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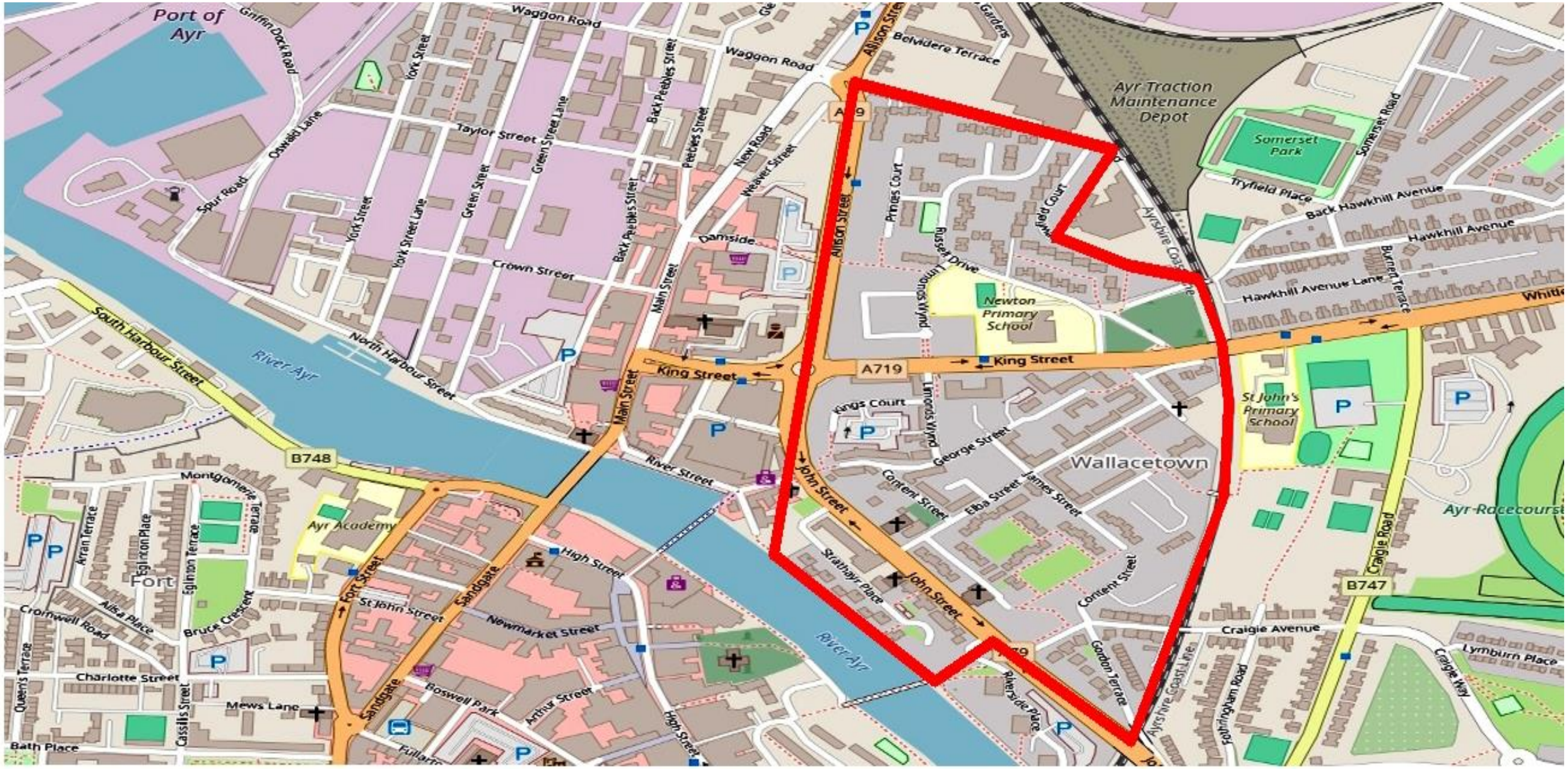
Regeneration of Wallacetown District in Ayr : Low Carbon Heating

