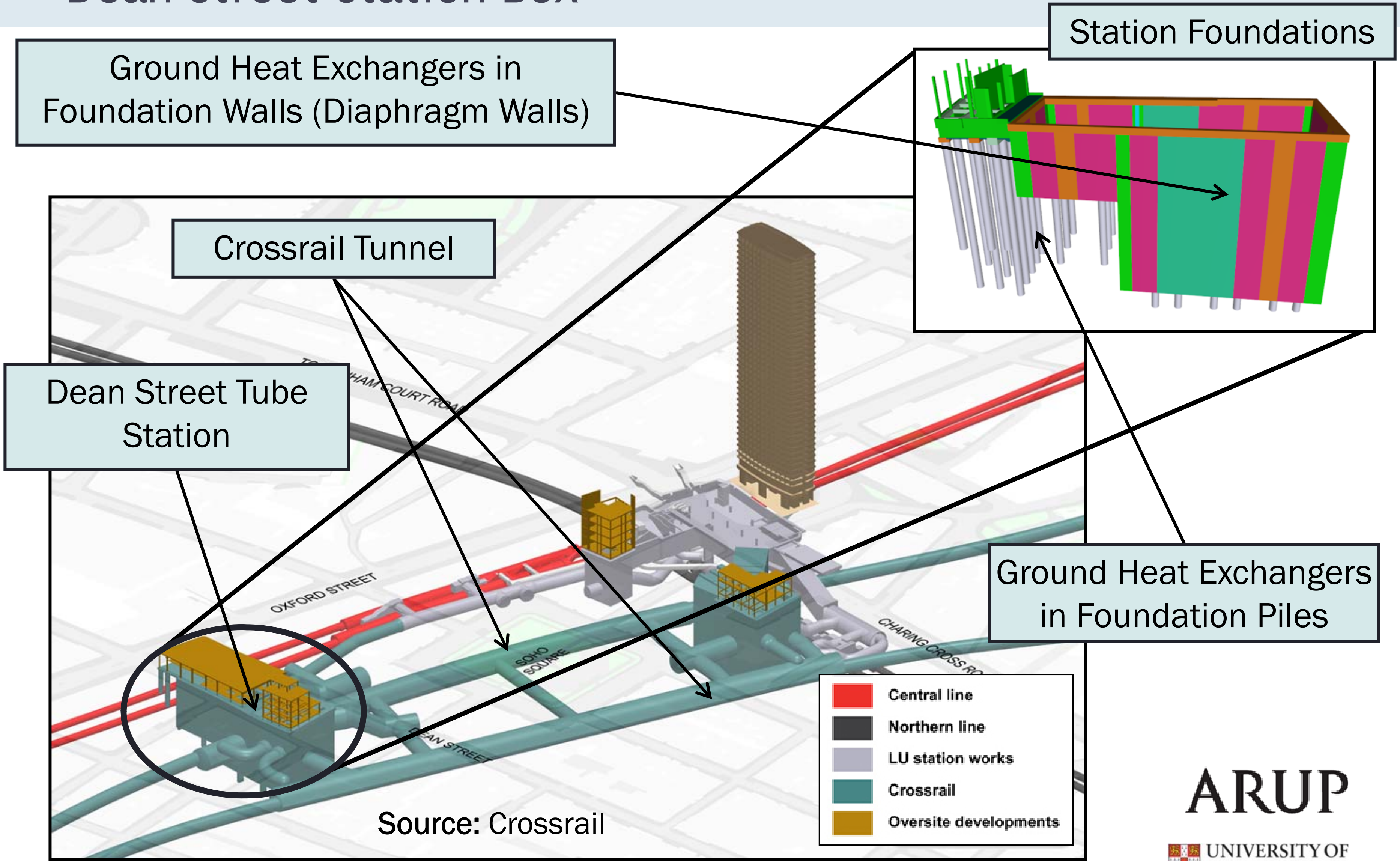
- Total energy consumption due to space cooling in London was in the order of 5.7×10^{12} KJ per sq. km (Day et al, 2009) and is expected to double by 2030.


Heat Consumption Map
Geological Map
St Paul's Cathedral
River Thames
Wembley
200 m
20 km
Bedrock Geology Key:
Bagshot Formation
London Clay Formation
Harwich Formation
Lambeth Group
Thanet Sand Formation
Chalk Group
Temperature Map
Python Coding
Extracted Geothermal Energy Map
• Includes data of the maximum geothermal power that should be extracted from the ground of the city
• Includes data of the borehole distributions to meet the heat demand of the city
• Can be integrated with the underground infrastructure information to make the energy used more effectively at the city-scale

The Relationship between the Model Components



Dean Street Station Box



Source: Crossrail

ARUP

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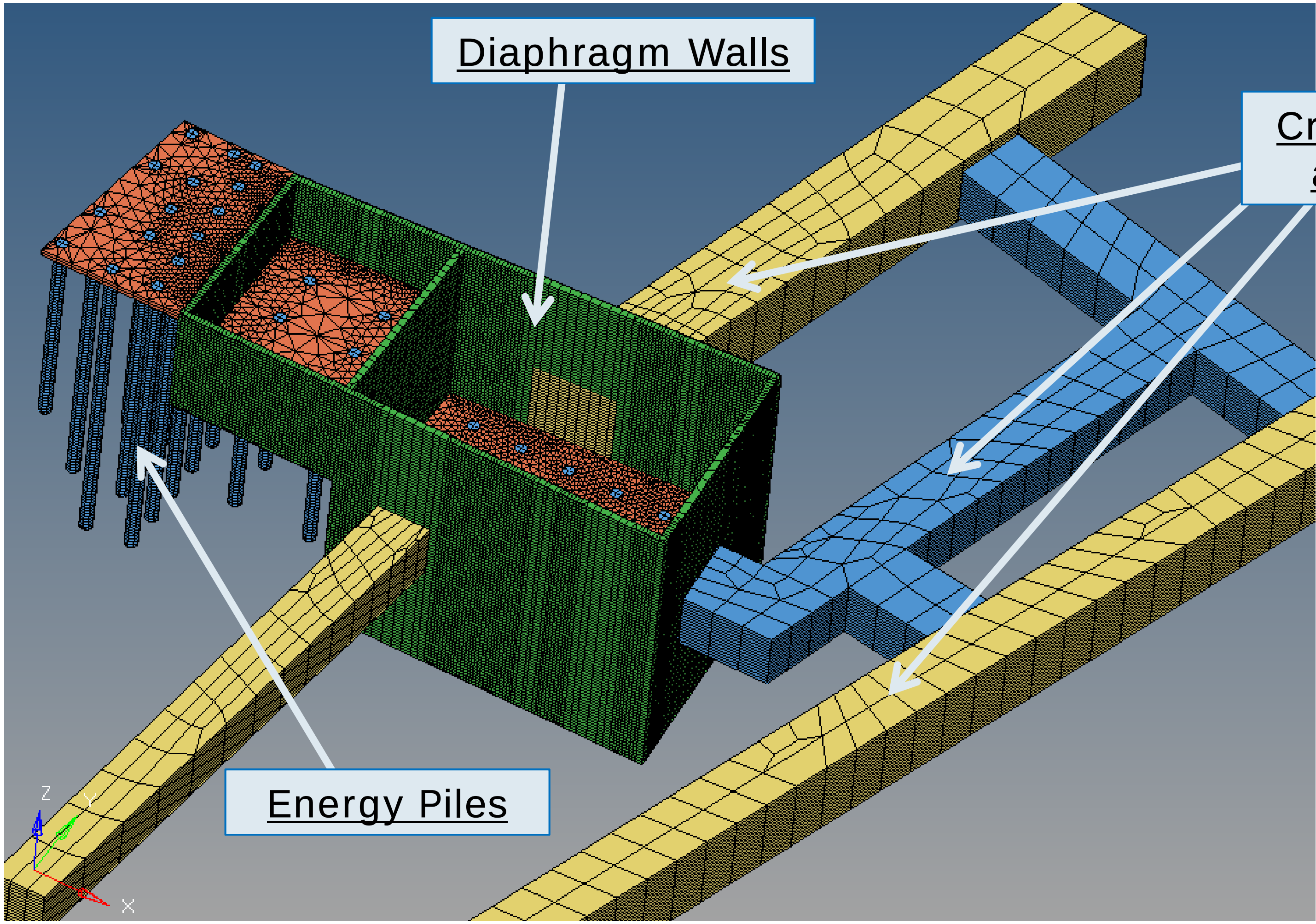
Dean Street Station Box – Model Mesh



