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# Shallow Geothermal Energy: Technology and Evolution

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# Contents

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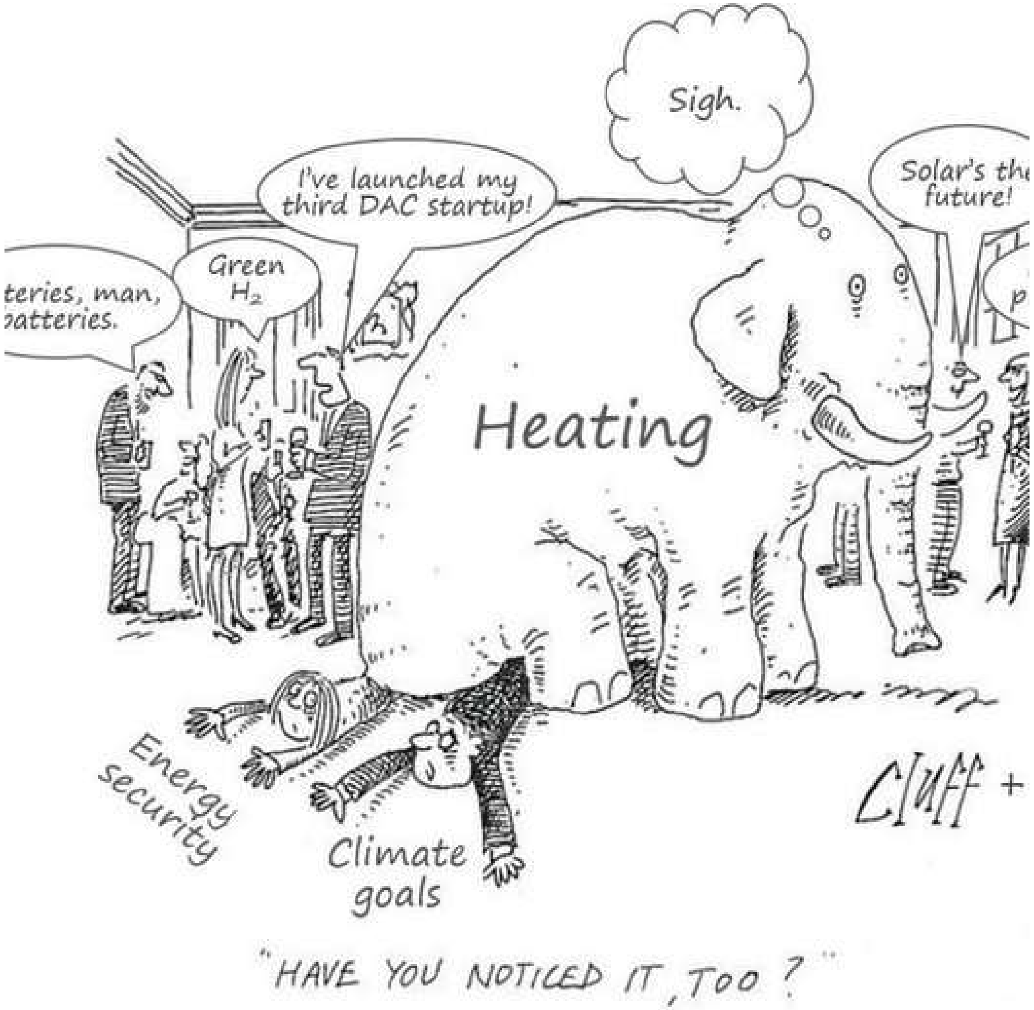
# Background & The Energy System



# How to we Heat Buildings?

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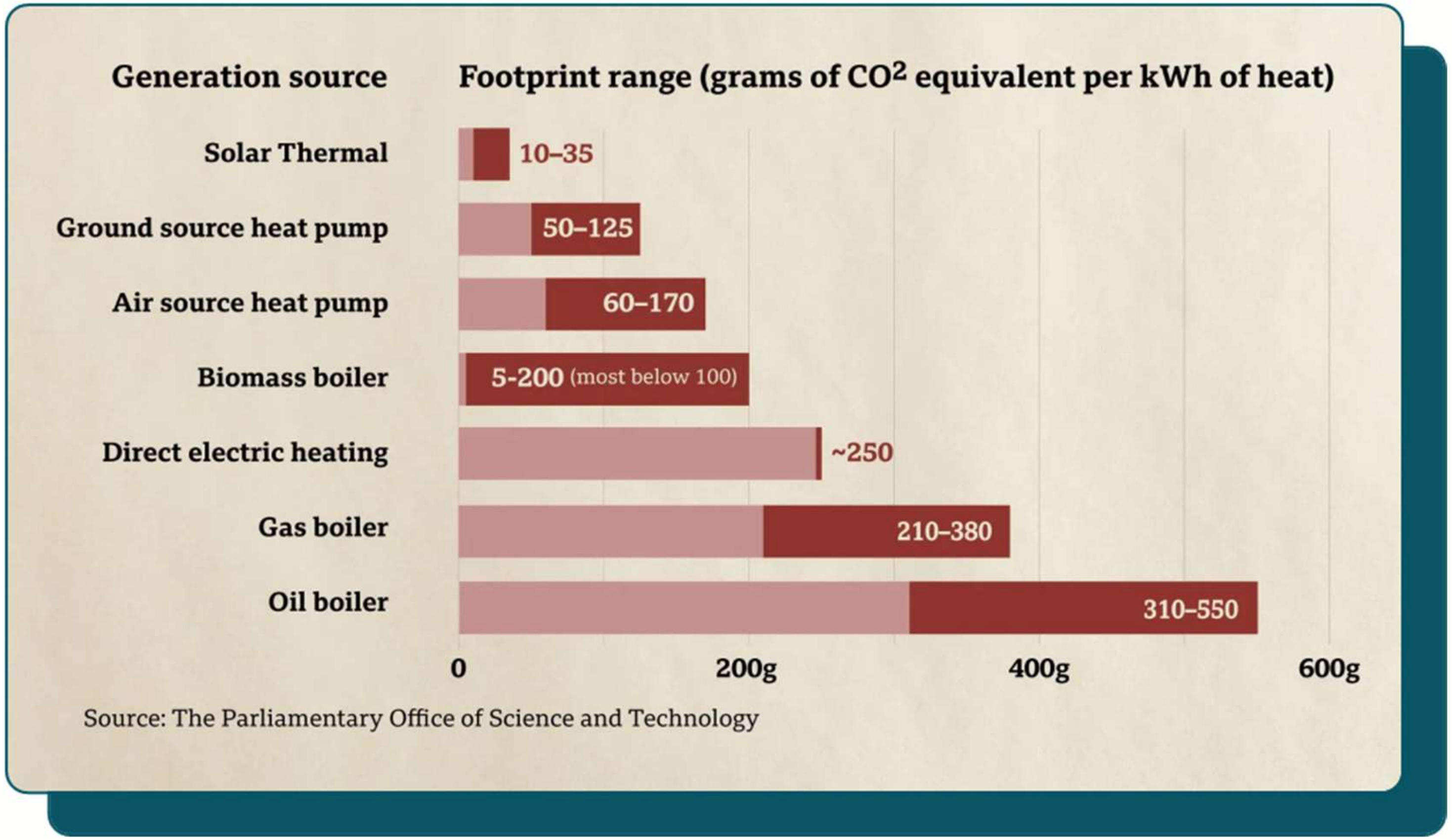


*BBC News, 2023*

**Grid carbon yesterday: 171 gCo2/kWhr**

**(it was zero earlier this week and for 87 hrs this yr)**

**Gas:**

- **35% of power;**
- **81% of emissions**

https://dashboard.neso.energy/

# For a Single House

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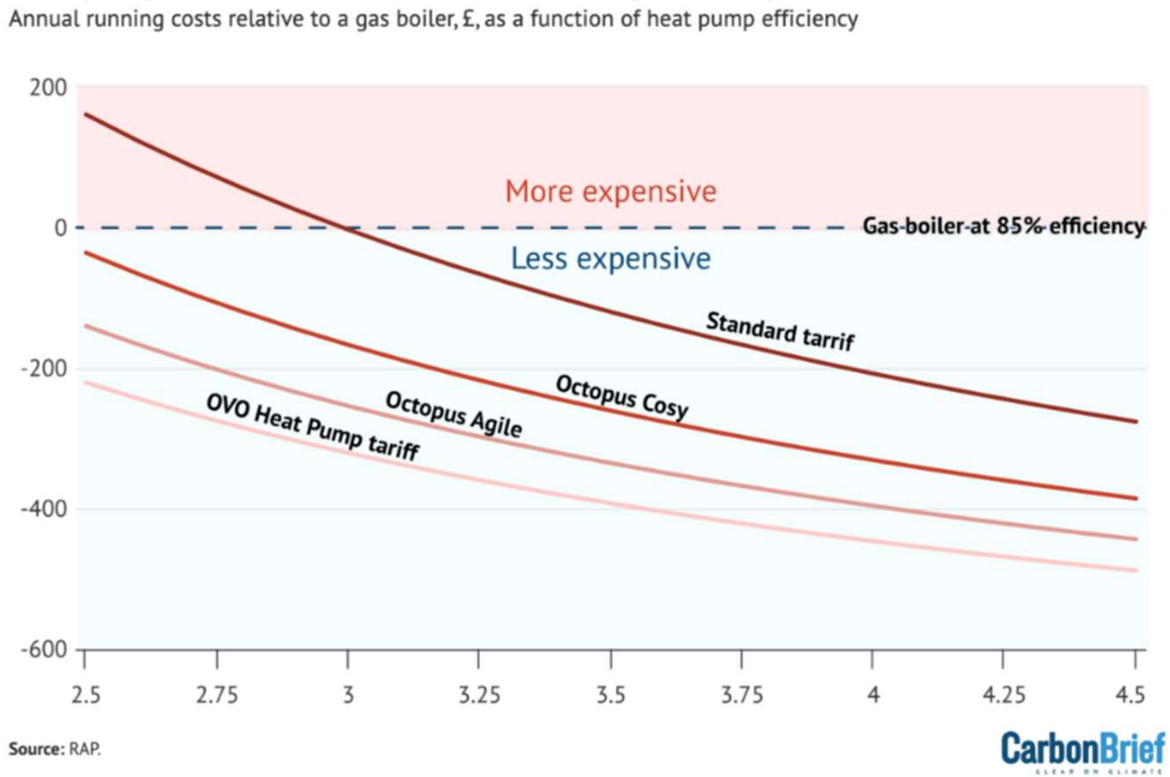
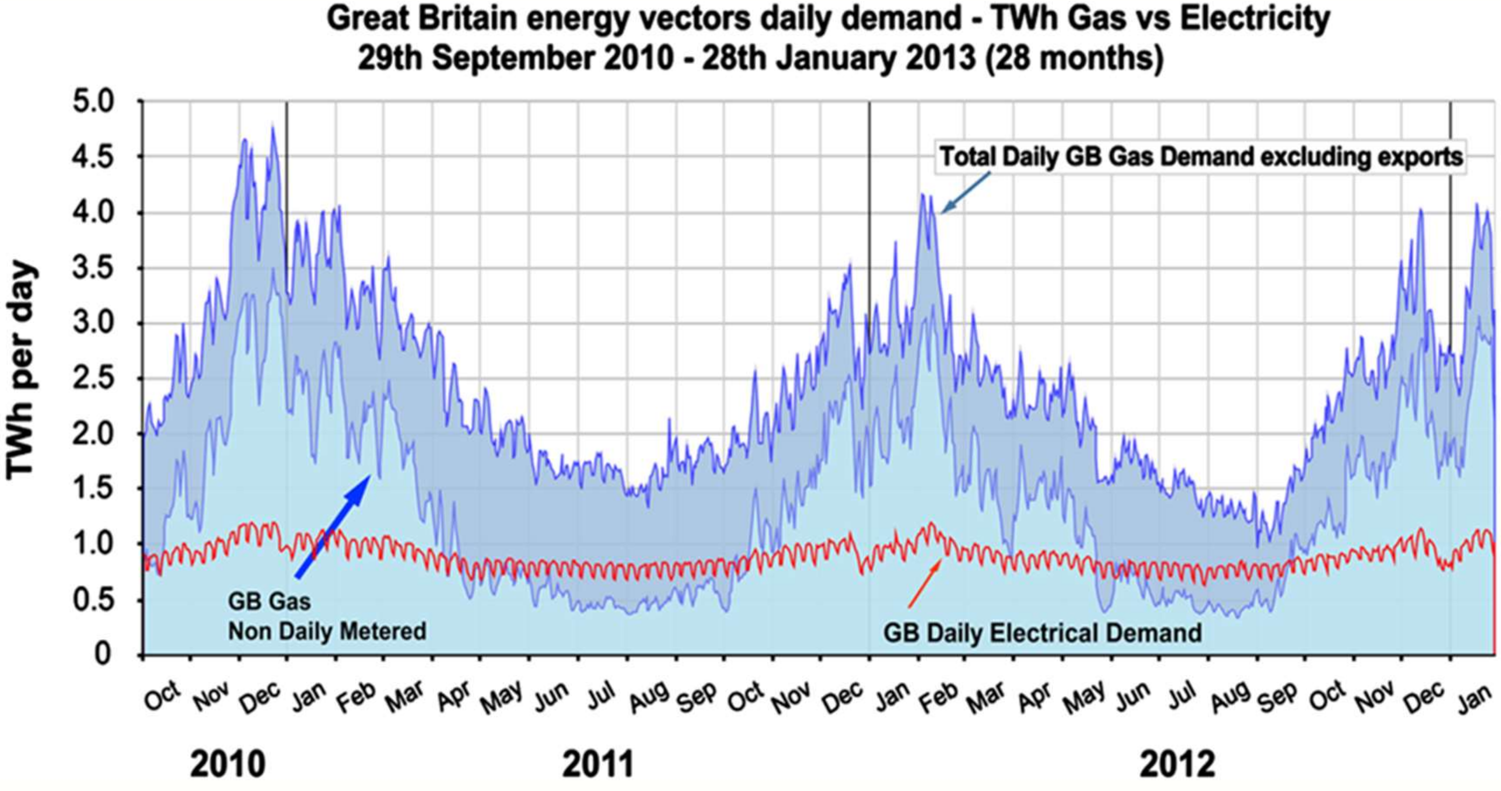
- Air Source Heat Pumps have high capex, e.g. min €6,000 to €18,000 for domestic scale
- Lower Opex dependent on elec/gas price ratios (spark gap) and efficiency
- Ground source heat pump vs air source heat pump
  - More expensive again
  - Greater efficiency
  - Can be used for cooling/storage
  - Implications for grid demand & electricity infrastructure




Annual running cost of heat pumps and gas boilers, £, as a function of system efficiency, SCoP. Gas boilers and heat pump standard tariff use the April-June 2024 price cap. Figure based on an earlier methodology updated with the latest energy price data. Source: RAP.