About Wallacetown



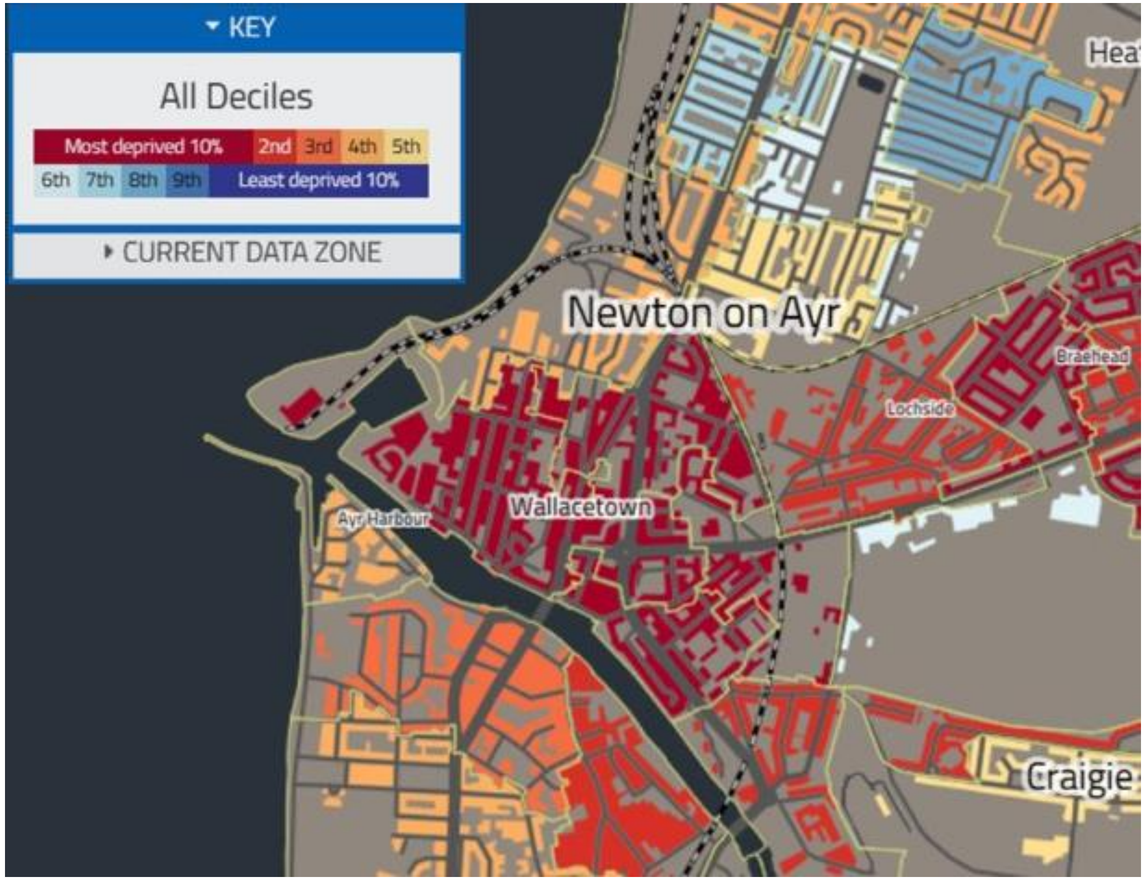
Wallacetown’s main focus area

Wallacetown Background

Wallacetown is located in South Ayrshire, and is in the lower decile of the Scottish Index of Multiple Deprivation (SIMD)

Wallacetown estimated population 2600

1311 domestic properties in Wallacetown.



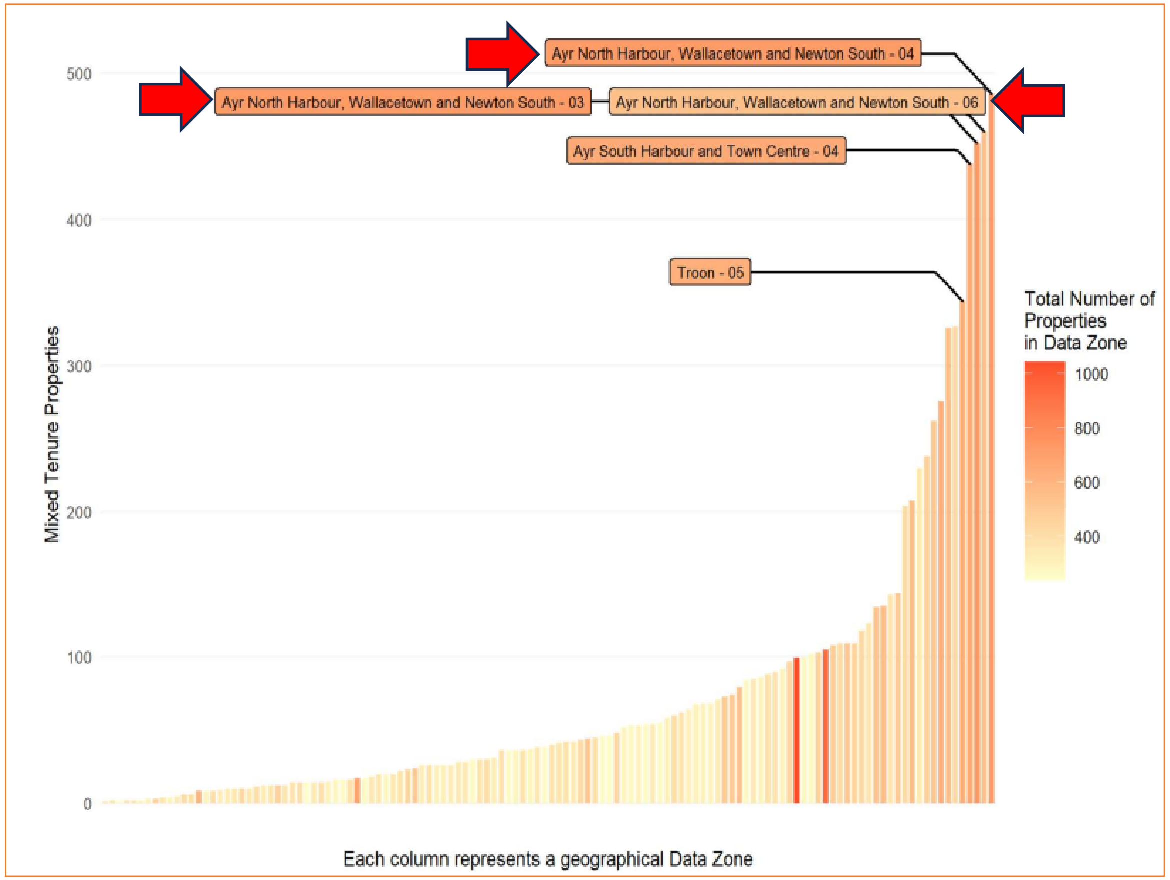
Source: Scottish Index of Multiple Deprivation 2020