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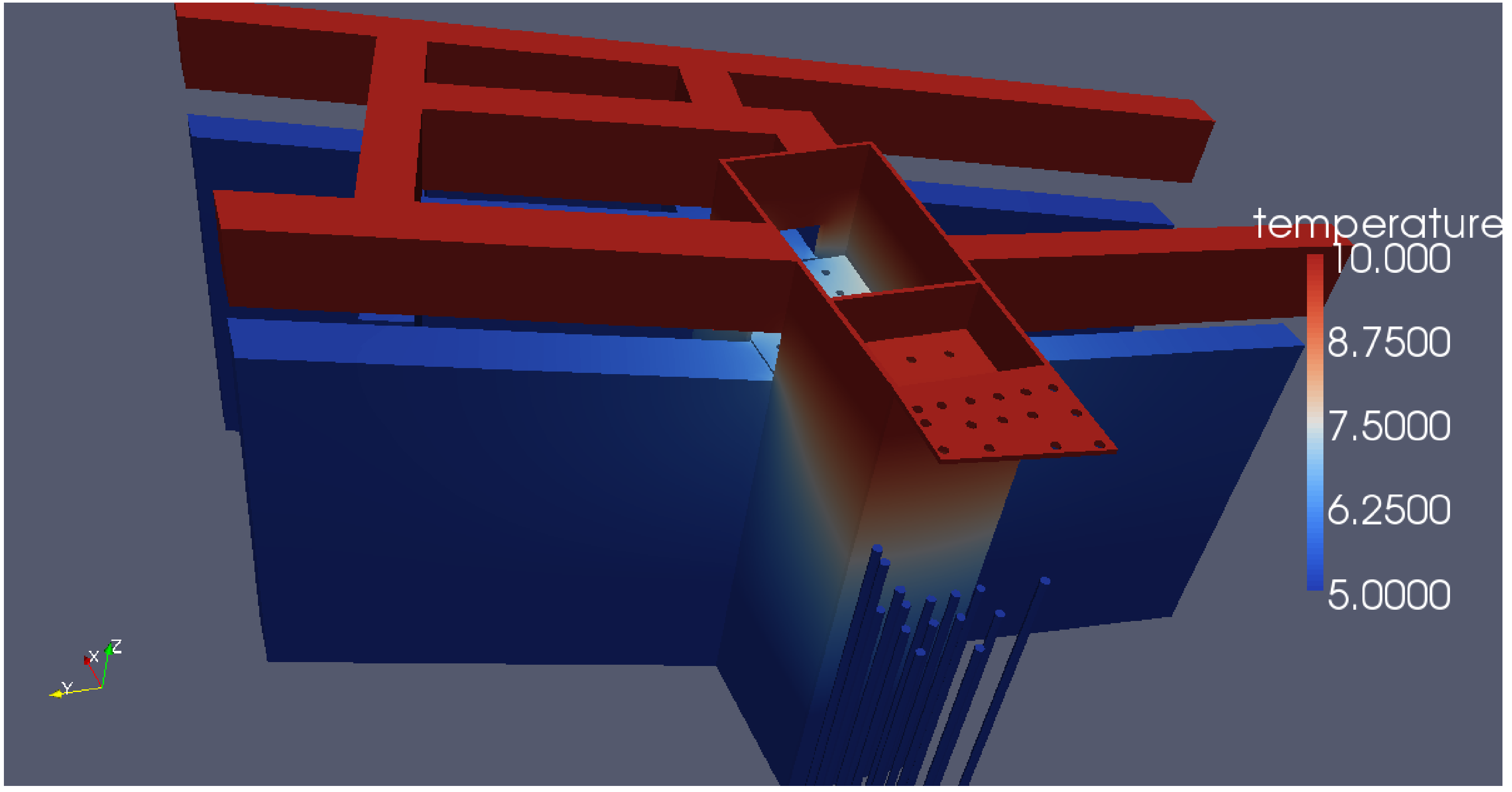
Dean Street Station Box – First Modelling Attempts



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Implementation and validation of a ground source heat pump (GSHP) system model in a TRNSYS energy simulation environment – case study

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Department of Engineering, University of Cambridge

With support from Geothermal International

Case Study – Oxford University Earth Science Department, UK

Building

Heat Pump

63 x 65 m
Boreholes

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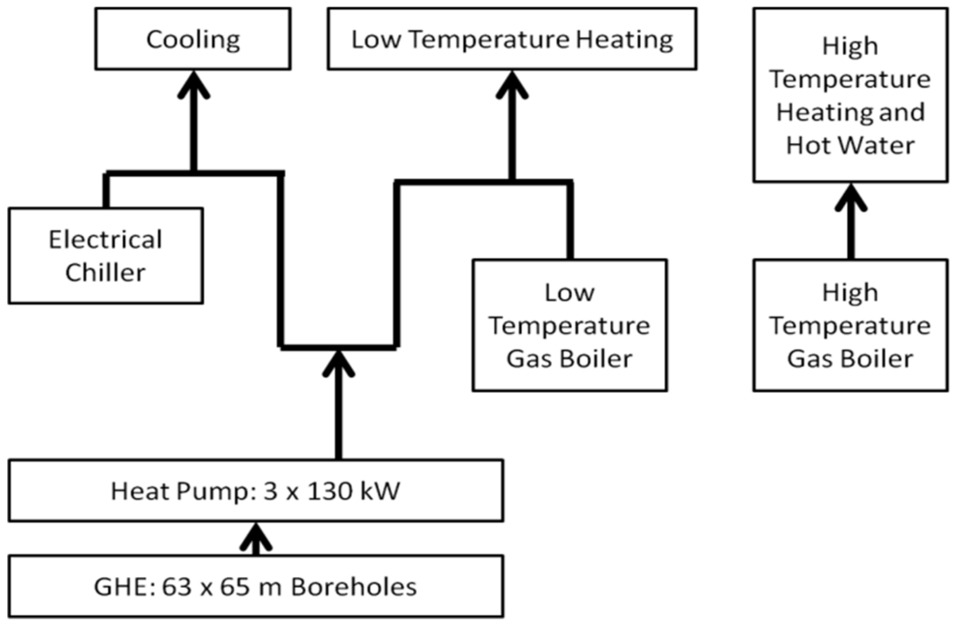
The System



The hourly demand schedule was generated using IES Virtual Environment Energy Modelling Software.

The total annual estimated design heating demand was 1850 MW and cooling demand was 600 MW.

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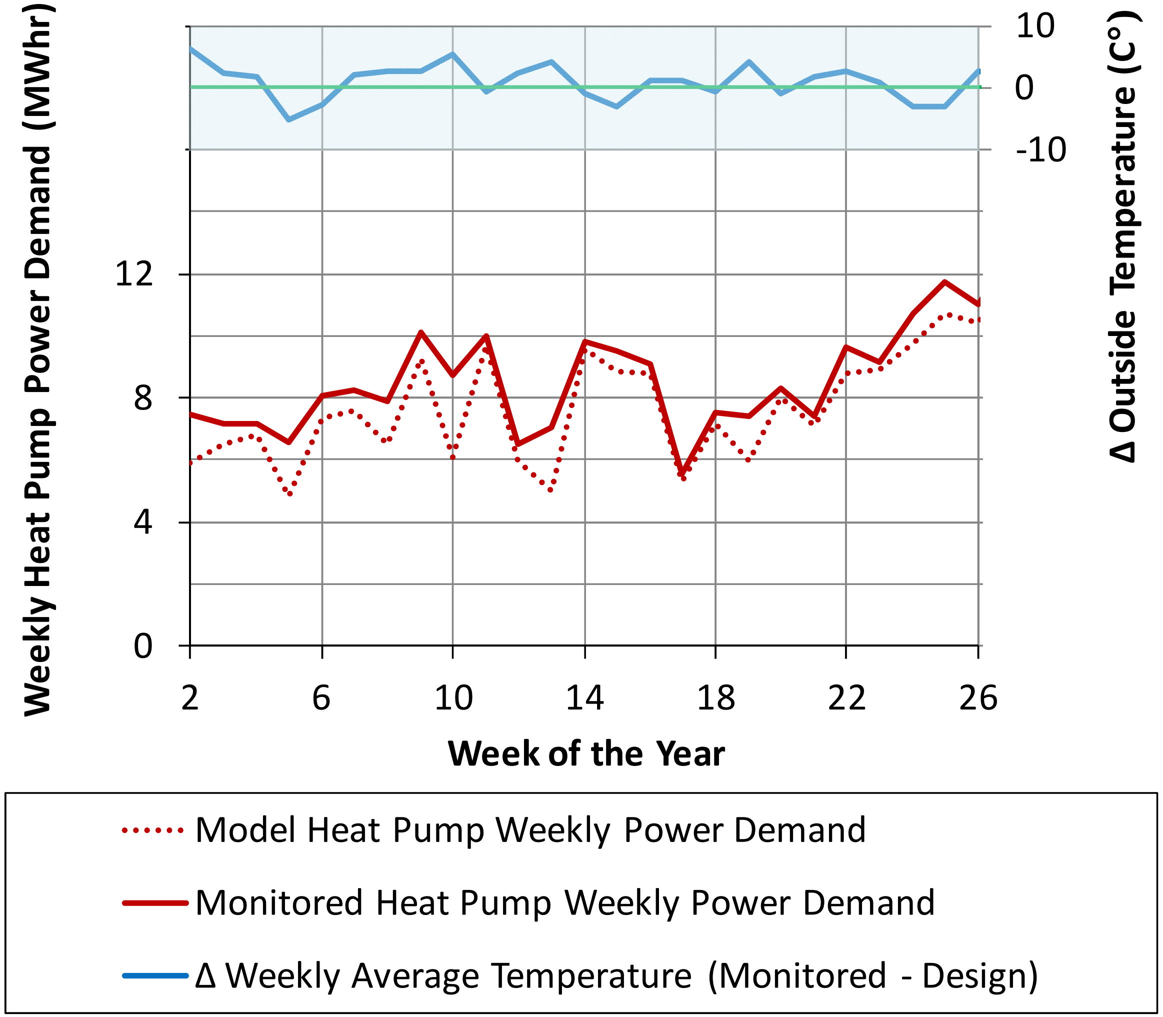
Monitored Data – Heat Pump Electricity Consumption