# The Energy System






*Wilson et al, 2013. Historical daily gas and electrical energy flows through Great Britain's transmission networks and the decarbonisation of domestic heat. Energy Policy 61, 301–305.*

## The Energy System

- Grid constraints
  - The physical limit to the amount of power that can be safely transmitted
  - Need to grid reinforcement
  - First come first serve for new connections
- Curtailment
  - Can't get wind energy to centres of demand due to constraints
  - We pay to stop generation


https://archy.deberker.com/the-uk-is-wasting-a-lot-of-wind-power/

# The Energy System

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- Grid constraints
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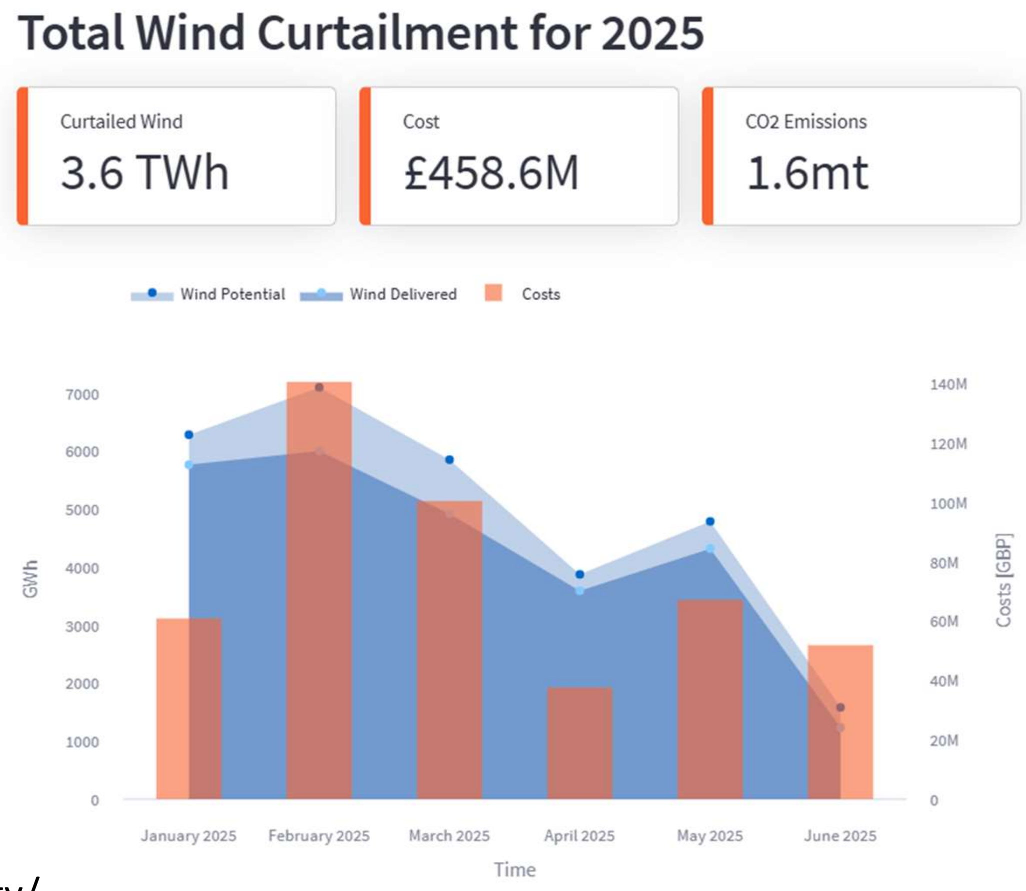


https://wind.axle.energy/

# Advantages of Ground Source Heat Pumps

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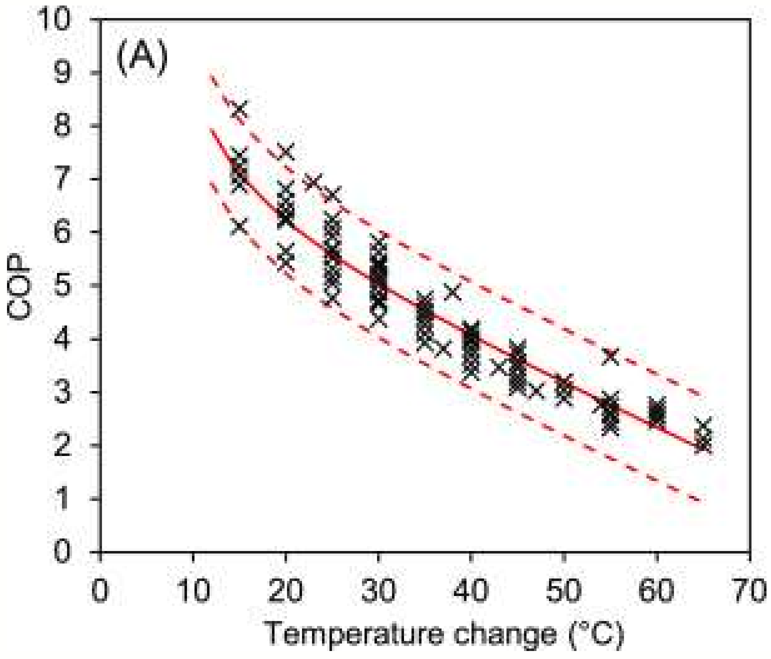
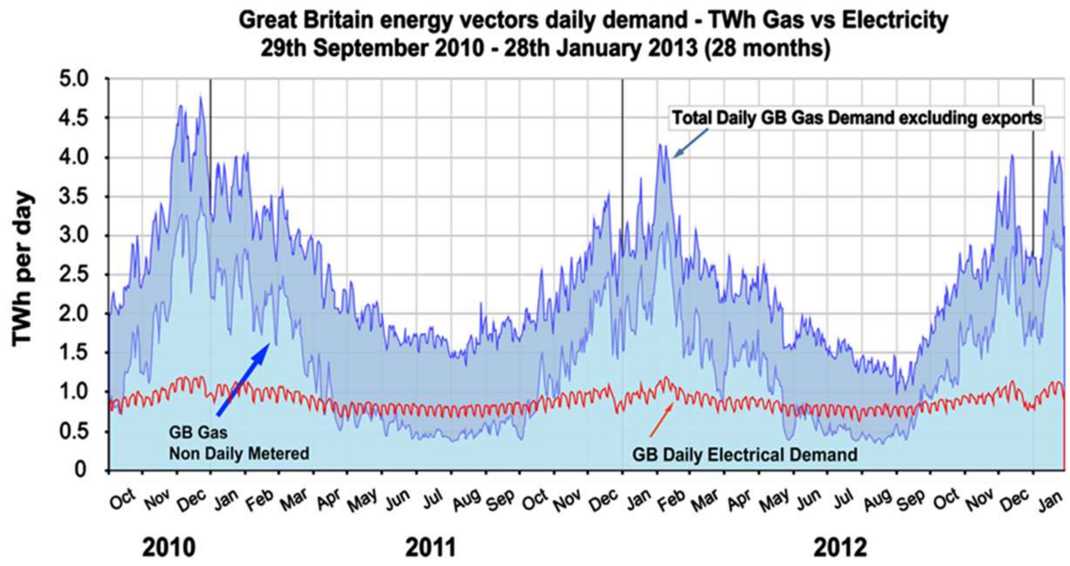
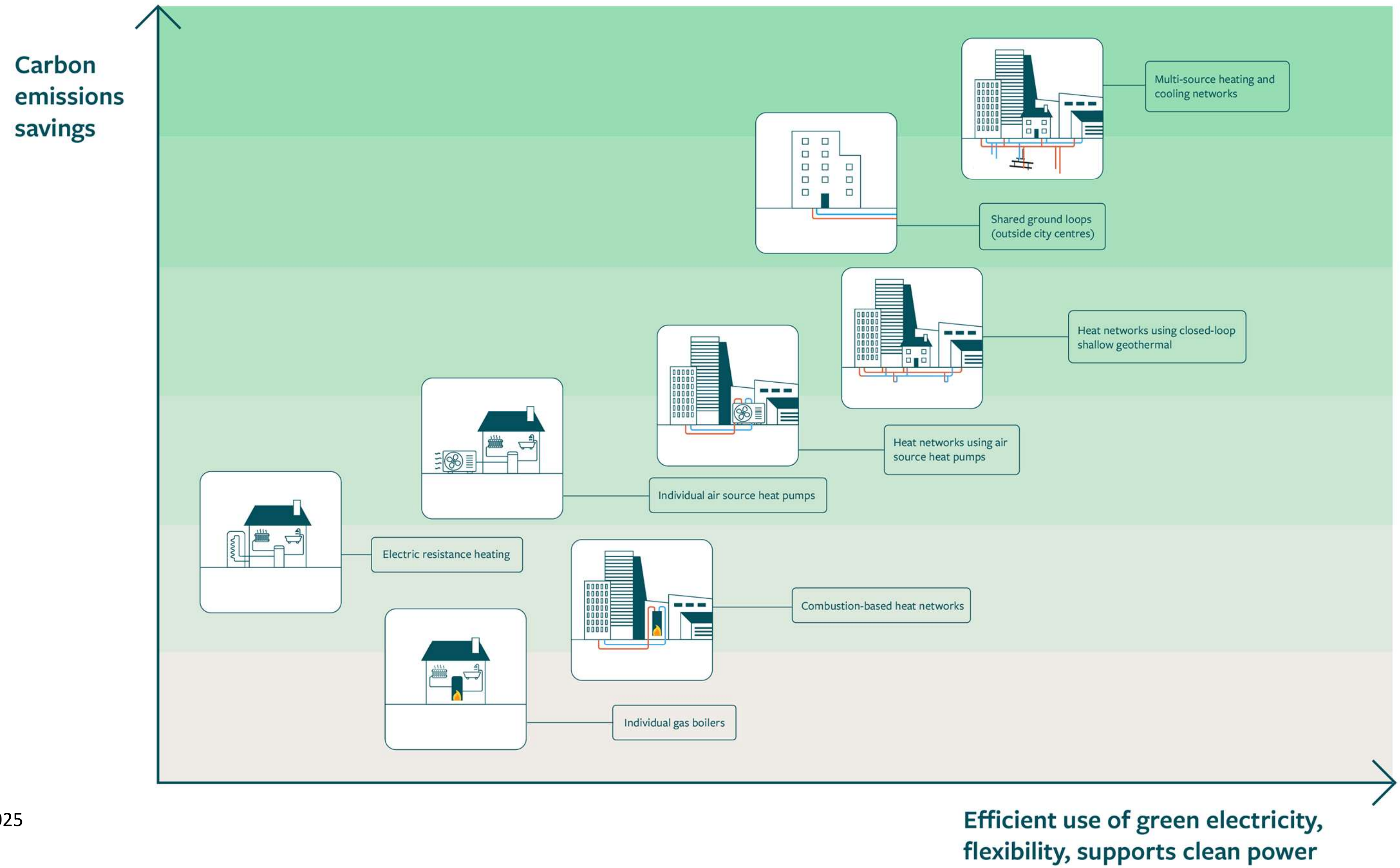
- Efficiency
- Storage
- Flexibility




Jackson et al, 2024 https://doi.org/10.1016/j.apenergy.2024.124096



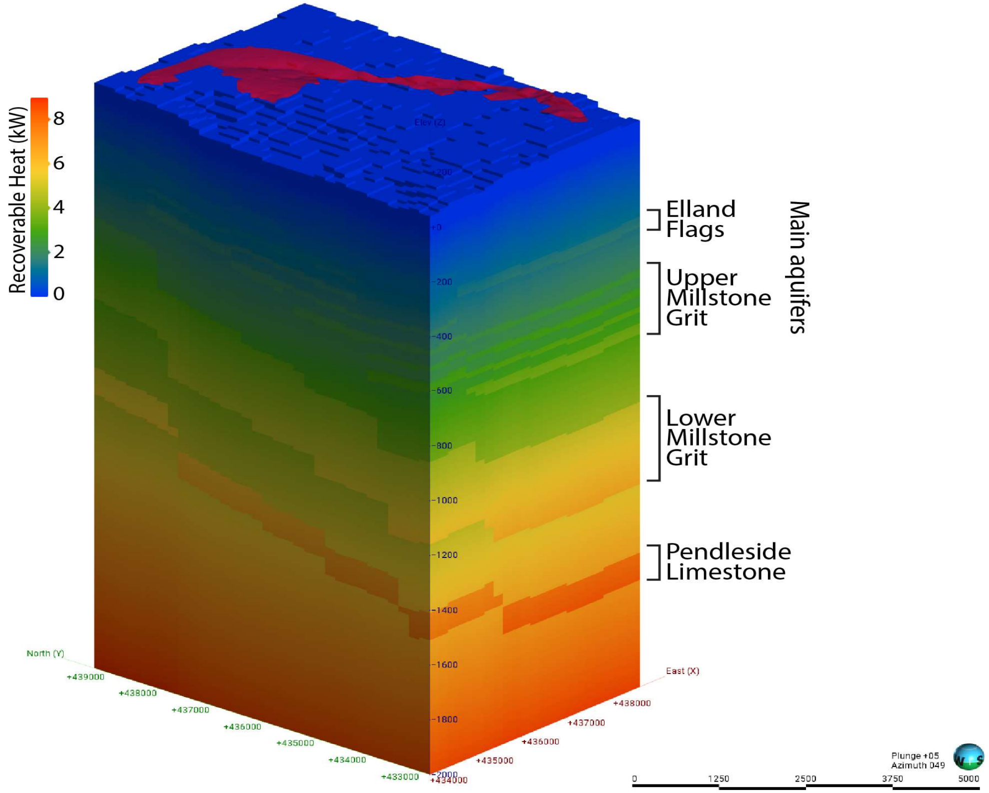

*Wilson et al, 2013. Historical daily gas and electrical energy flows through Great Britain's transmission networks and the decarbonisation of domestic heat. Energy Policy 61, 301–305.*