Most common construction type is cavity walls

<2% of homes have solid walls

Housing diversity: owner-occupied, rented, social housing.

It has a higher number of mixed tenure properties comparing to other areas in South Ayrshire



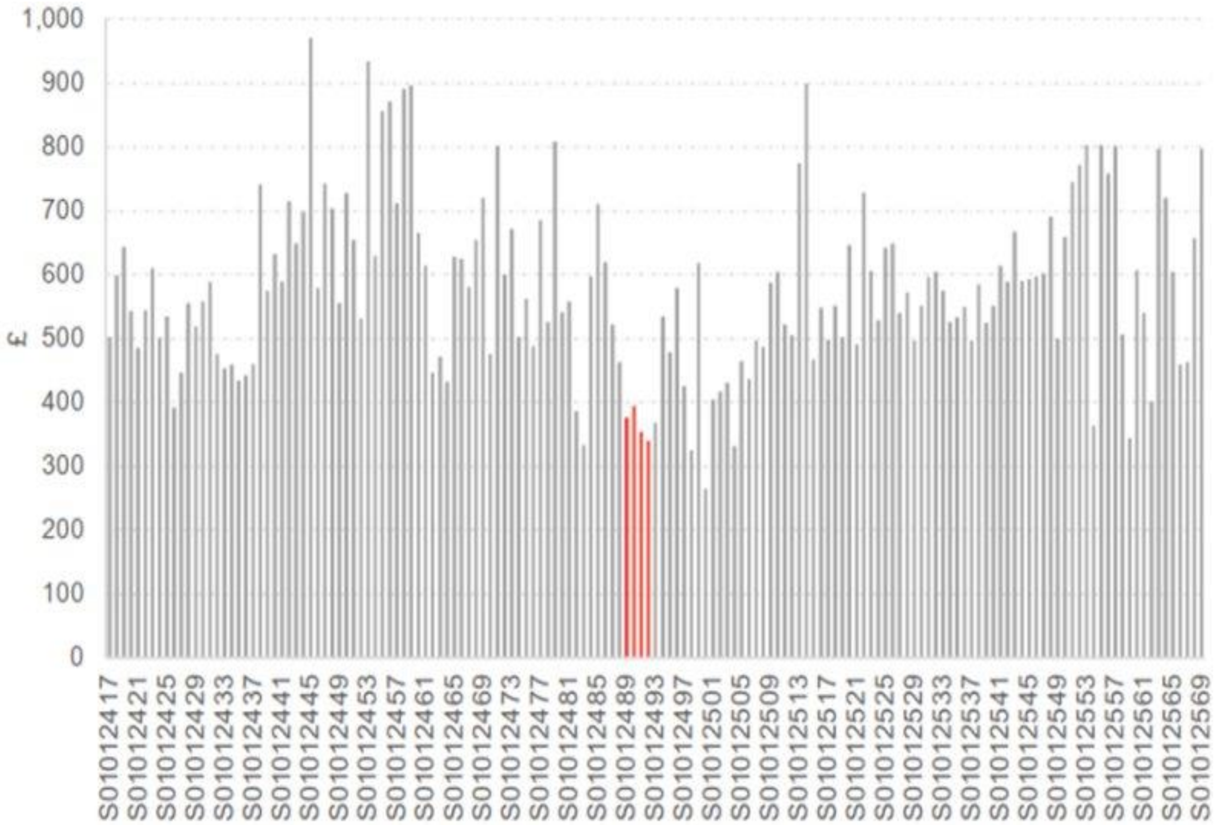
Histogram of Number of Mixed-Tenure Buildings – Data Zone Level