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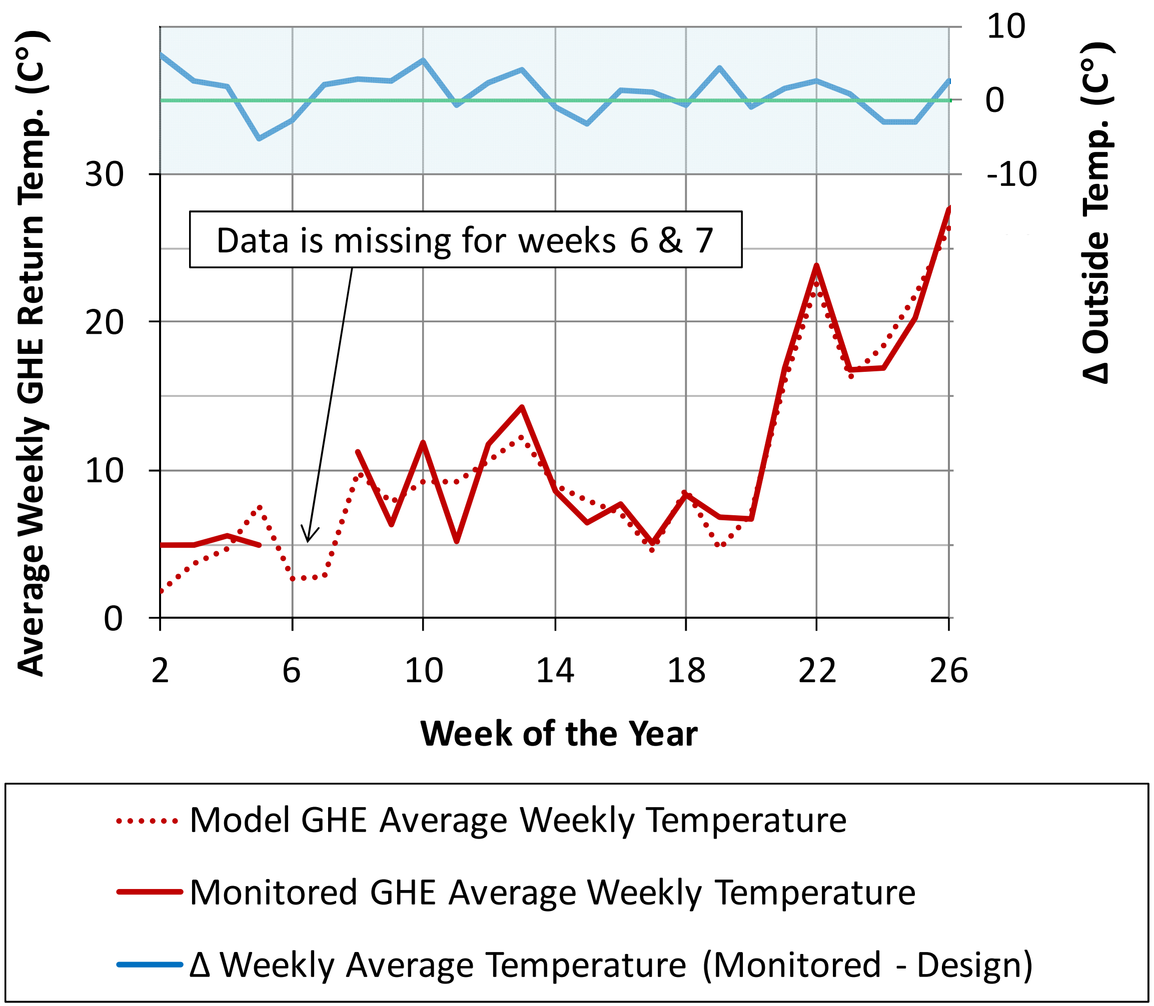
Monitored Data – GHE Return/Outlet Temperatures