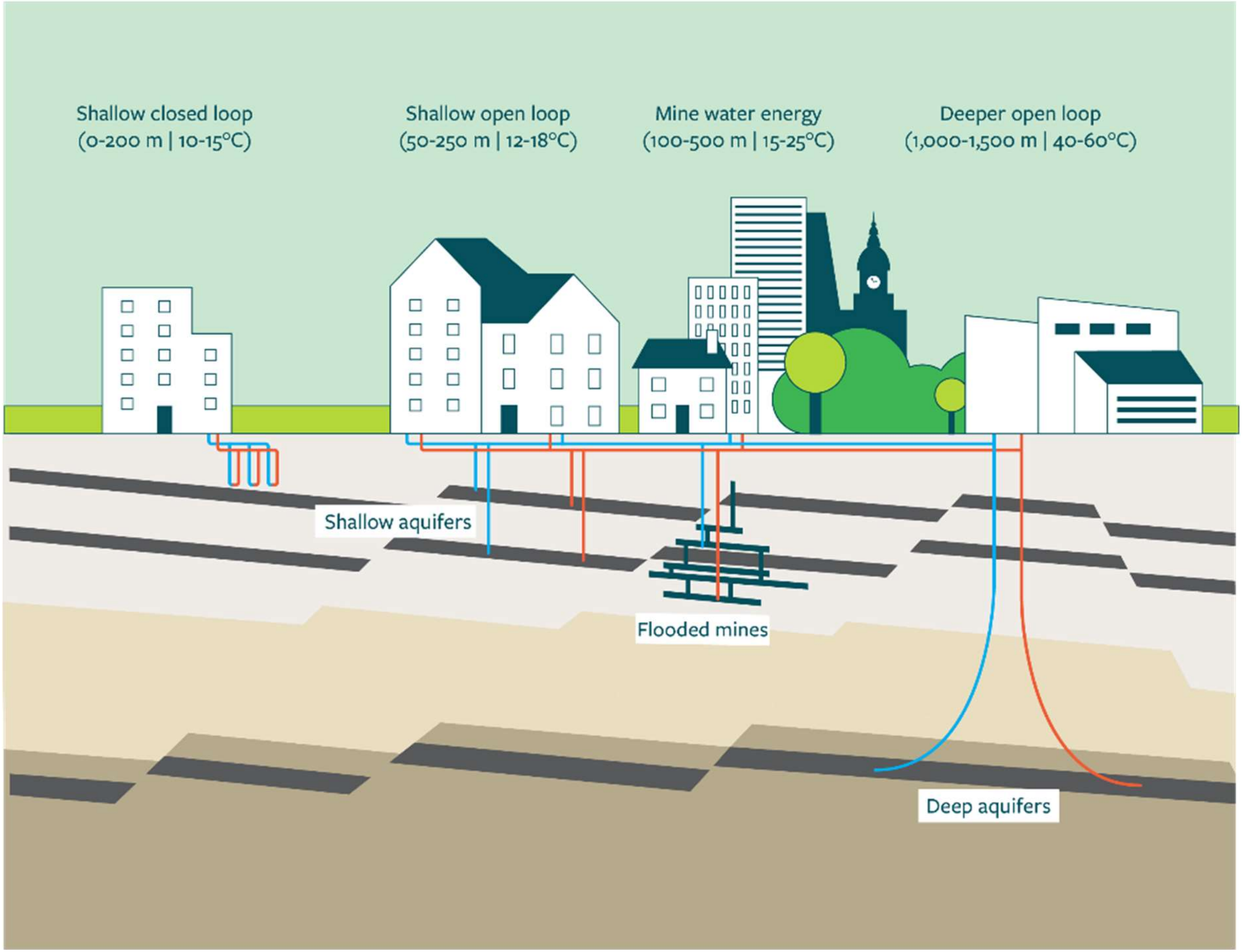



Barns et al, 2025

# Shallow Geothermal Energy

B: Recoverable Heat model




Shallow closed loop
(0-200 m | 10-15°C)
Shallow open loop
(50-250 m | 12-18°C)
Mine water energy
(100-500 m | 15-25°C)
Deeper open loop
(1,000-1,500 m | 40-60°C)
Shallow aquifers
Flooded mines
Deep aquifers

# Concepts: storage vs extraction



Not an unlimited supply of shallow geothermal energy

- Source: environmental interactions at shallow depth; geothermal flux at greater depth
- Natural recharge of heat in the summer; OR
- Engineered recharge:
  - Inter-seasonal storage - balance of heating and cooling
  - Solar thermal collectors to aid recharge
- High efficiencies if work in terms of storage

# Concepts: do you need a heat pumps?



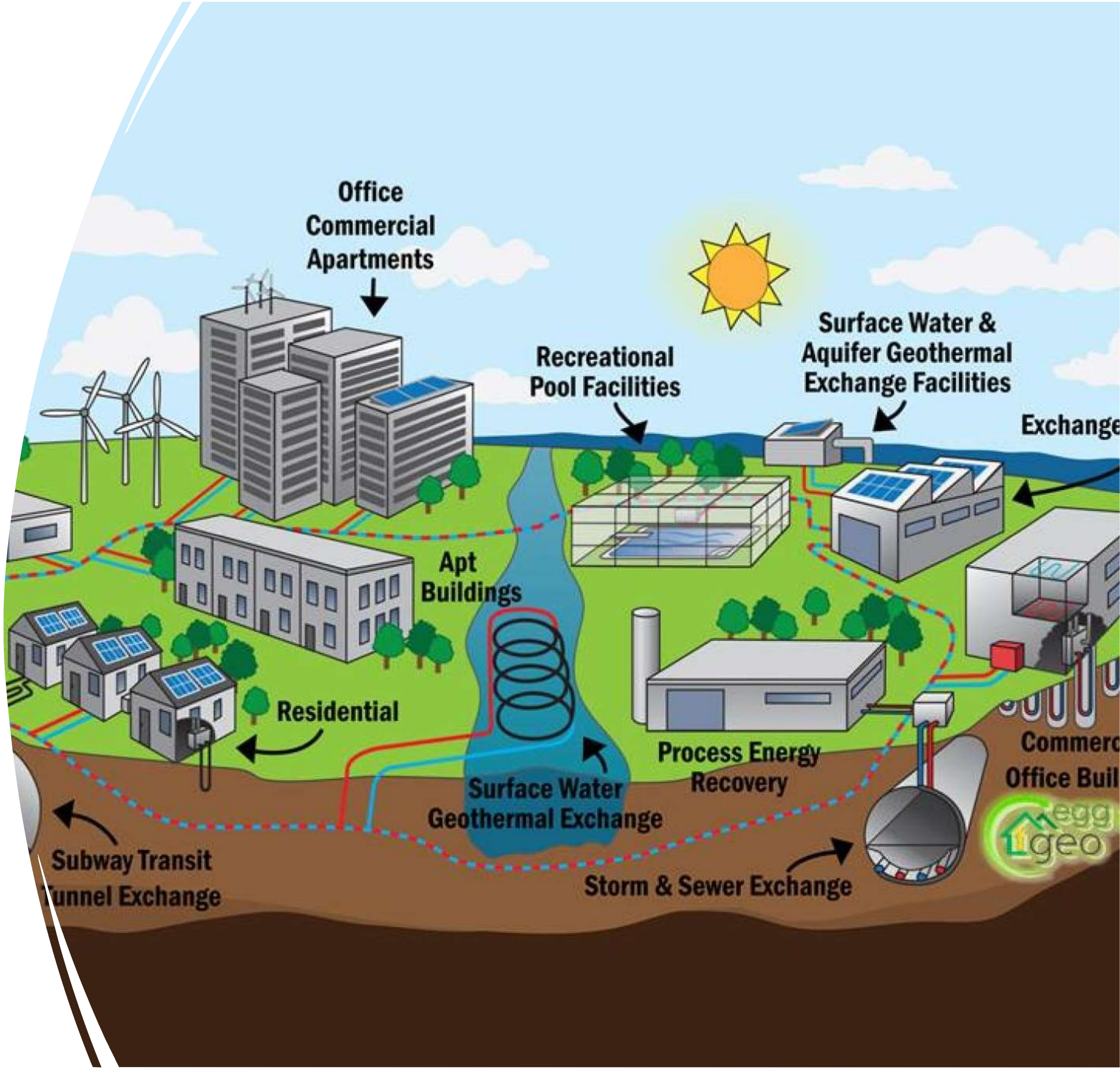
Heat pumps allow a change in temperature to be achieved by input of electrical energy

- If the source is cold or hot enough can be used directly without a heat pump
- Higher efficiencies
- Most commonly for cooling – “free cooling”
- Deeper higher temperature “direct use”
- Works best with low temperature heating or higher temperature cooling

Best efficiencies

- Balance heating and cooling
- Large temperature difference between source and use

# Energy Geostructures: Challenges and Opportunities




https://www.nationalgeographic.com/environment/great-energy-challenge/2013/10-myths-about-geothermal-heating-and-cooling/

# Energy Geostructures & the Energy System



Energy Geostructures: where the ground heat exchanger part of a GSHP system is embedded in an engineering sub structure, e.g. foundation pile, retaining wall, tunnel etc.

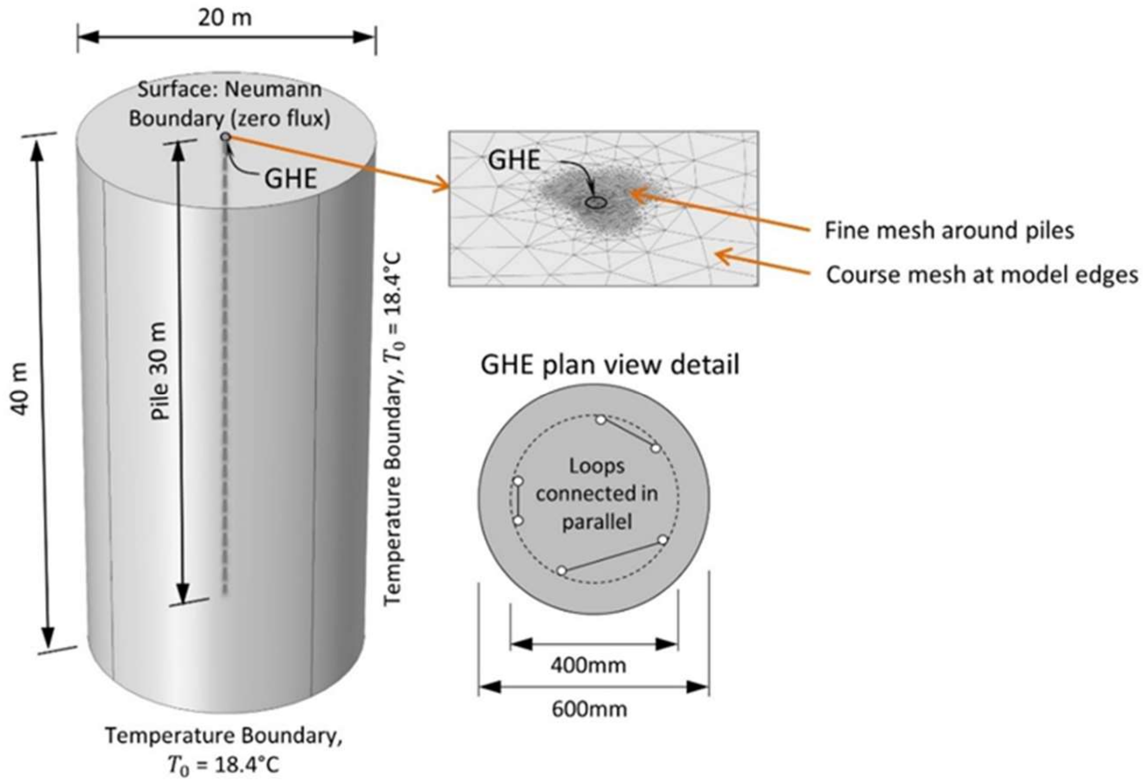
Role in the energy system:

1) Reduce up front costs
2) Delivering high efficiency / seasonal performance factor
   a) high source temperature
   b) other sources of heat
3) Integration
   a) Electricity system (reduced demand, reduced reinforcement needs)
   b) District heating (flexibility, efficiency)
   c) Other renewables (reduce curtailment, other storage)