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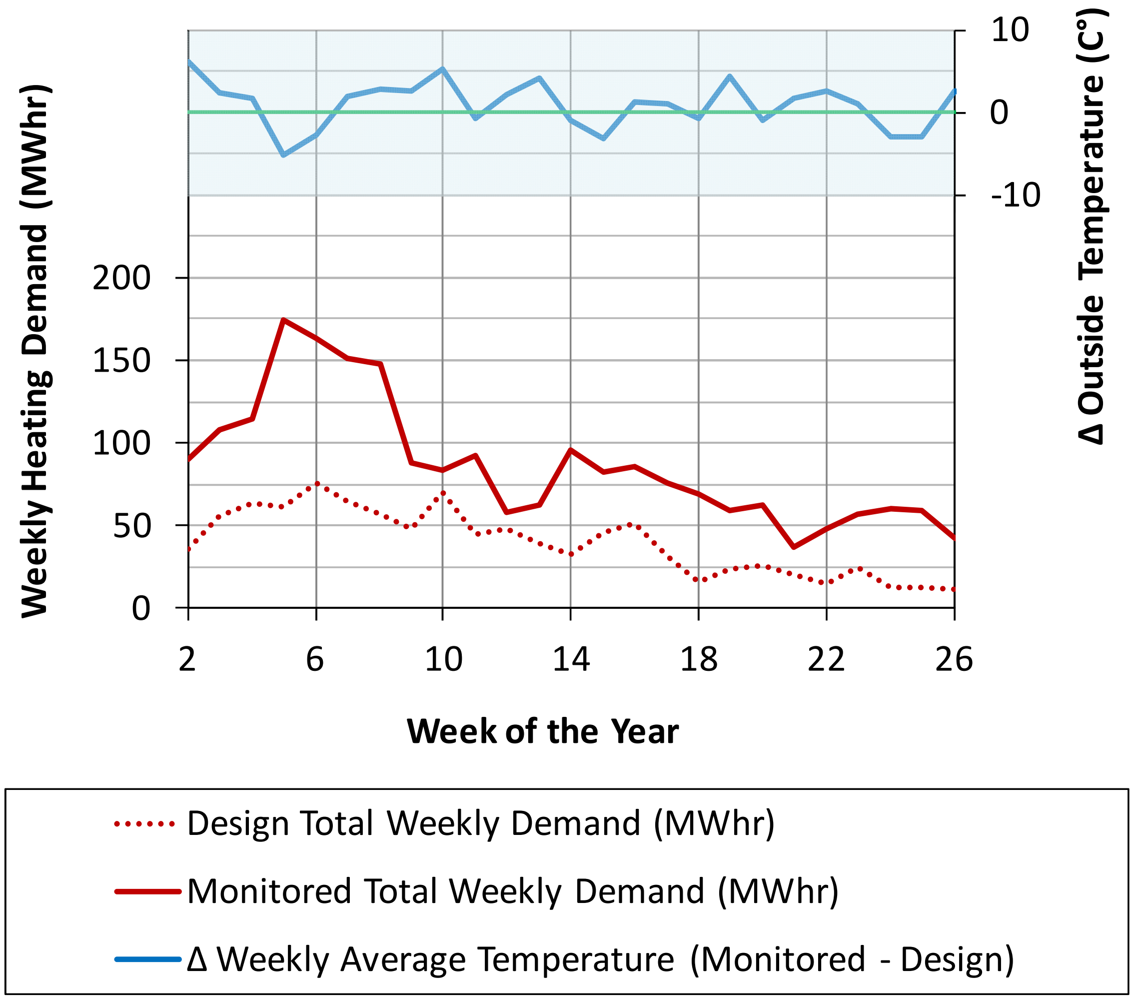
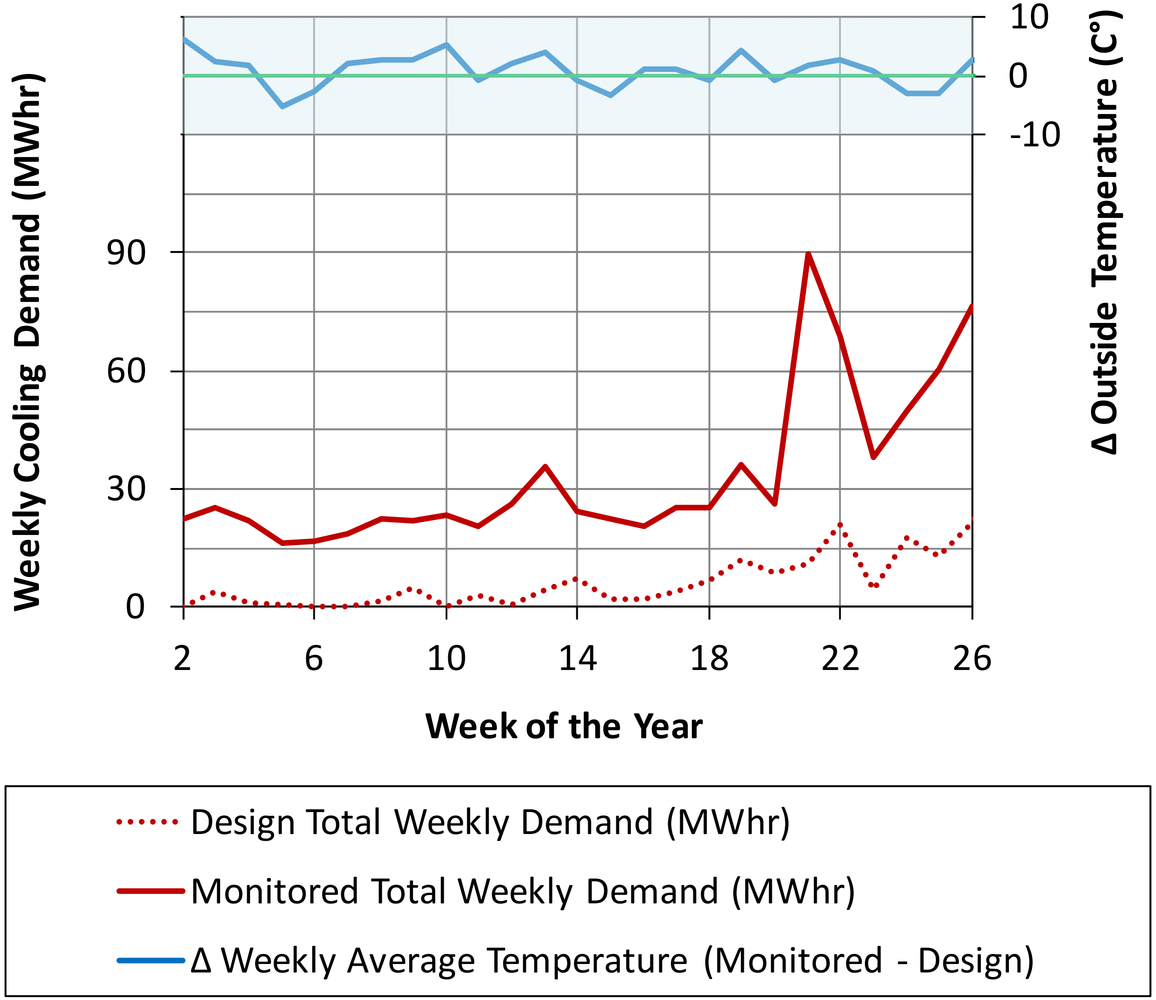
Monitored Data – Heating Demand



Monitored Data – Cooling Demand



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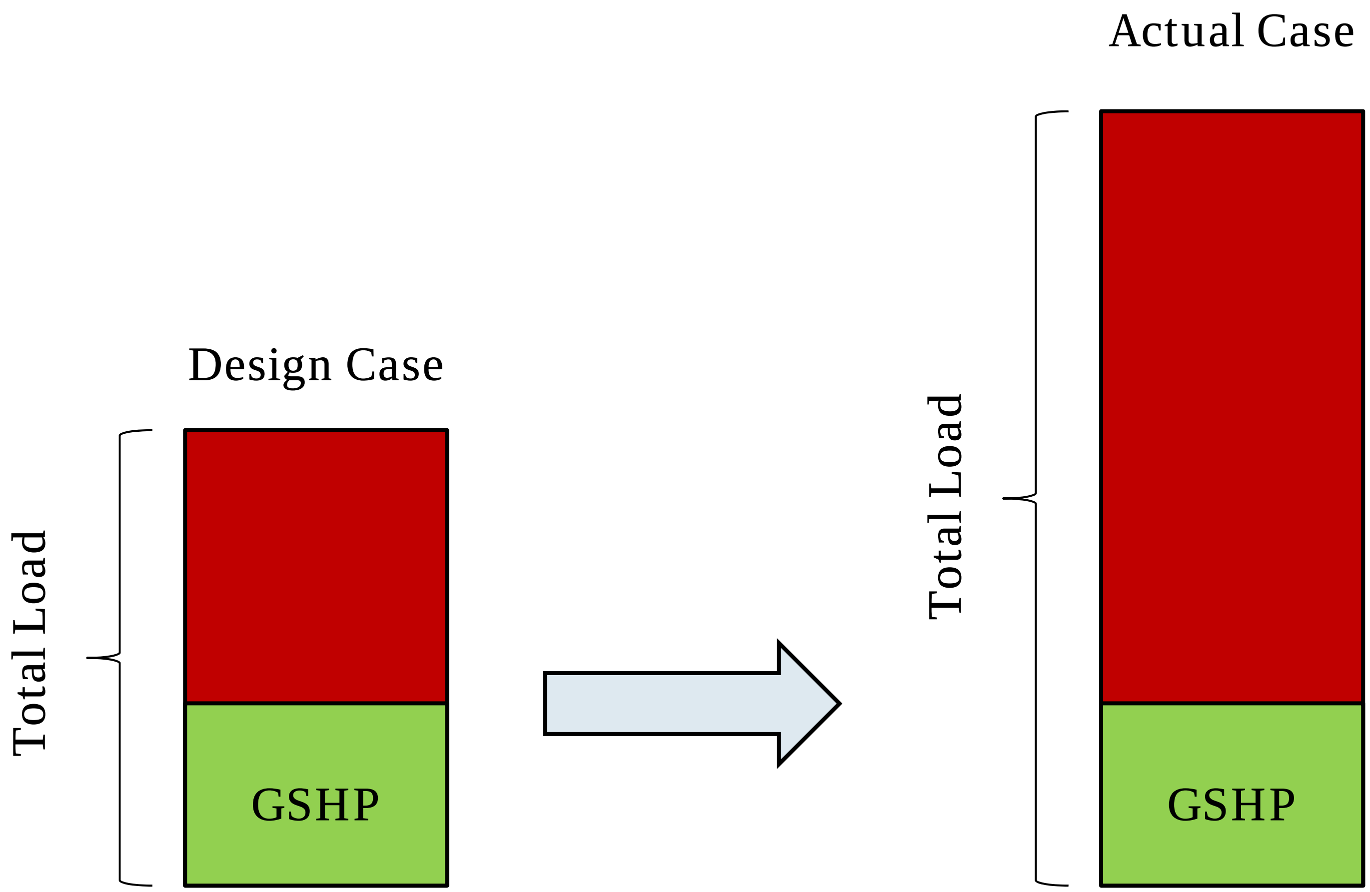
Why?



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Remarks

- The current case study is not the only case in the UK where actual loads deviated from design values
  - Keble College, University of Oxford
  - Architecture Studio Building, University of Cambridge
- Actual building heating/cooling demands are unpredictable
- Because the GSHP is designed for a specific net energy extraction/rejection rate into the soil, GSHPs are more sensitive to change in loads then conventional fossil fuel HVAC systems
- The uncertainty in the design loads should be taken in account when designing full-size GHSP systems

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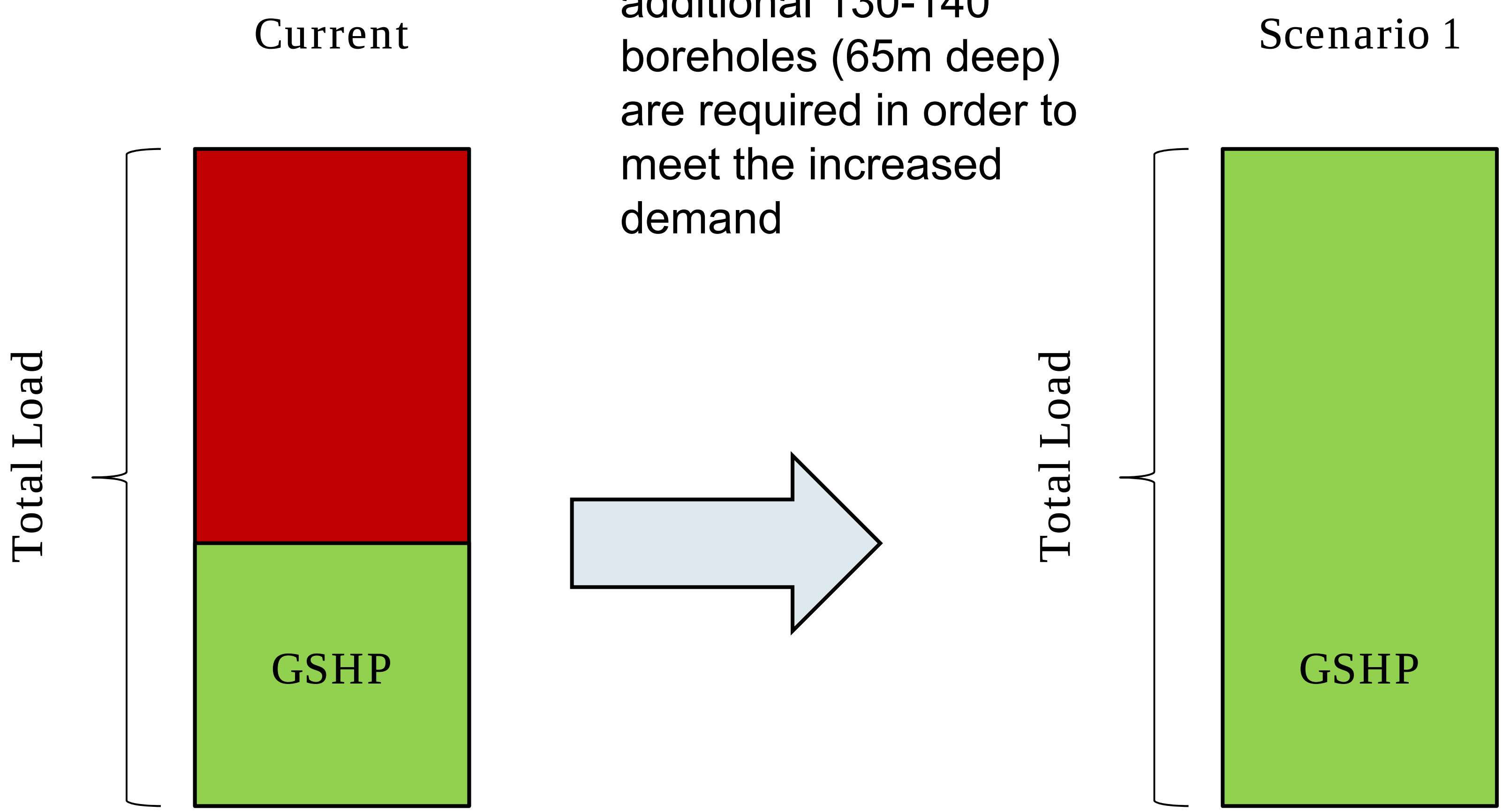
Scenario 1 – No Auxiliary System (Design Loads)

additional 130-140 boreholes (65m deep) are required in order to meet the increased demand



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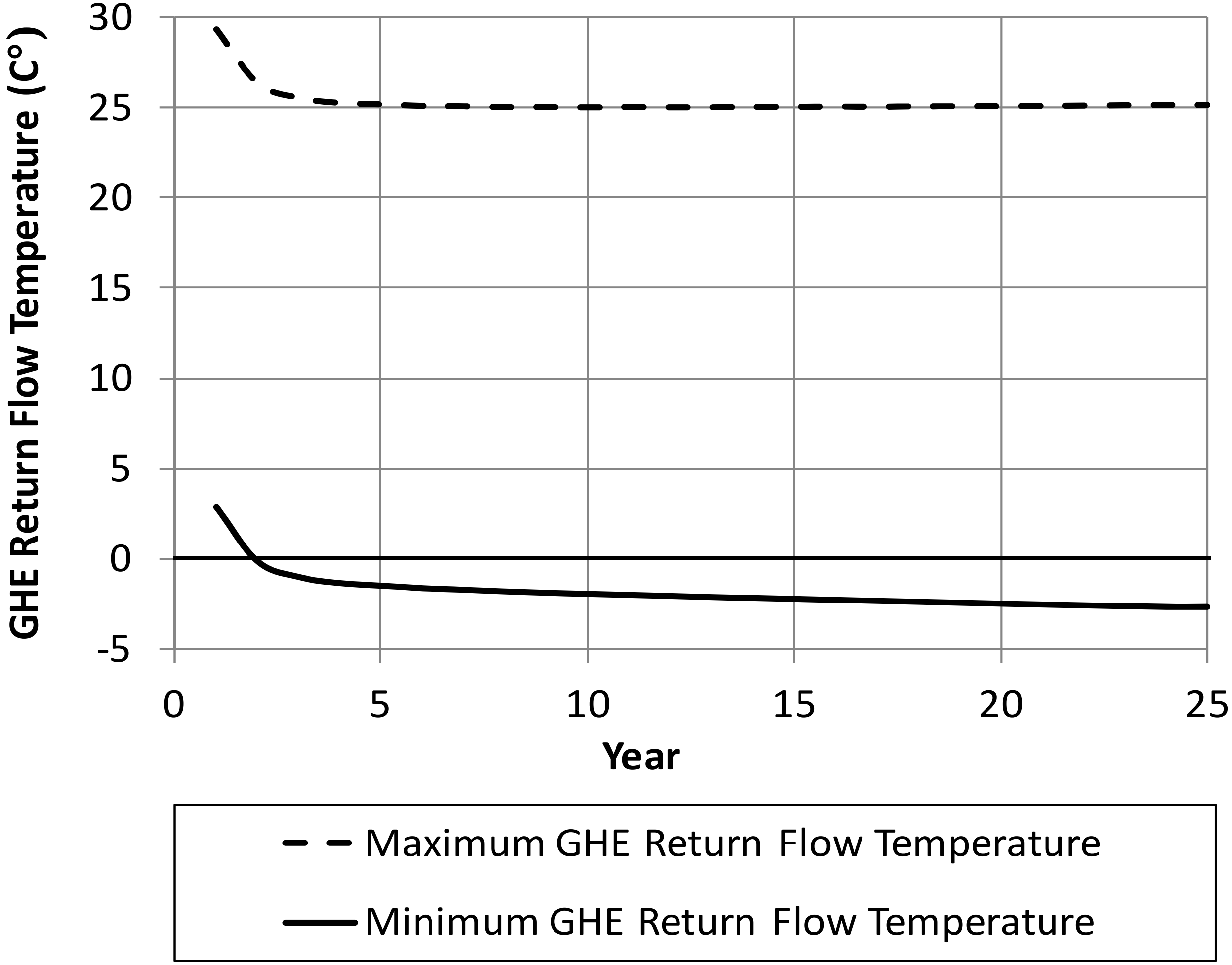
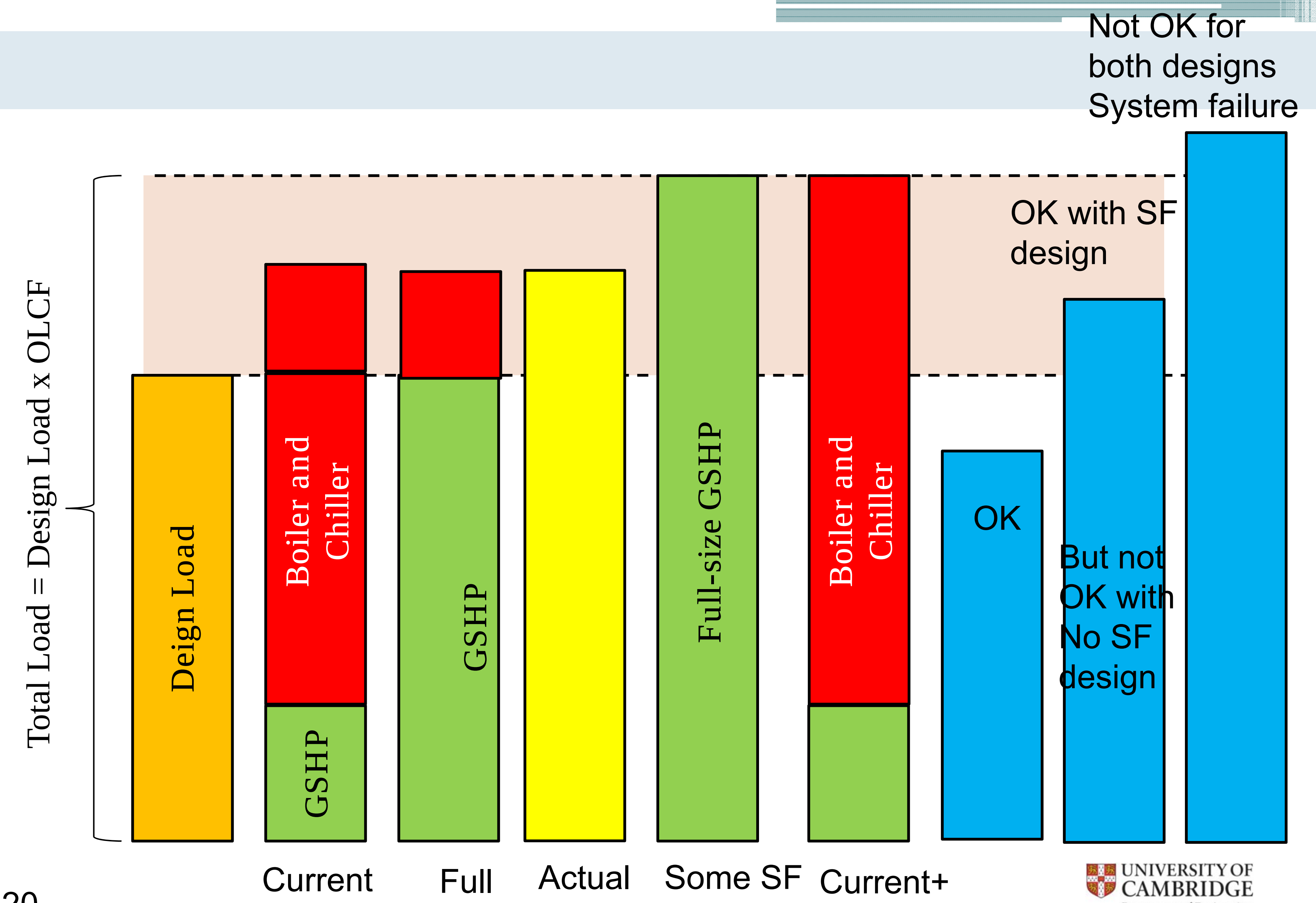
Scenario 1 – GHE 30 Year Min/Max Return/Outlet Temp.