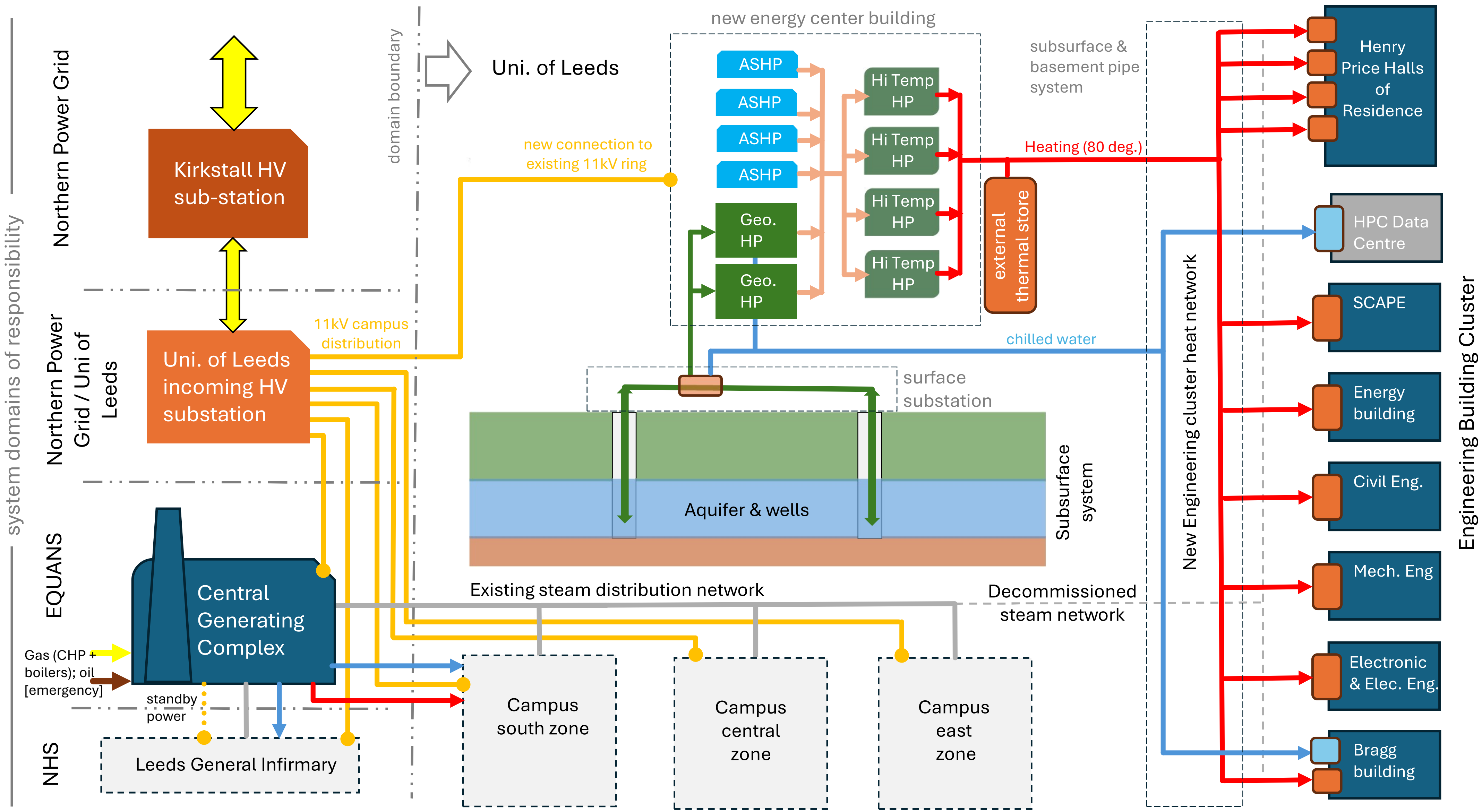
# Need for Analytical Models



- Analysis aim – energy available within temperature limits
- Numerical models shown to capture thermal behaviour really well, e.g.
  - Pile geometry detail
  - Non homogenous ground conditions
- But system design often deals with hourly time steps over decades
  - Computational expense




Jensen-Page, Loveridge, Narsilio, 2019 doi:10.3390/en12142700



system domains of responsibility
Northern Power Grid
Northern Power Grid / Uni of Leeds
EQUANS
NHS
Kirkstall HV sub-station
Uni. of Leeds incoming HV substation
11kV campus distribution
Central Generating Complex
Gas (CHP + boilers); oil [emergency]
standby power
Leeds General Infirmary
domain boundary
Uni. of Leeds
new connection to existing 11kV ring
new energy center building
ASHP
ASHP
ASHP
ASHP
Geo. HP
Geo. HP
Hi Temp HP
Hi Temp HP
Hi Temp HP
Hi Temp HP
external thermal store
subsurface & basement pipe system
Heating (80 deg.)
chilled water
surface substation
Aquifer & wells
Subsurface system
Existing steam distribution network
Decommissioned steam network
Campus south zone
Campus central zone
Campus east zone
New Engineering cluster heat network
Henry Price Halls of Residence
HPC Data Centre
SCAPE
Energy building
Civil Eng.
Mech. Eng
Electronic & Elec. Eng.
Bragg building
Engineering Building Cluster

# Integration with the system

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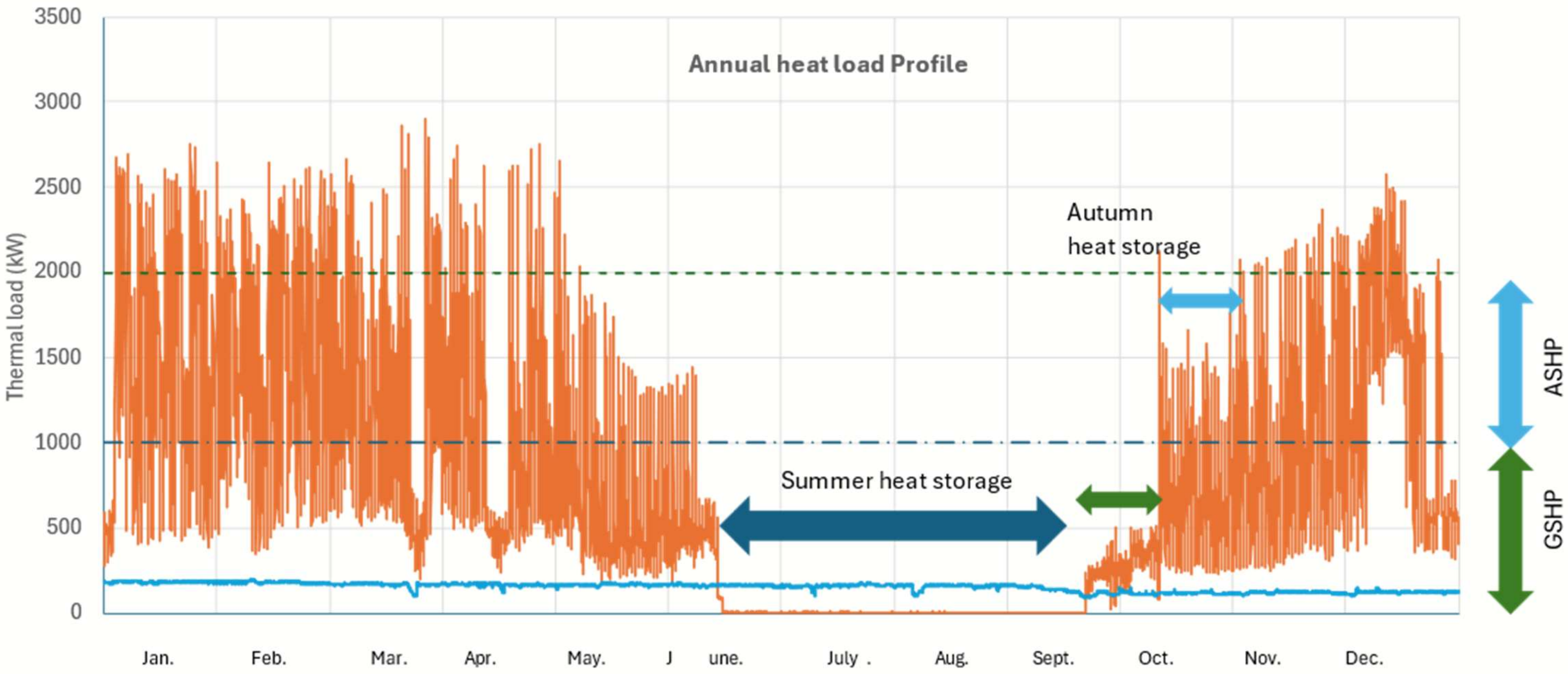
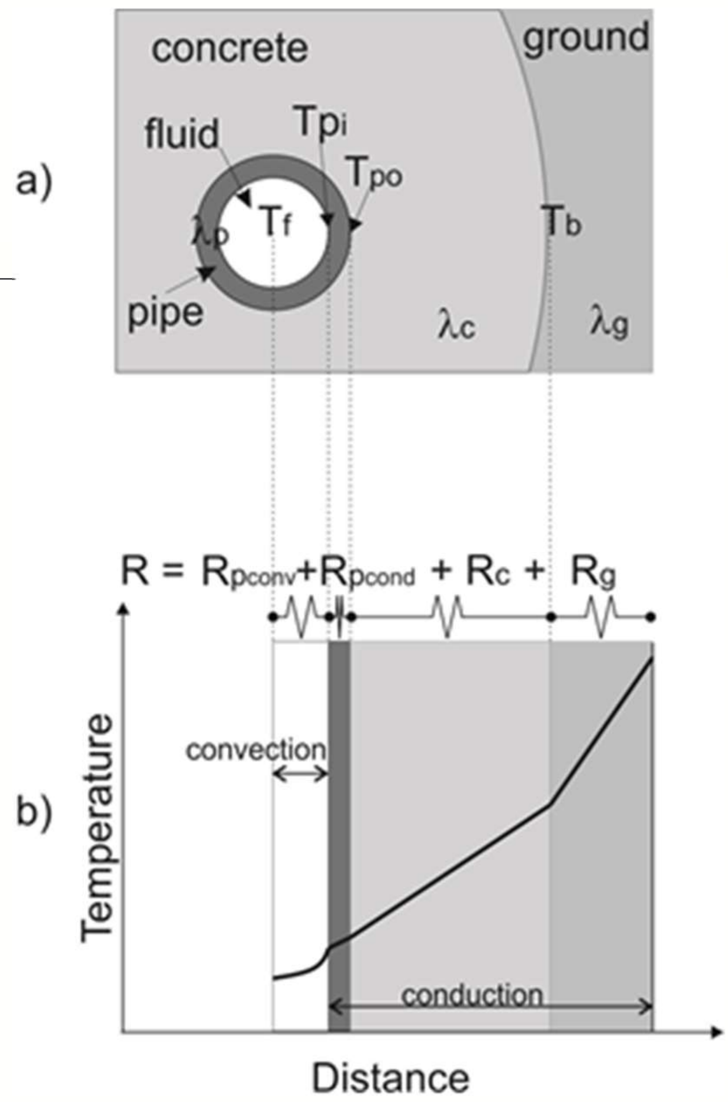


# Traditional Step Response Approach: Piles

Superposition of

- Transient thermal response in the ground
- Temperature change across the heat exchanger (steady?)

- Time varying demand (temporal superposition)
- Multiple piles (spatial superposition)



# Traditional Step Response Approach: Piles

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Classic analytical models for ground response adapted for piles

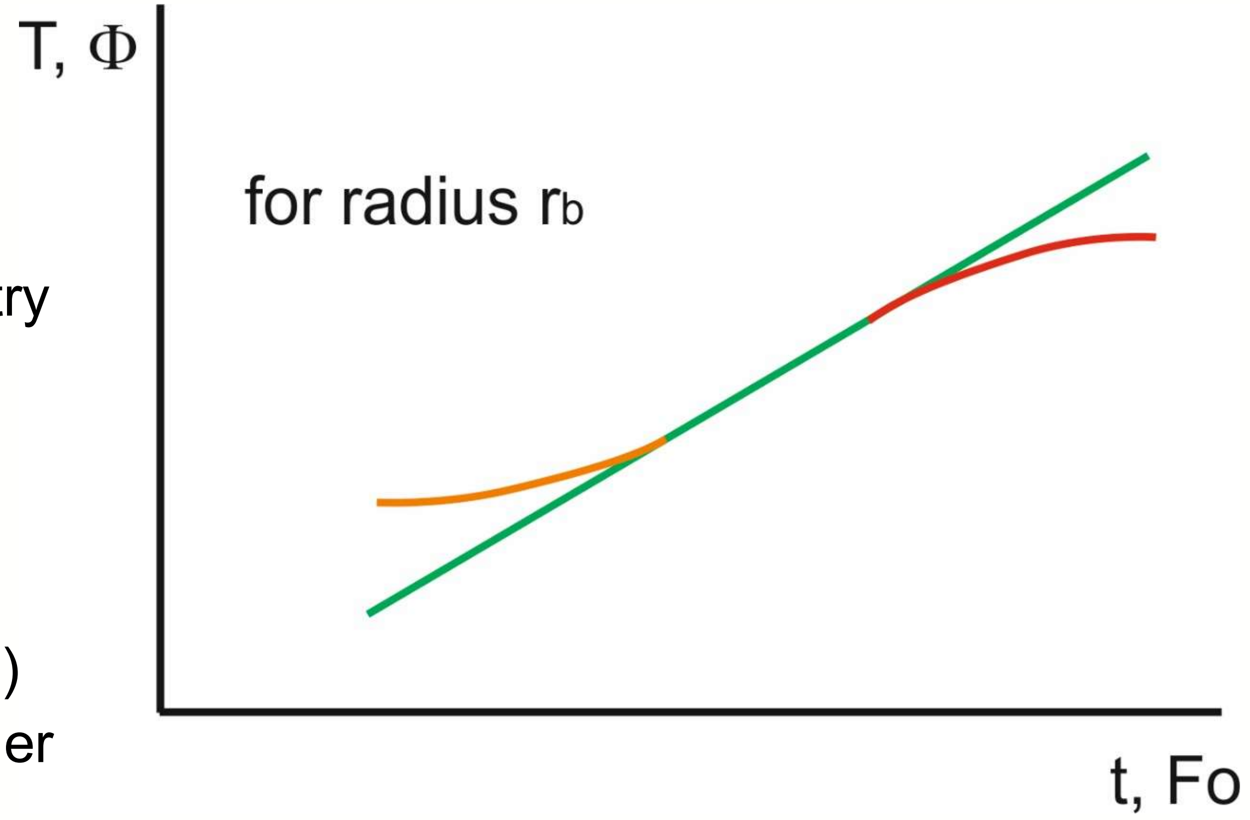
- Infinite line source
- Finite line source

Short term dependent on pile geometry details

Long term dependent on

- Pile aspect ratio
- Open to air (tests, piled walls ?)
- Insulated head (beneath a building)

Longer, thinner & insulated have higher temperature response



# Integration of piles – work still to do

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| Model | Ease of Use | Pile Specific Geometry | Pile Open to the Air | Pile Beneath a Building | Multiple Piles | Transient Pile Behaviour |
|---|---|---|---|---|---|---|
| Infinite Line Source | √√√ | x | xx | √√ | √√√ | NA |
| Infinite Cylindrical Source | √ | xx | xx | √√ | √√ | NA |
| Finite Line Source | √ | x | √√√ | xx | √√ | NA |
| Pile G-functions | √√ | √√ | √√√ | xx | x | NA |
| Semi-finite Cylindrical Source | √√ | xx | x | √√√ | x | NA |
| Transient Radial Model | √ | √√ | xx | √√ | √√ | √√√ |

# Step Response Approach for Walls

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Superposition of

- Transient thermal response in the ground
- Temperature change across the heat exchanger (steady?)