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The Question

- Can we over-size the GHE during design in order to reduce the risk of system under performance (i.e. provide a safety factor) while still keeping the installation and operational costs below those of other HVAC systems?
  - And if so up to which safety factor?

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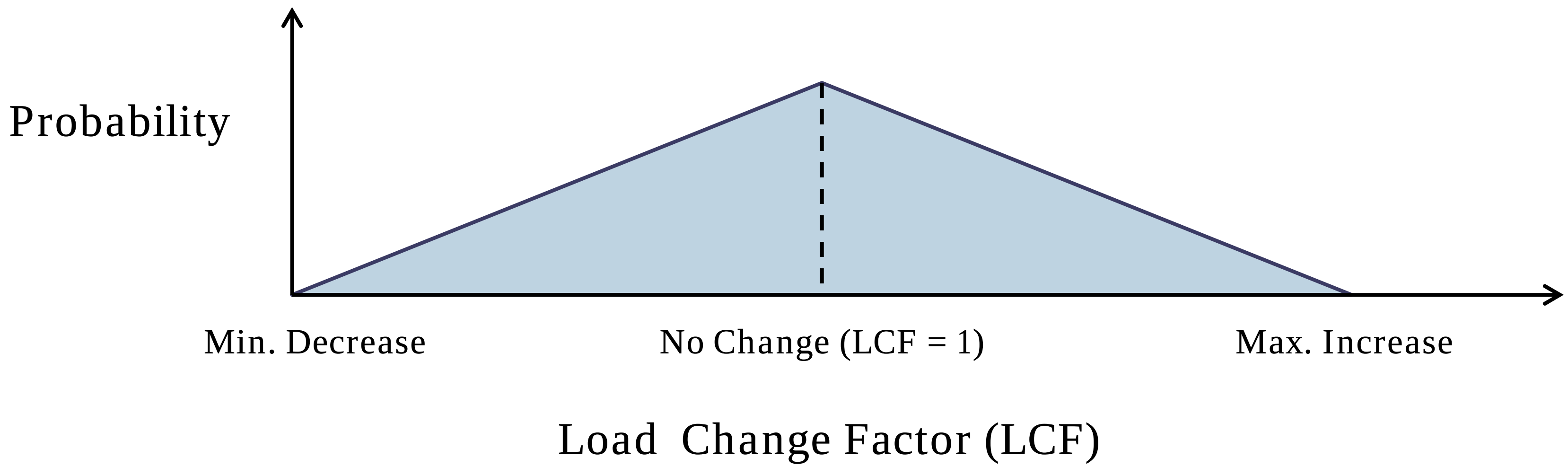
Load Change Factor (LCF)

- For GSHP design we are concerned with a LCF which will increase or decrease the TOTAL loads over the lifetime
- Lets assume that this LCF has the following triangular probability distribution:



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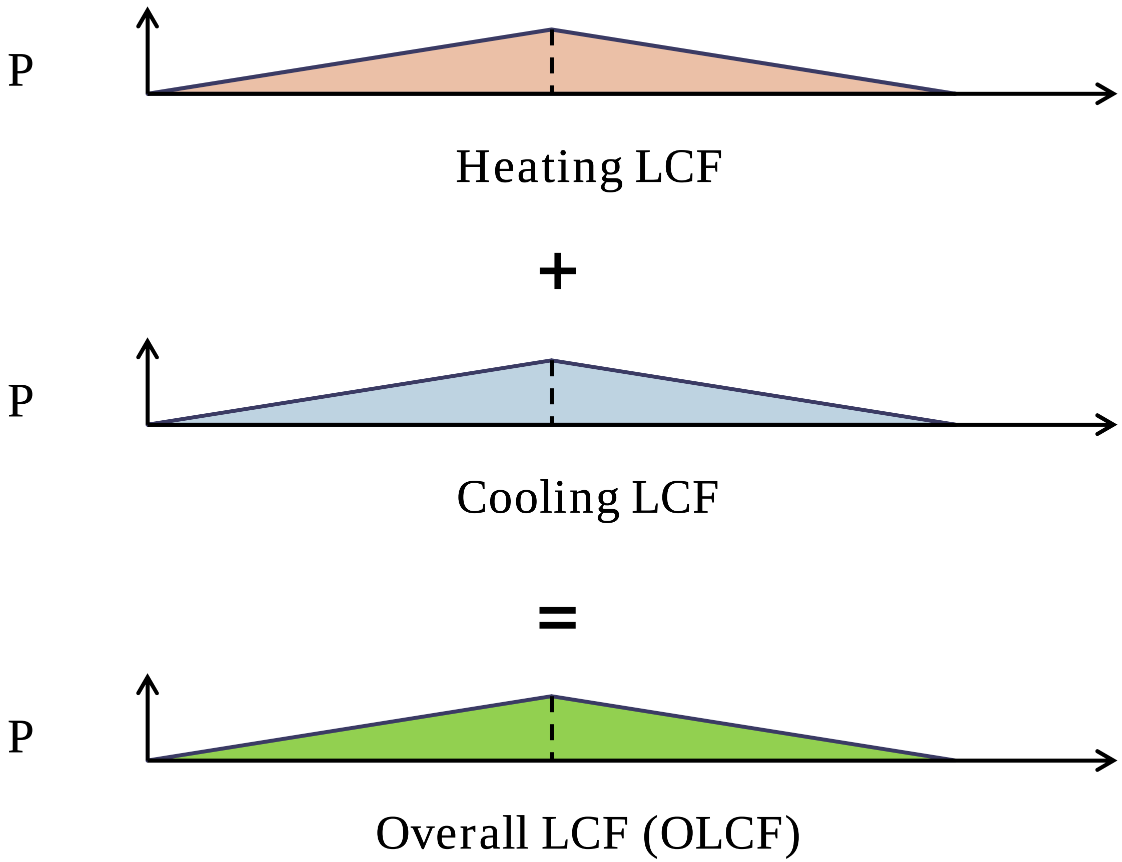
Overall Load Factor (OLCF)

- The LCF can be different for the cooling and the heating loads:



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Uncertainties

Parameter	Minimum	Median (Most Likely Case)	Maximum
Cooling/Heating Load Increase Factor	0.3	1.0	3.0
£/kW Gas	0.032	0.041	0.05
£/kW Electricity	0.1190	0.1345	0.1500
Borehole Installation Cost (£/m)	25.0	37.5	50.0
Boiler Efficiency	0.94	0.96	0.98
Chiller Efficiency	3.5	4.0	4.5
Gas (kg CO_2/kW)	0.185	0.194	0.203
Electricity (kg CO_2/kW)	0.40	0.42	0.55
Air Source Cooling COP	3.0	3.9	4.5
Air Source Heating COP	3.0	4.0	4.9

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Installation of additional GSHP boreholes with safety factor

- Increased cost for the installation of GSHP compared to alternative technologies
  - More cost with higher SF (i.e. longer borehole lengths)
- Compared to alternative technologies, savings made after 30 years by an actual demand (which is variable). (Operational Savings)
- Relative Benefit = Operational savings – GSHP Installation Cost
  - Case A – Savings > GSHP Installation – Good investment
  - Case B - Savings ~ GSHP Installation
  - Case C – Savings < GSHP Installation – Not good investment
  - Case D – Actual demand > Design Load x SF – System failure

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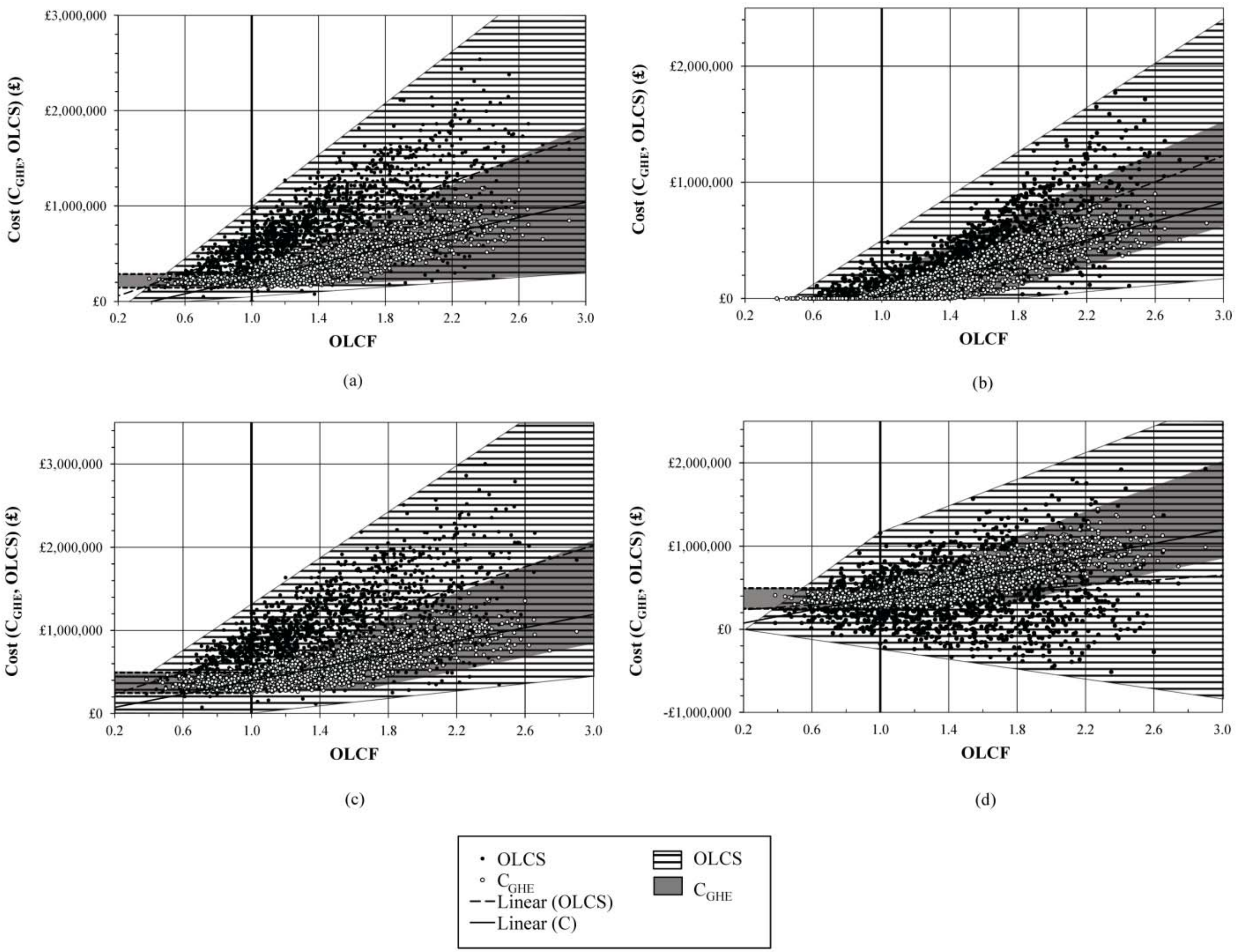
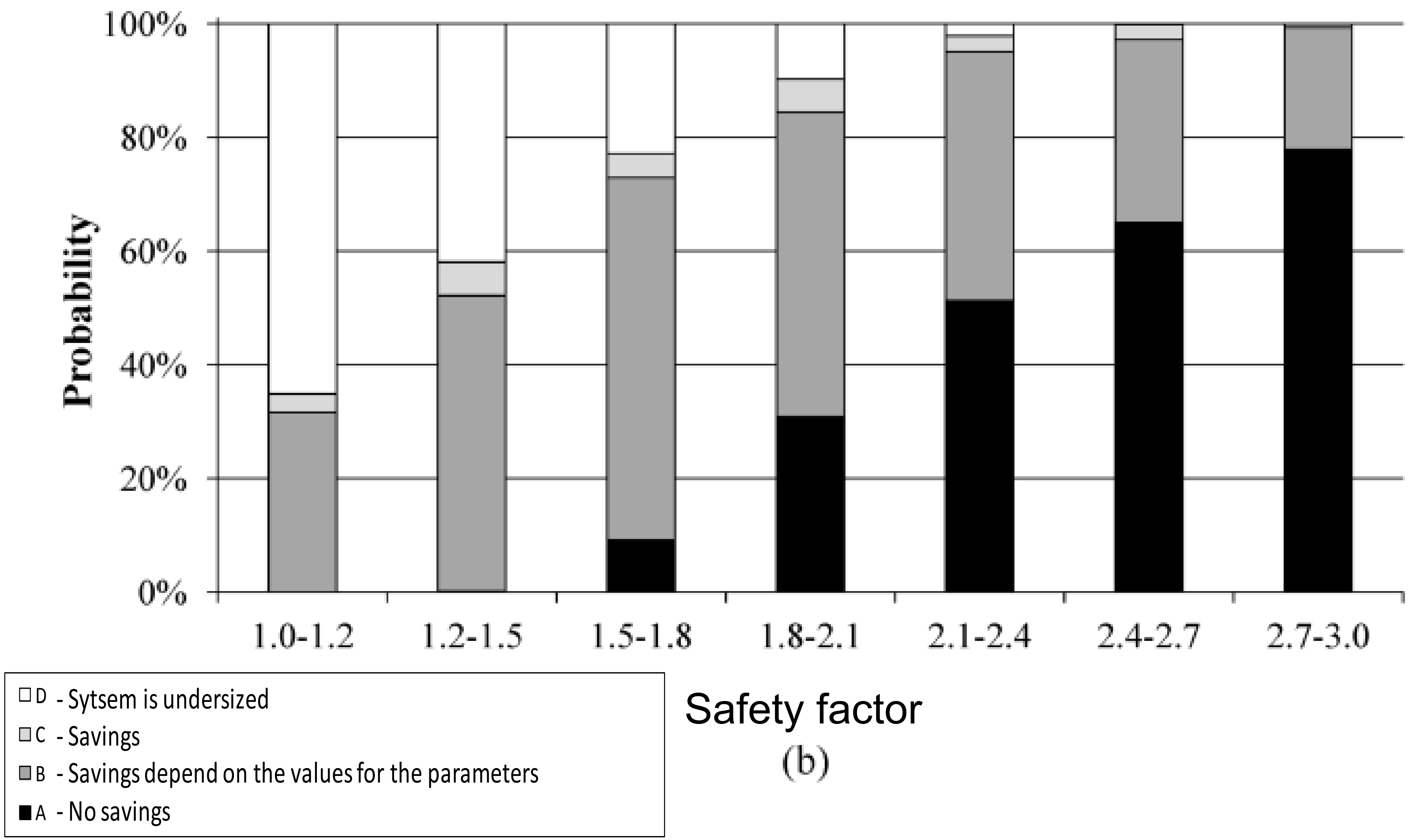
Results (for the Oxford Building case)