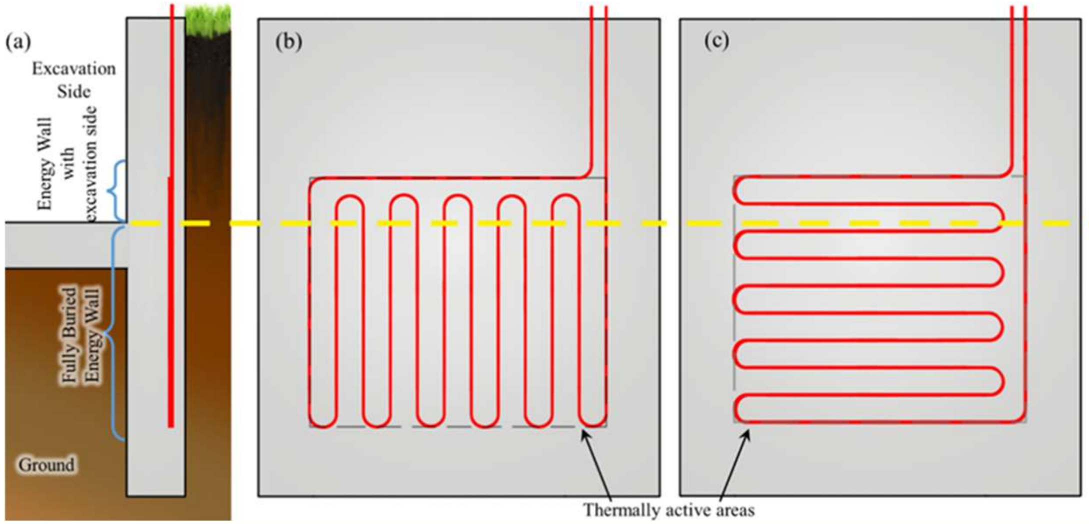
But no experience of classic analytical models for ground response

- Develop Infinite Plane Source

And no solutions for the wall itself

- Test and develop steady state solutions for wall

Challenge: part of wall exposed to the air




Gupta, 2024

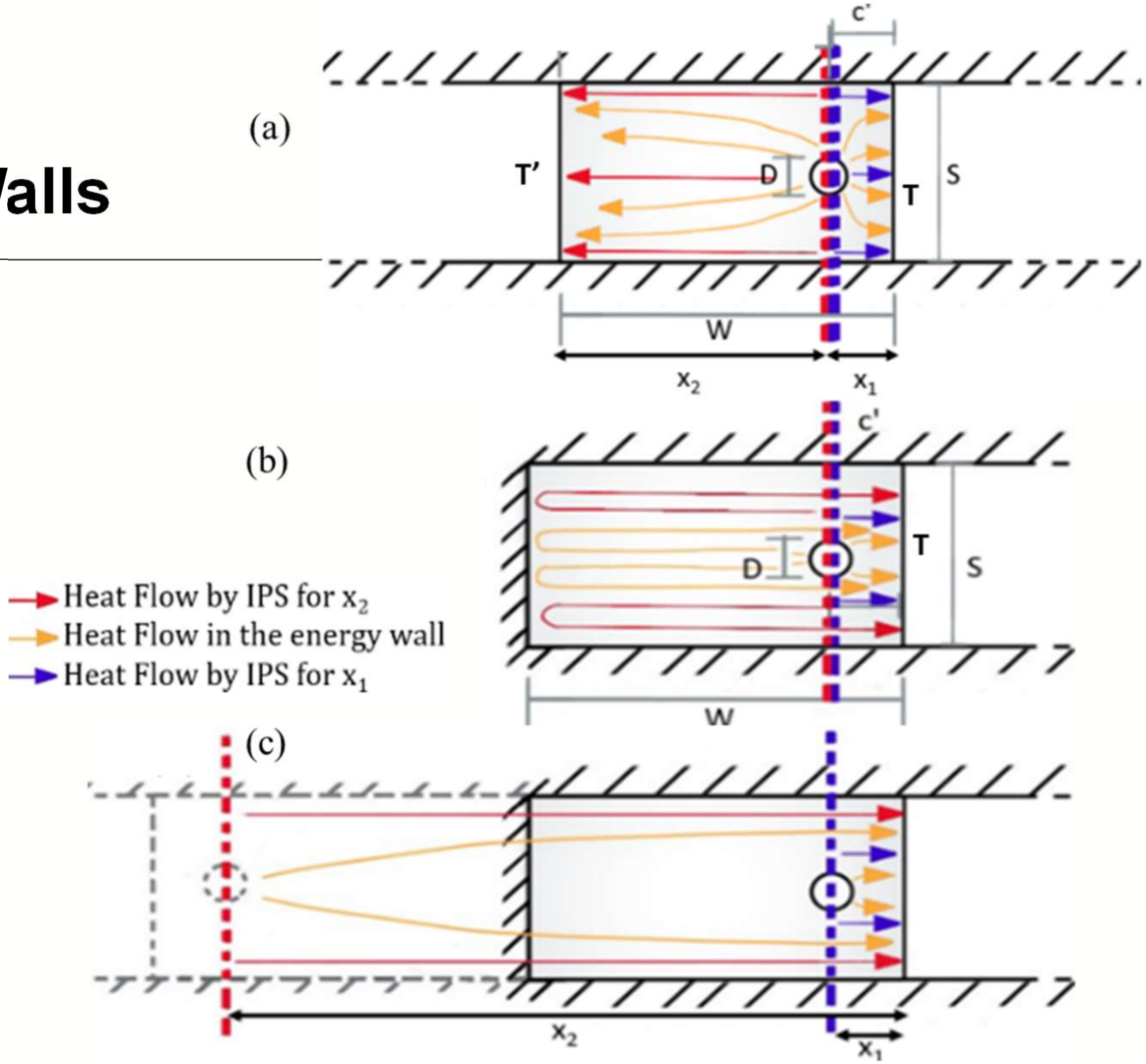
# Step Response Approach for Walls

Implementation of infinite plane source

- Calculate temperature on back of the wall
- Correction for short walls

Key assumptions:

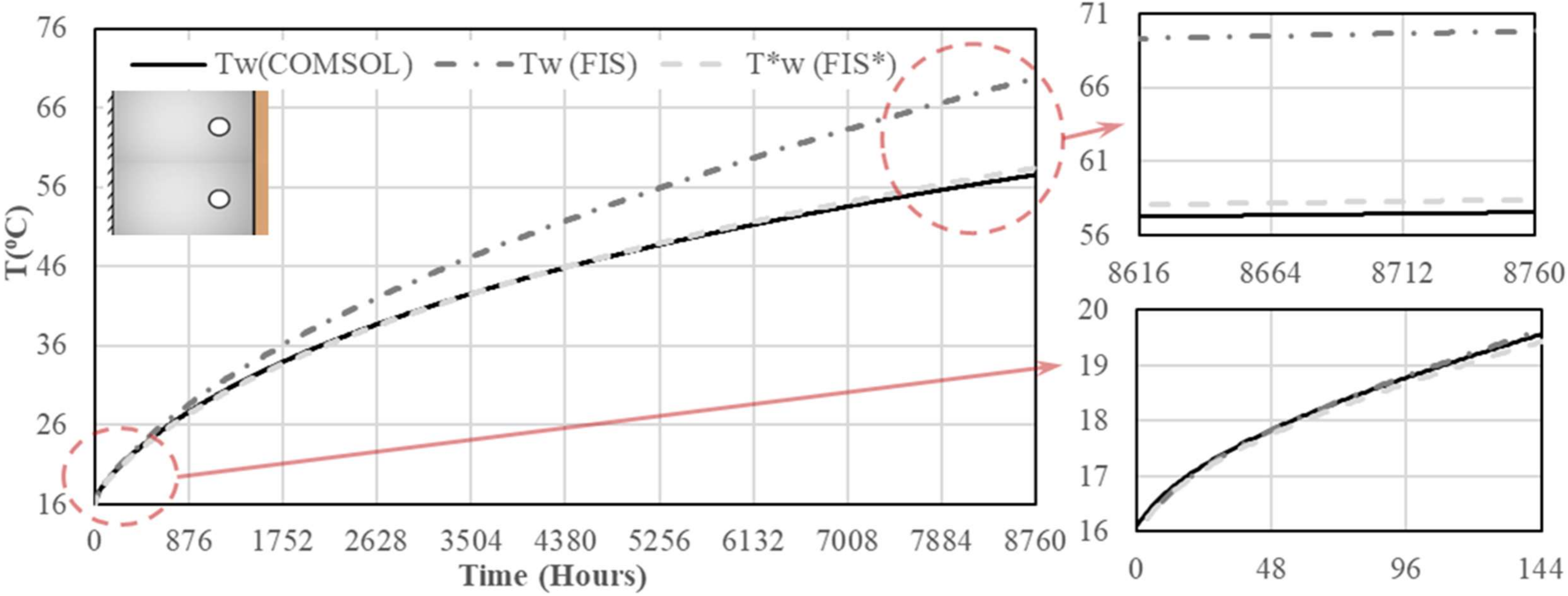
- Insulated wall (conservative)
- One row of pipes (but extension for two pipes is coming soon!)




Gupta, 2024

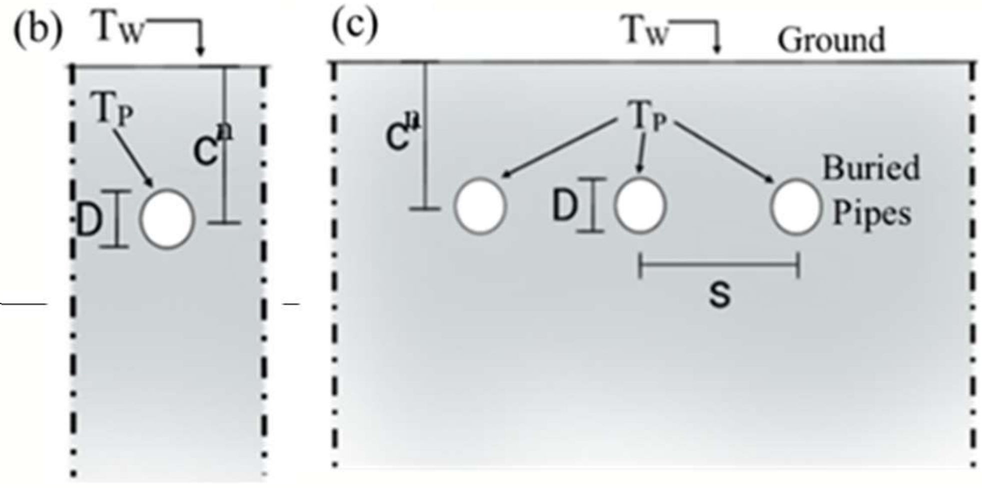
# Step Response Approach for Walls





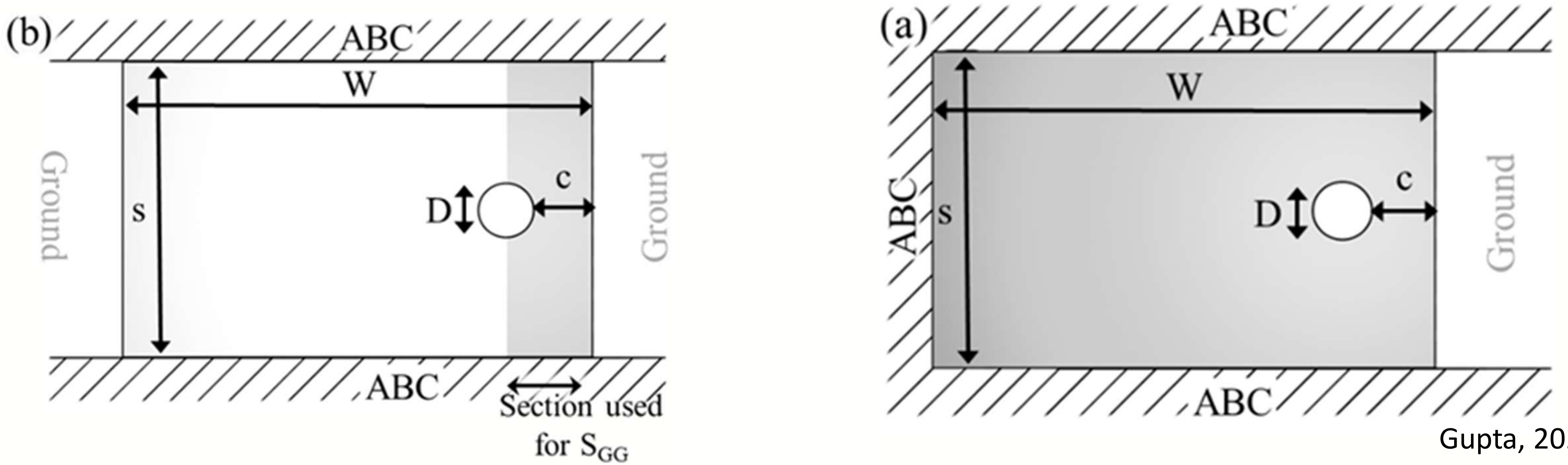

Gupta, 2024

# Step Response Approach for Walls




Steady state resistance model based on fuel pipelines

Key assumption: insulated wall




Gupta, 2024

# Step Response Approach for Walls

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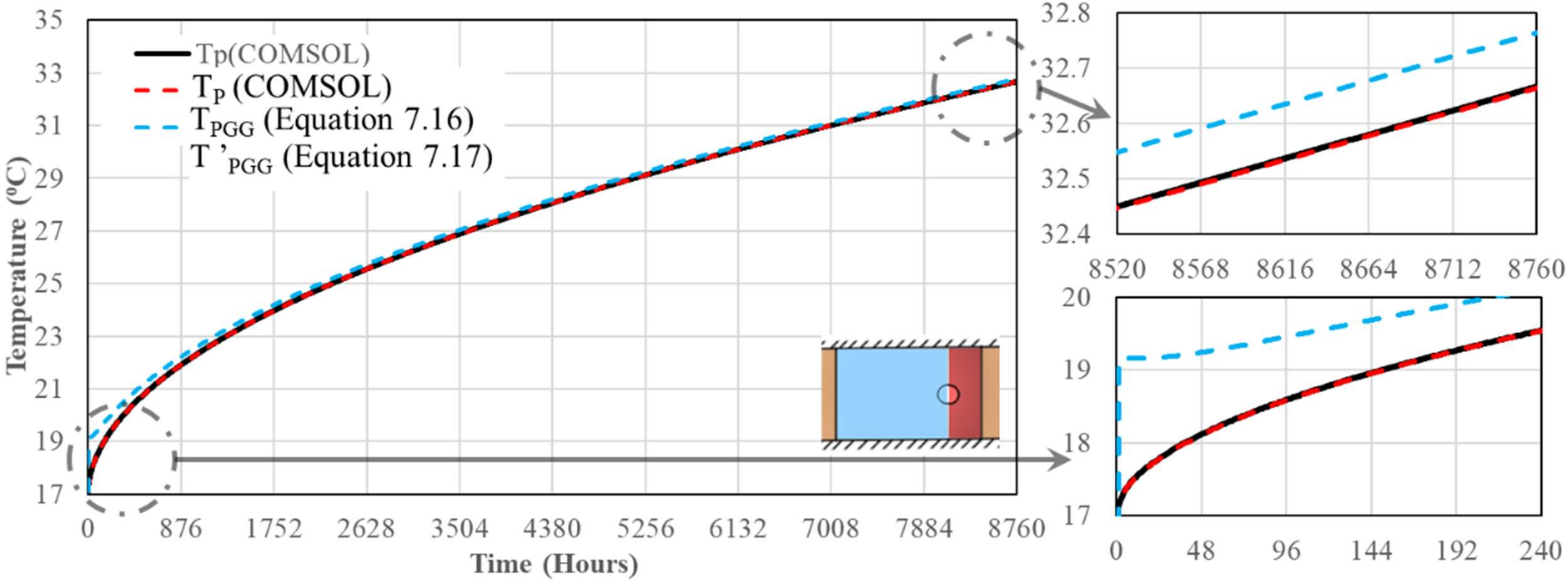


Gupta, 2024

# Validation

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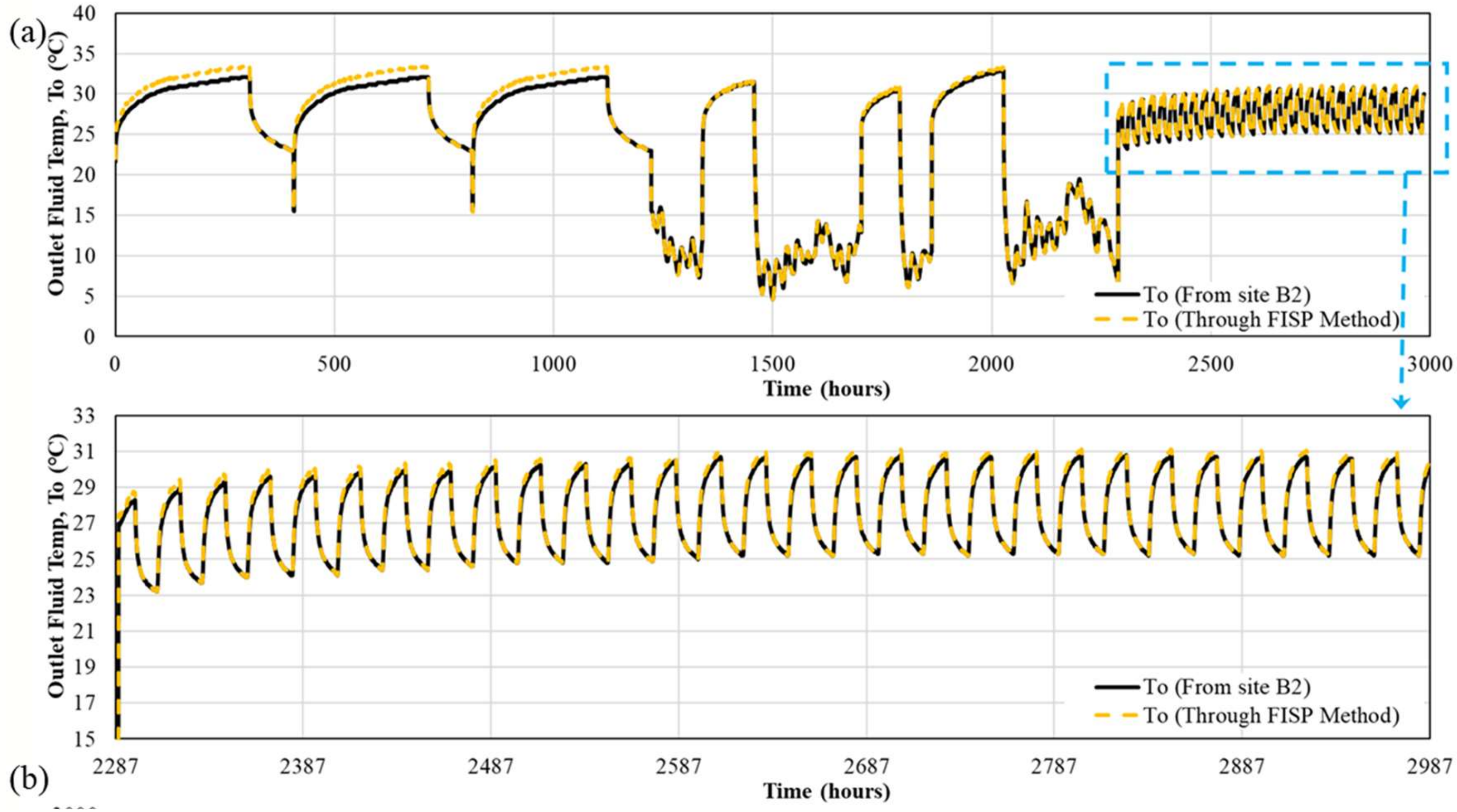
- Wall model relatively short term (4 months) field validation
- EPSRC-FAPESP project under way to build wall test site at University of Sau Paulo.




Gupta, 2024

# What next?

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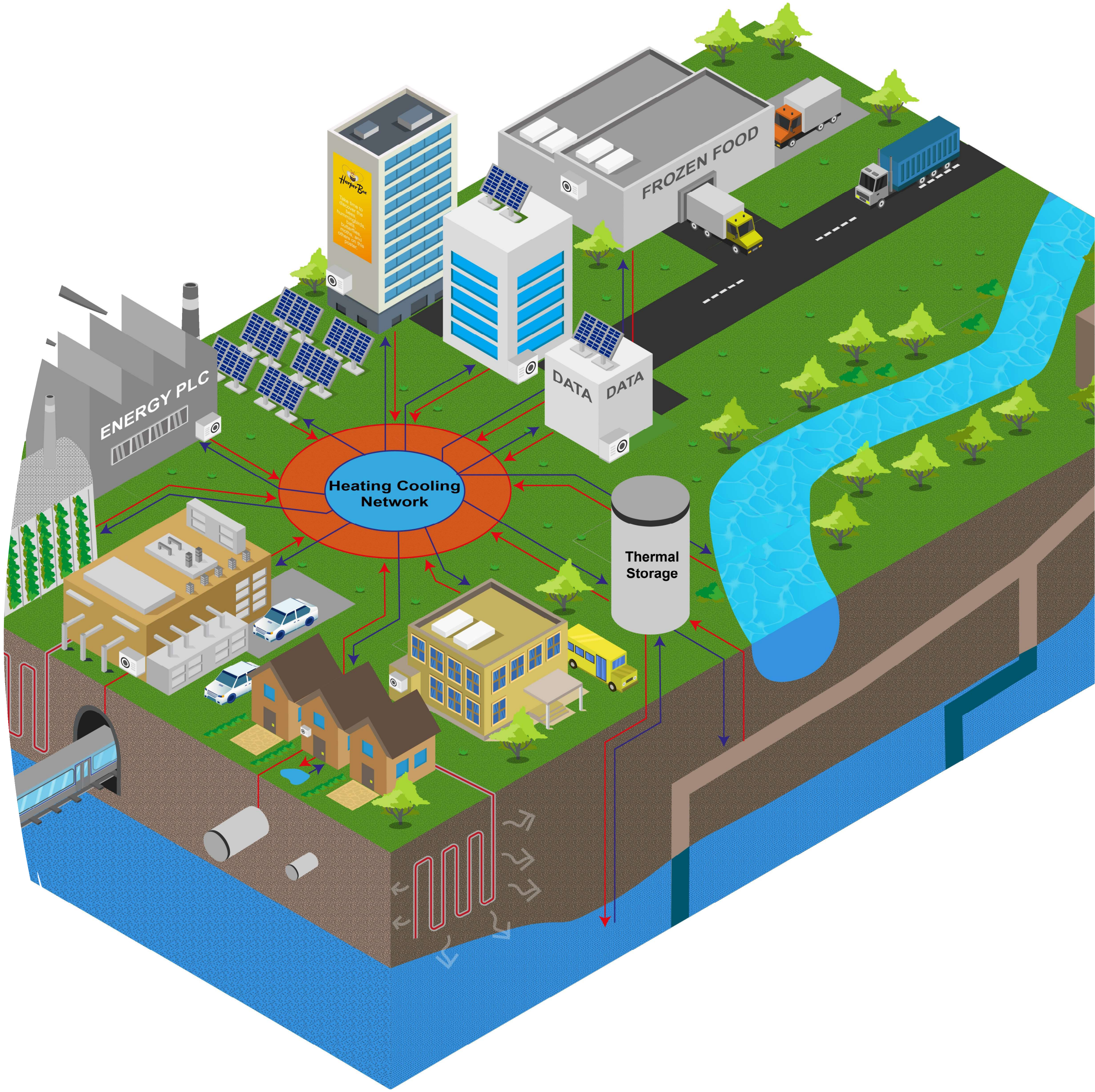
- Perfect is enemy of good enough – understand key processes & validate
- Then upscale to integrate and connect to the wider system
- Need to embrace our friends in mechanical and electrical engineering
- Lots of opportunities for innovation
  - Models need to account for internal boundary conditions (heat source!) in walls and tunnels
  - What about drainage and waste water systems?

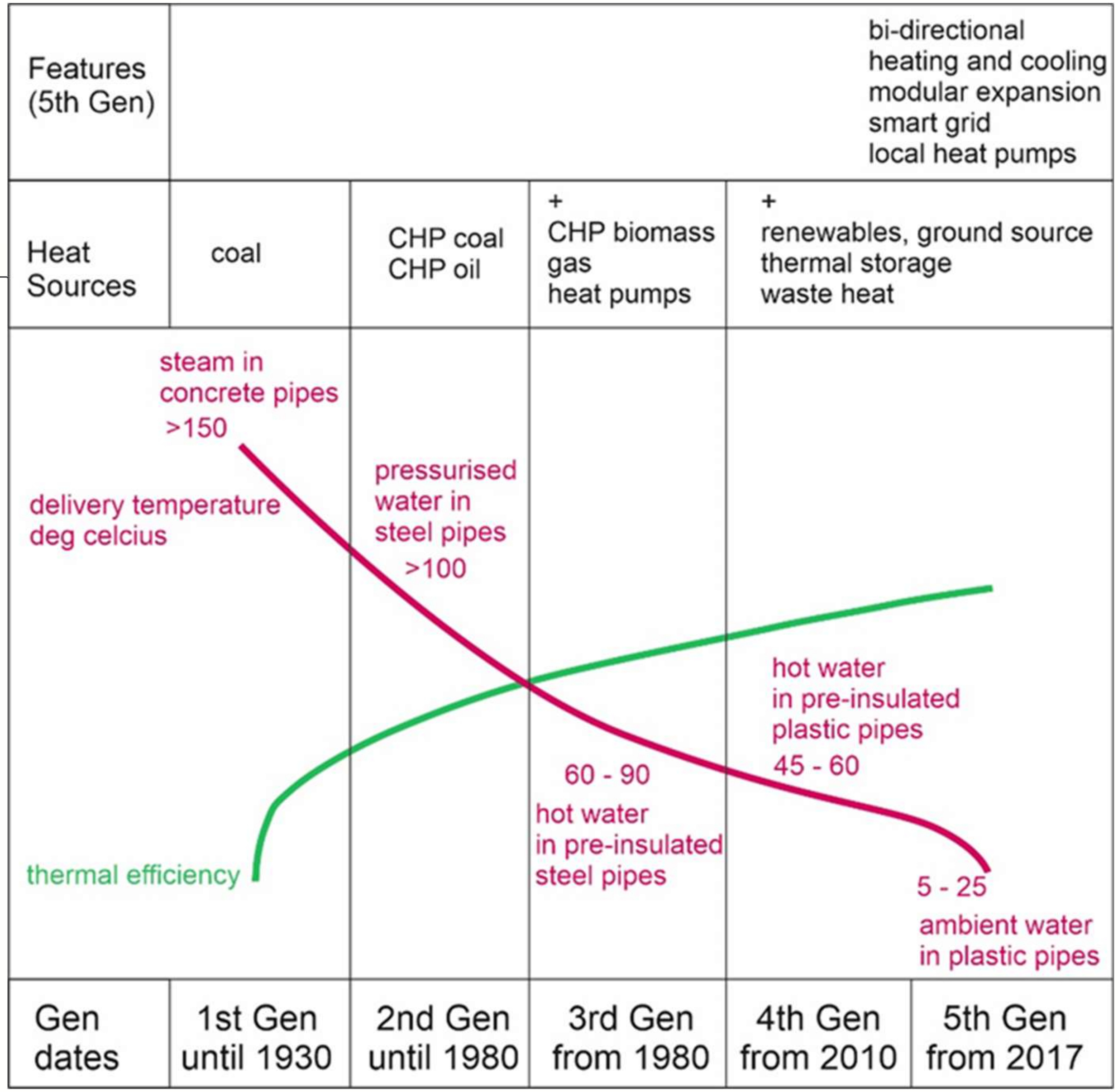
In the UK about 2/3 to 3/4 of domestic heat could come from waste water and surface water drainage system!