Full GSHP versus Current GSHP+Boiler&Chiller



System failure decreases with increase in SF (Actual demand>design load)
No saving increases with increase in SF (Extra GSHP was not used)

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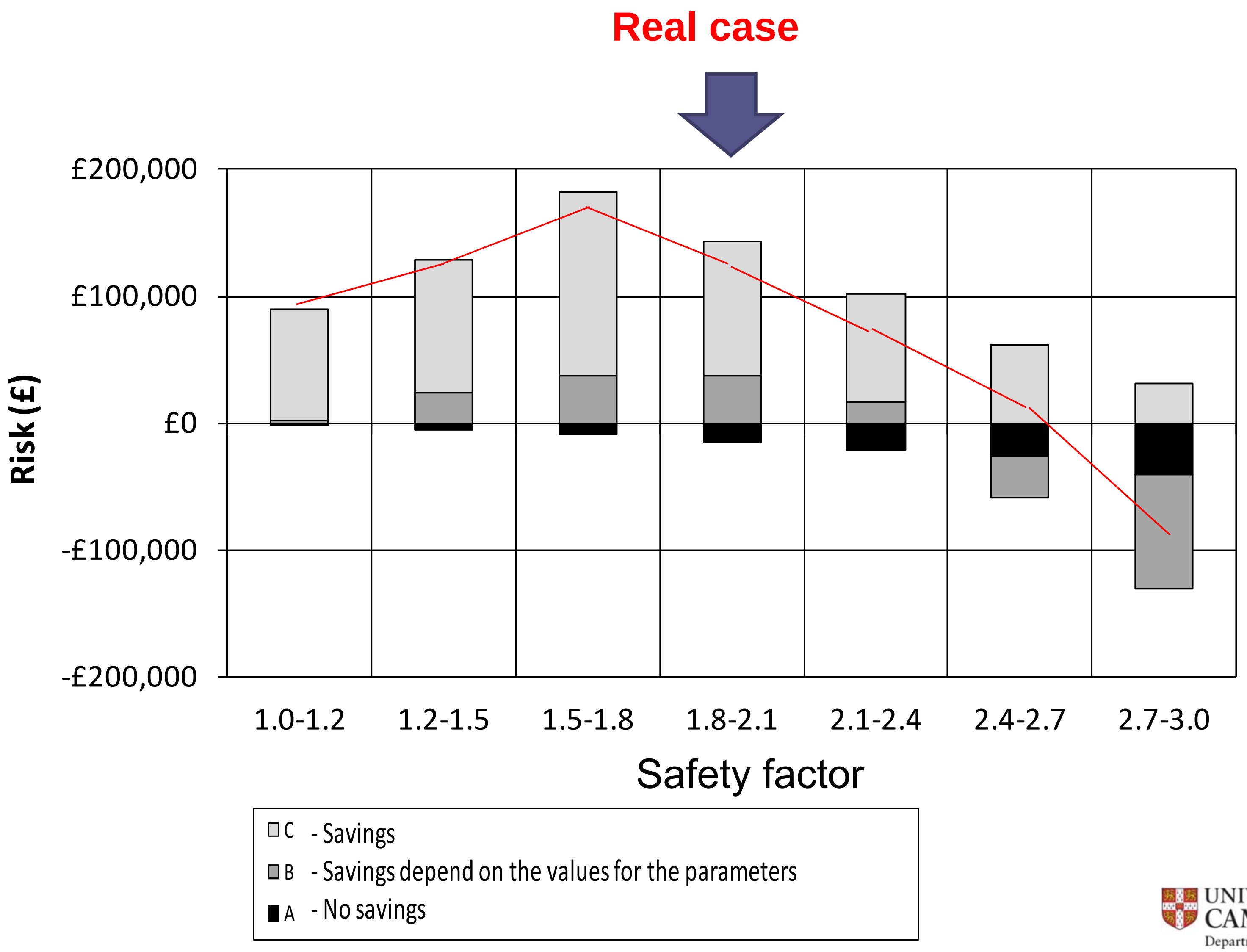
Life cycle savings by Full GSHP to Current system



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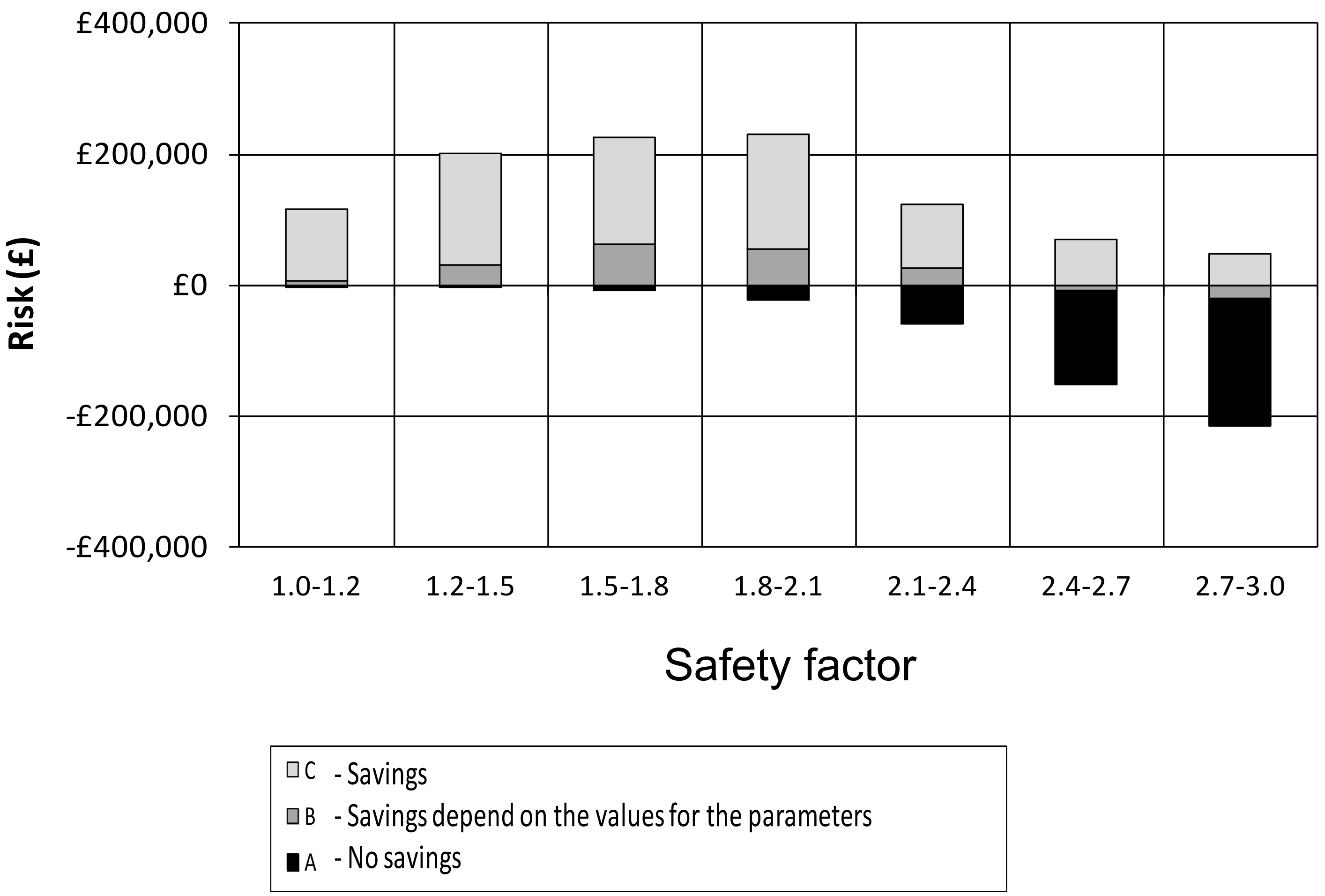
Life cycle savings by Full GSHP to full gas boiler& chiller



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Main conclusions (for the Oxford Building case)

- When GSHP performance is compared to the hybrid system the positive risk outweighs the negative one up to an SF of 2.4
- When comparing to a conventional gas-fired boiler and electrical chiller system, the saving largely outweighs risk up to an FS of 2.1. This suggests that even if the GSHP incorporates a redundancy of up to twice the design loads it is still more likely to yield savings over its lifetime
- A full-size GSHP with auxiliary back is potentially the most cost efficient configuration (ASHP might provide larger savings but at the same time there is a higher performance uncertainty).

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