Two orders of magnitude more capacity than traditional energy geostructures

# Scale Up - District Heating

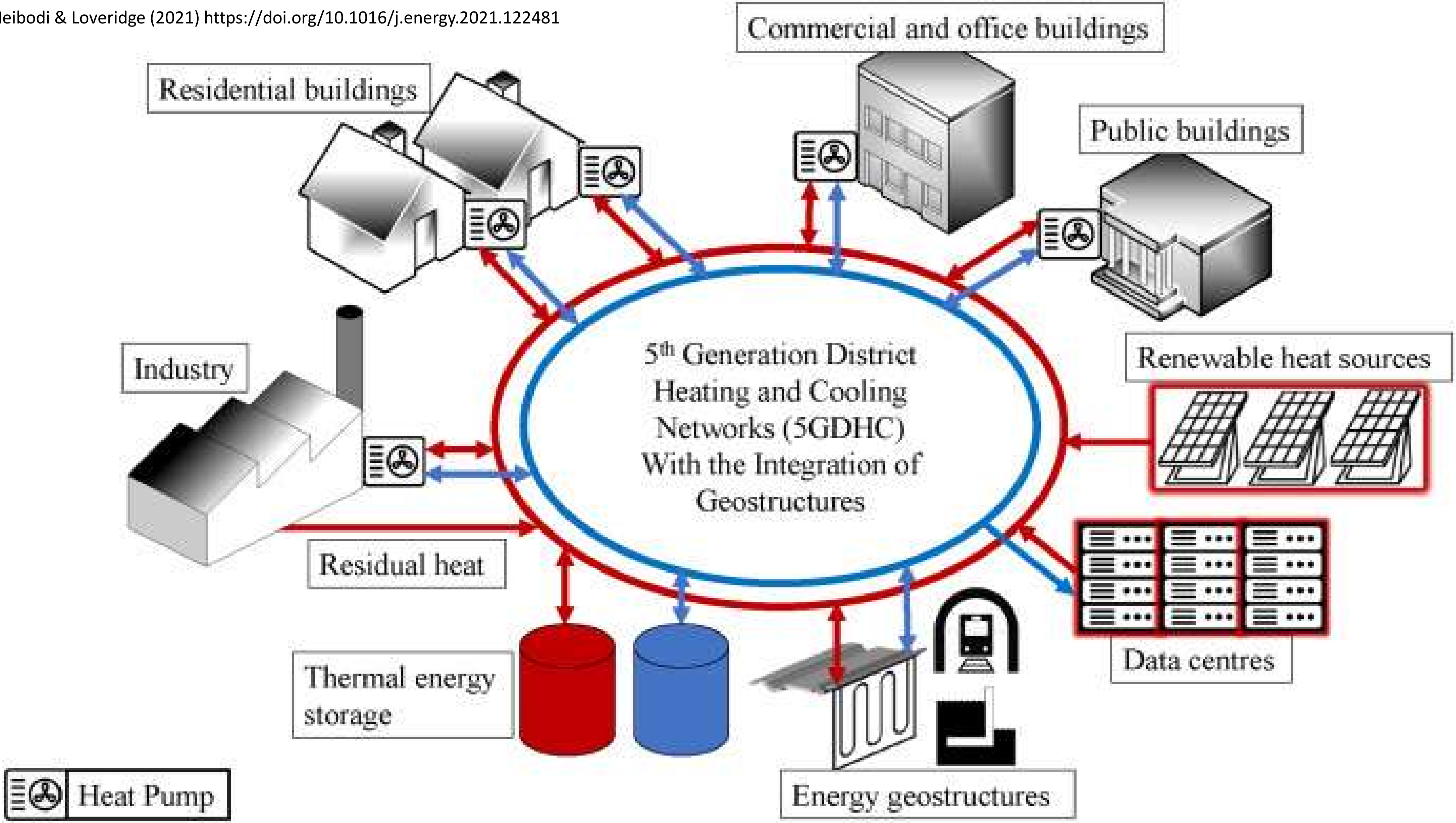


# District Heating




Evolution of District Heating Technology to 5th Generation, adapted and extended from Lund (2014)

Meibodi & Loveridge (2021) https://doi.org/10.1016/j.energy.2021.122481



# Offtakes and Social Value

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- Health Service Decarbonisation

- Affordable heating in social housing

# Costs Benefit Analysis Example

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## Additional costs

- Additional capital costs
  - Geothermal pipework
  - Installation costs during tunnel construction
  - Higher cost of GSHPs vs ASHPs
- Timing of investment
  - Tunnel design & construction, 2028-2034
  - Time value of money

## Benefits (self consumption)

- Higher efficiency GSHPs vs ASHPs (+ $CO_2$ savings)
- Lower electricity consumption

## Benefit not costed

- Availability of heat source
- Reduced demand for green electricity
- Social & Cash value to community

# Costs and business modelling

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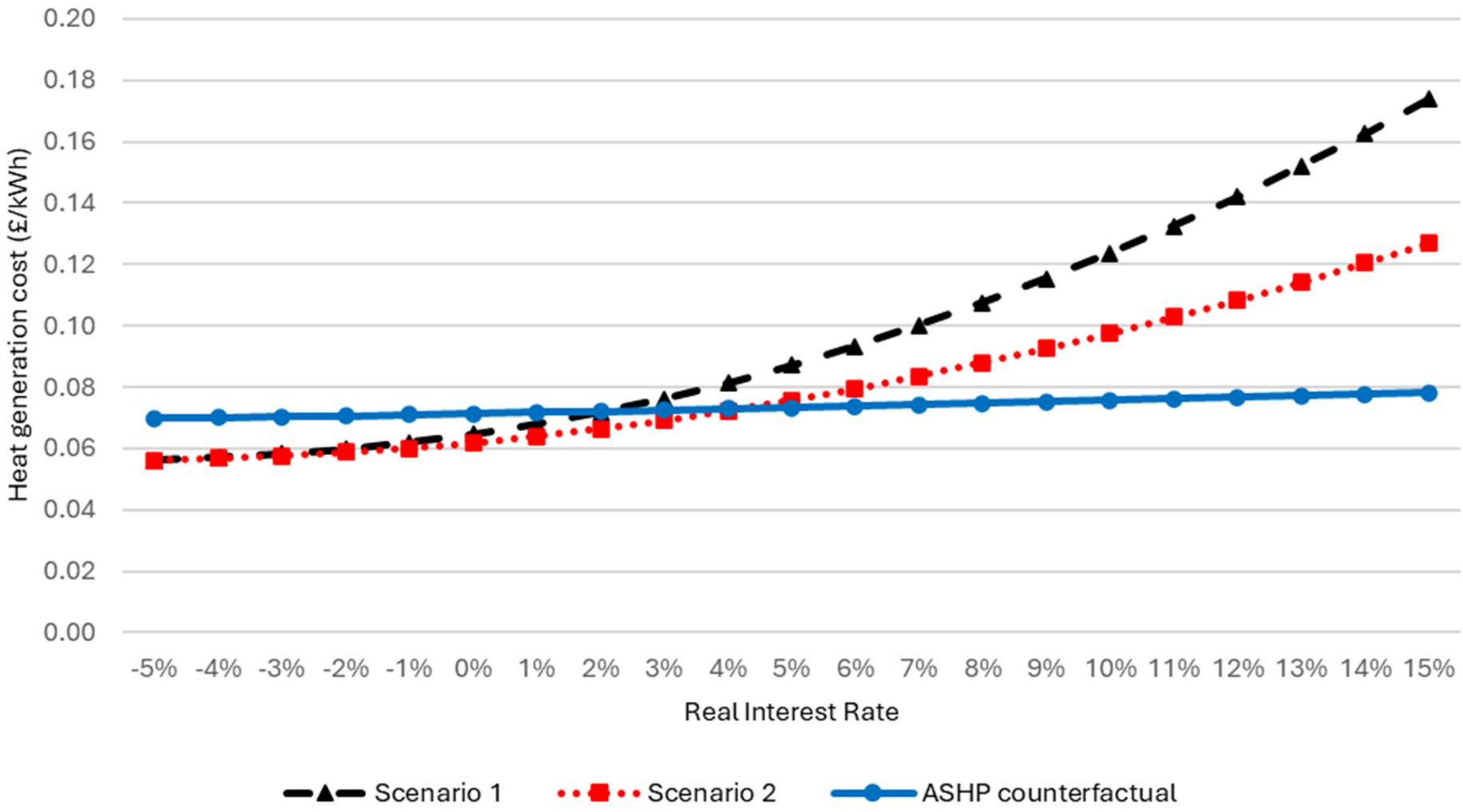

# Costs and business modelling

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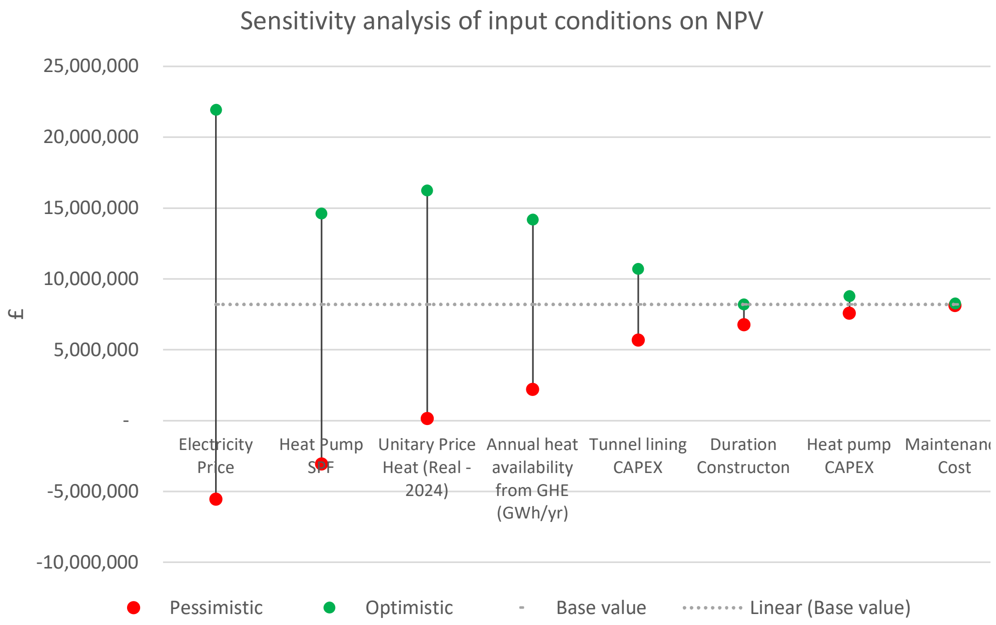
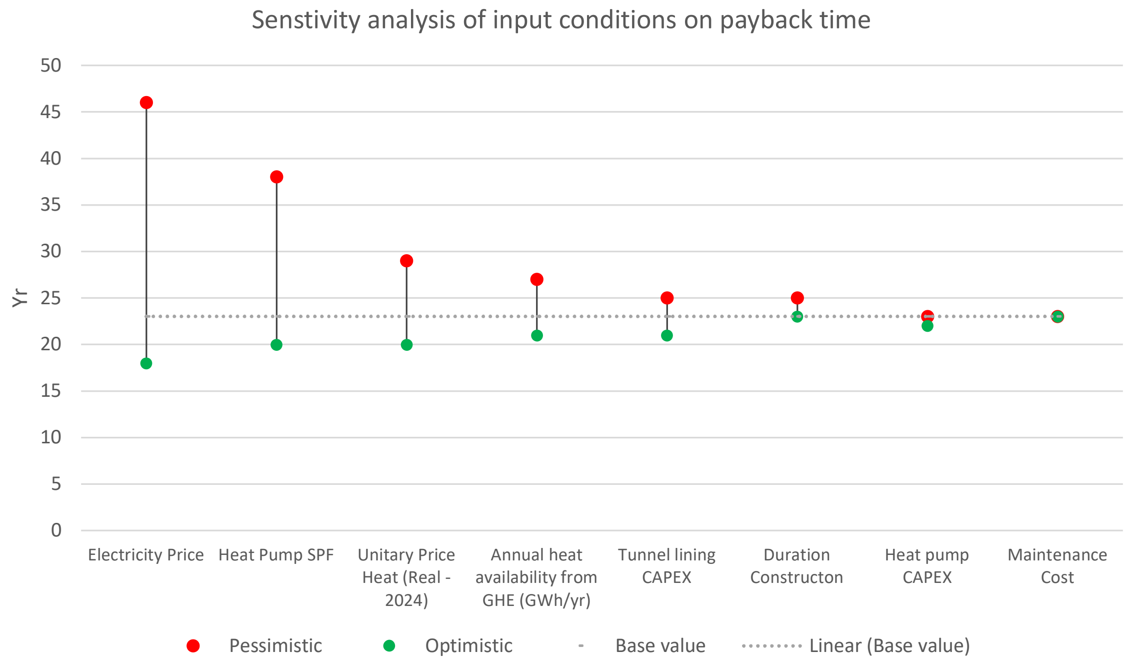
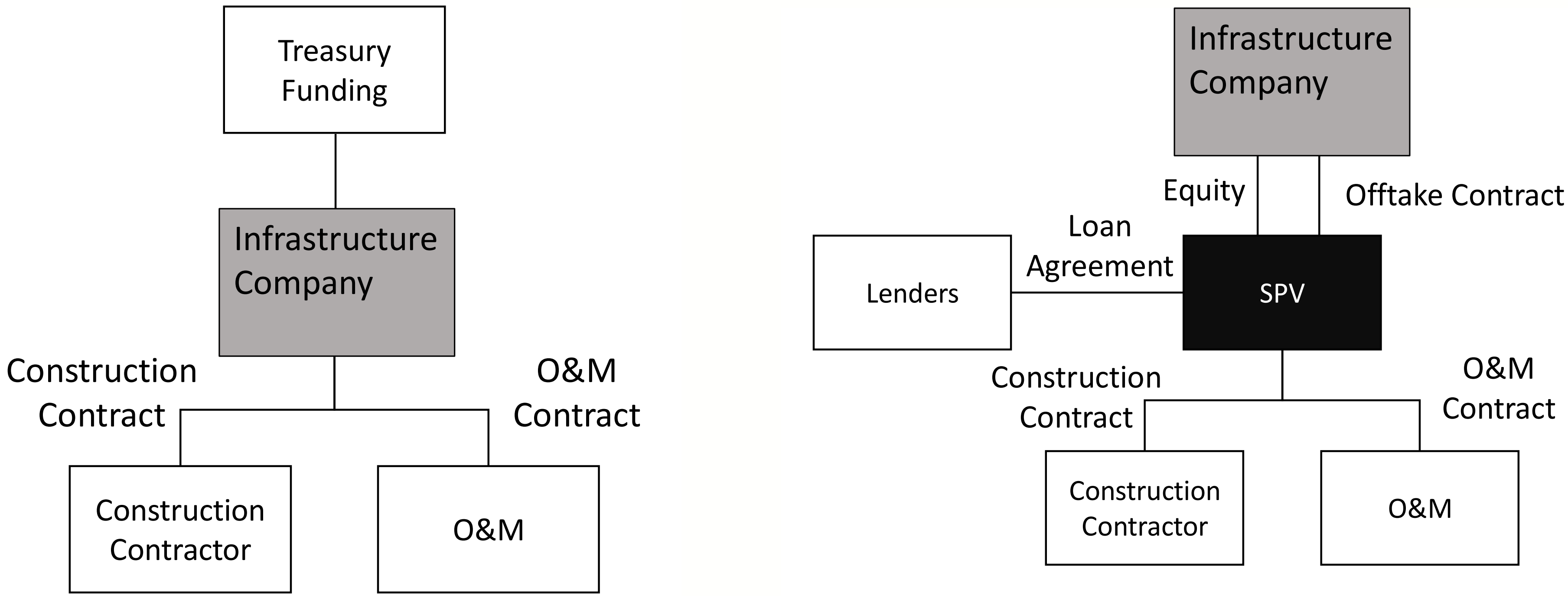



- Most important inputs: electricity price, heat pump SPF, unitary price of heat and the annual heat availability
- Indicating the priority for reducing uncertainty

# Energy Geostructures and District Heating





# Energy Geostructures and District Heating



- Networks need heat sources and stores over various timescales
- Additional heat sources from infrastructure beyond “ground source”
- But absence of design methods, standards, analysis methods
- Coupled with increased network complexity
- Need to work beyond traditional infrastructure boundaries
- Additional capital costs for infrastructure developers
- It’s not their core business
- More complicated business models
- Long timescales from investment to delivery

# Underground Thermal Energy Storage and District Heating

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- The ground offers opportunities for true long duration energy storage (LDES)
- Longer durations >> lower recovery
- Careful management of thermal resources needed
- Understand ground conditions & understand connected energy system

- Special care with energy geostructures (higher T??)

- Questions about regulation (higher T??)

# Underground Thermal Energy Storage and District Heating

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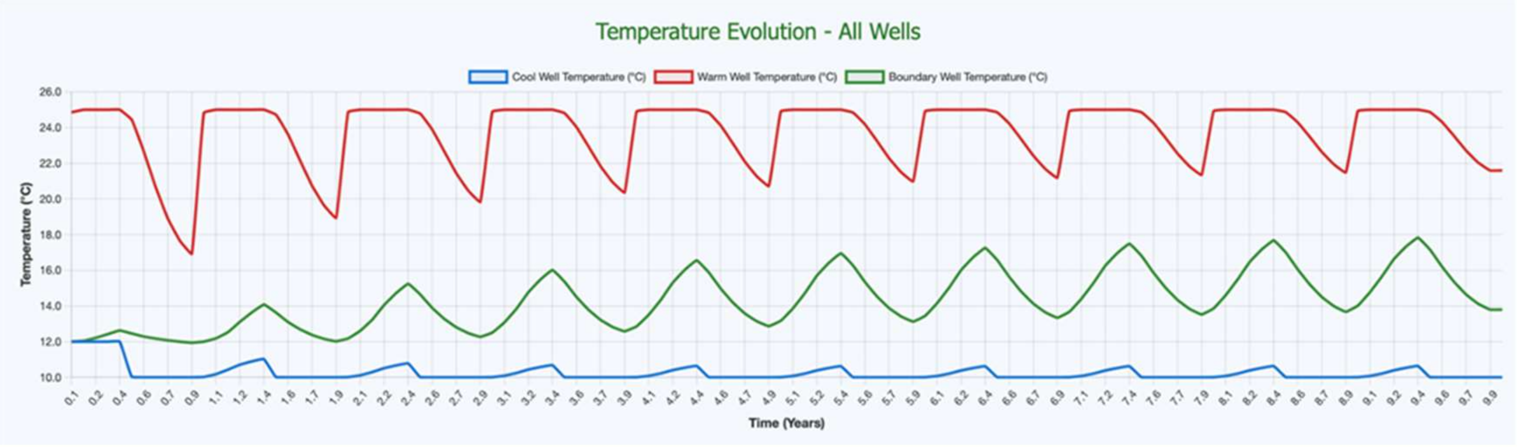
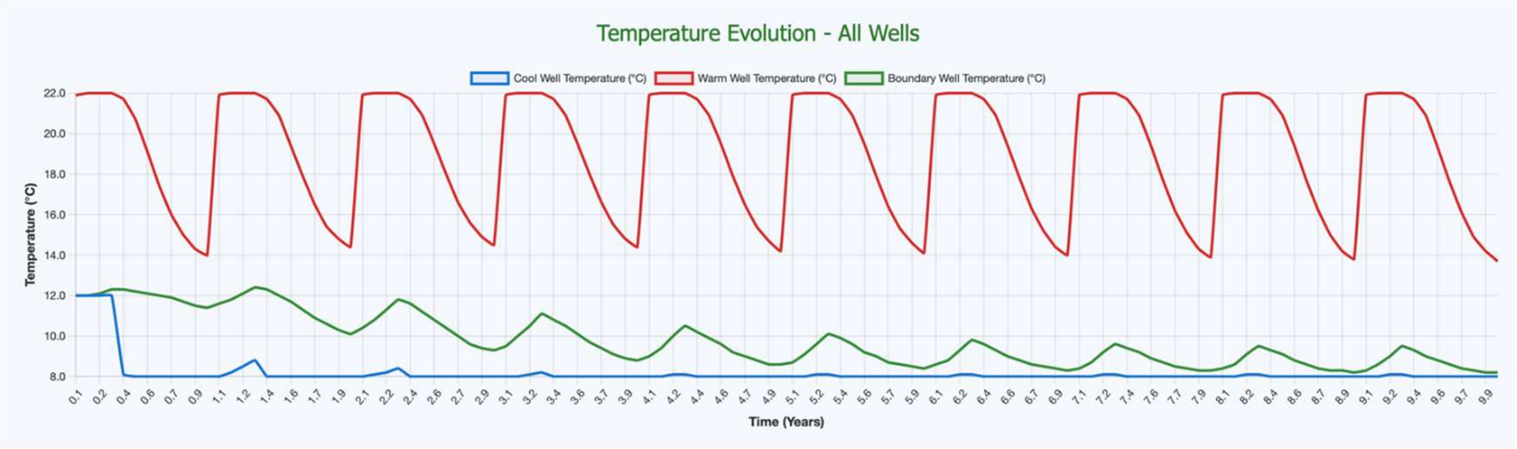
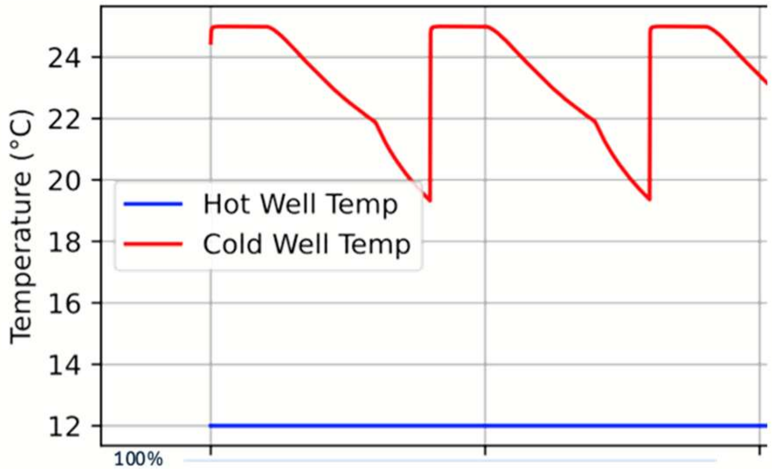


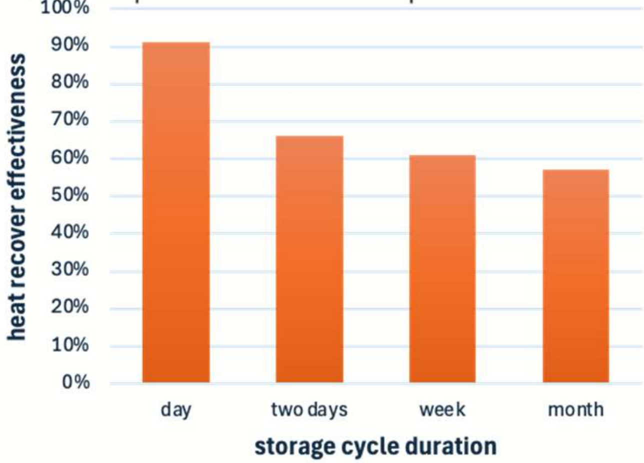



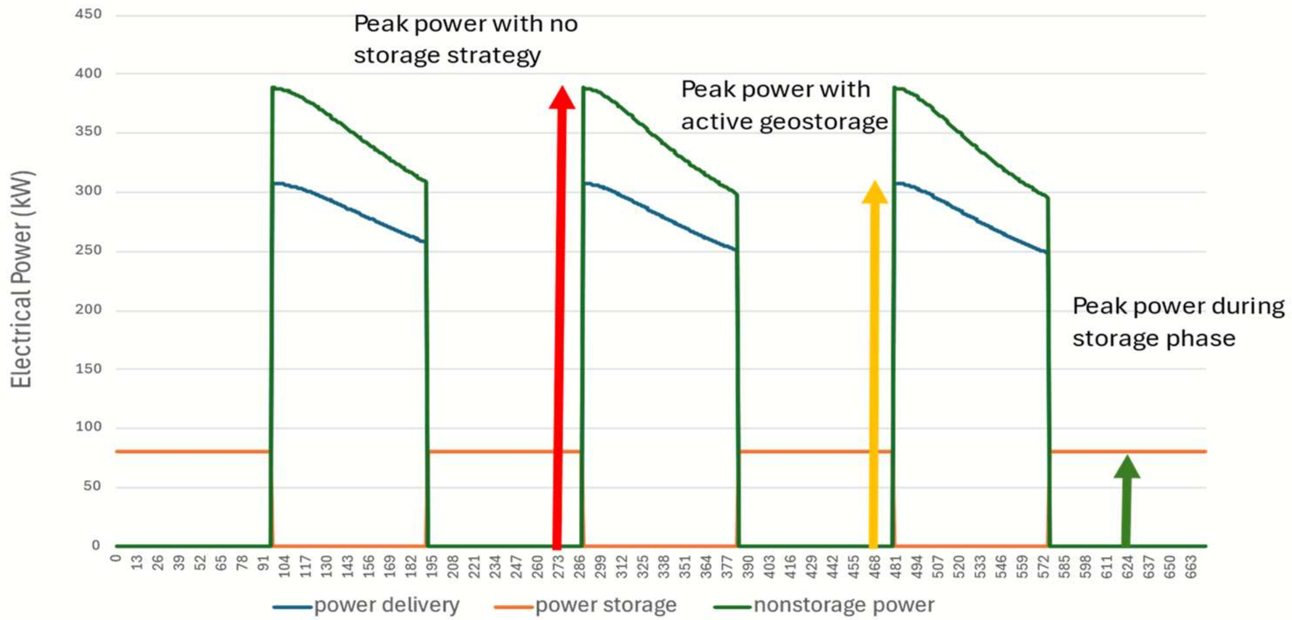

| Scenario | Case | Stored Thermal Energy | Recovered Thermal Energy |
|---|---|---|---|
| **1** | End of first injection | 3,126 MWhrs | 58% |
| **1** | End of simulation | 8,016 MWhrs | 75% |
| **2** | End of first injection | 2,266 MWhrs | 86% |
| **2** | End of simulation | 2,767 MWhrs | 75% |

# Underground Thermal Energy Storage and District Heating





# Underground Thermal Energy Storage and District Heating



- Network efficiency
  - Thermal network
  - Electricity network
- Charging the geo-battery uses electricity
  - May be additional
  - May be compensated in efficiency increase (higher T heat)
- Using the geo-battery reduces peak demand
- Ground temperatures need careful management (control systems)
- In the UK we need a storage tariff


# Closing Remarks

Image courtesy of Guillermo Narsilio

# Closing Remarks



- Shallow geothermal energy is part of a system stretching from the ground to society via buildings and energy infrastructure
  - Needs systems thinking!
- Integration with infrastructure to maximise potential: transport, water & wastewater, & electricity system
- We need to deliver:
  - Fast analysis methods to facilitate uptake via buildings & district heating
  - Long duration thermal storage solutions
- Major government projects need to take a broader vision of their purpose and value >> regional/national level systems thinking
- Stable policy and business environments are needed to encourage investment
- We shouldn’t be afraid of policy & politics. If nothing else please vote.

# Acknowledgements


| | | |
|---|---|---|
| Pile Models | Mott MacDonald<br>EPSRC<br>RAE | Southampton: William Powrie, Nick Woodman<br>BRGM: Charles Maragna<br>Melbourne: Linden Jenson Page, Guillermo Narsilio<br>Chalmers: Saqib Javed, Johan Claesson |
| Wall Models | EPSRC<br>FAPESP<br>EU Cost Action FOLIAGE | Aakash Gupta, Ida Shafagh, Simon Rees<br>Sao Paulo: Cristina de Hollanda Cavalcanti Tsuha, Alberto Hernandez Neto; Bruna Tosin; Dundee: Mike Brown, Jonathan Knappett, Gloria Guan; University Milan: Marco Gerola, Francesco Cecinato |
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| Storage | Innovate UK | LCP Delta<br>Cost Action FOLIAGE WG2 |