Problem

The area is facing serious issues of fuel poverty

Wallacetown has significantly lower incomes compared to other regions, below £400/week (2018)

Only 19% with Energy Performance Certificate (EPC)>C. With 14 % being F or G



Median Household incomes in South Ayrshire,2018 (Source: FSWCA).

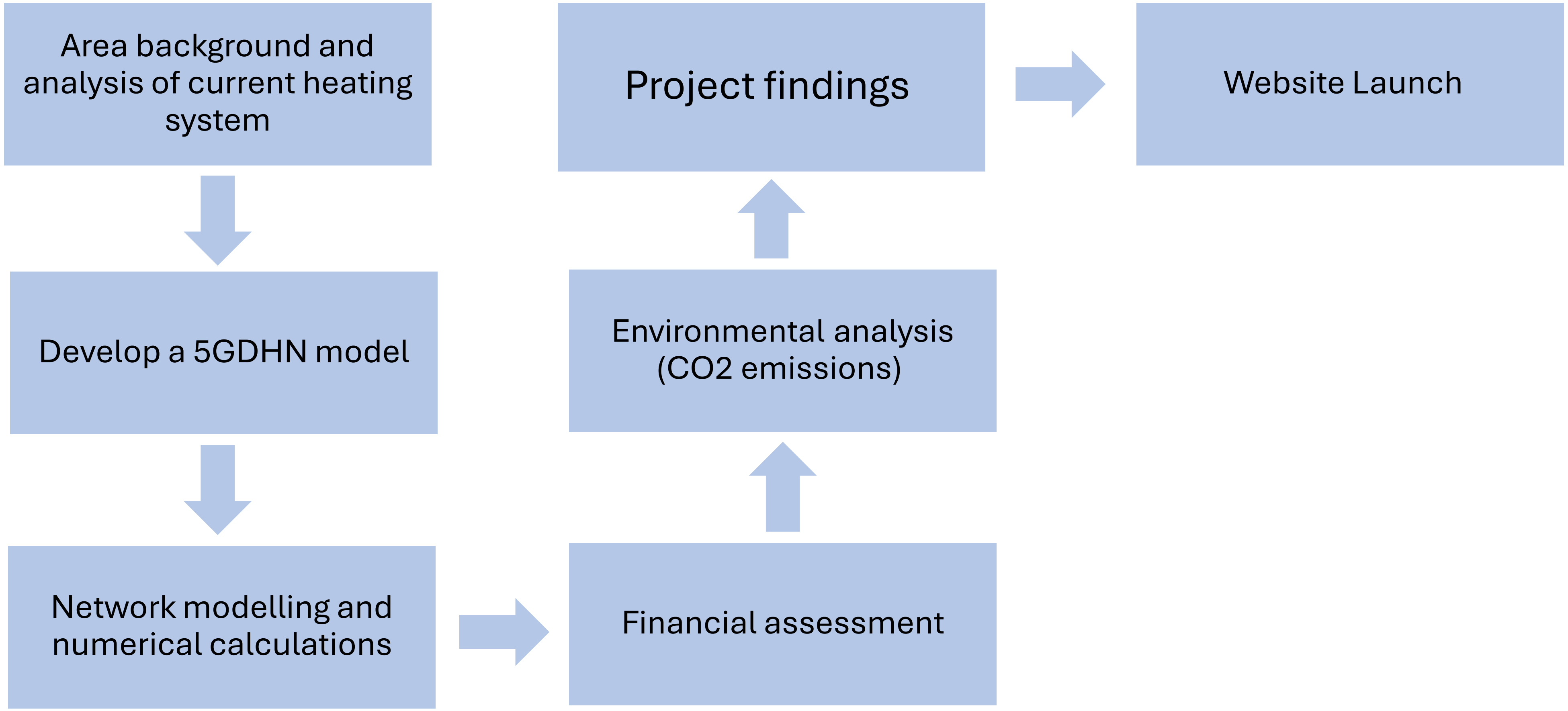
Aim

Transitioning Wallacetown's heating system to low carbon with a focus on tackling fuel poverty

Objective

Examine the feasibility of integrating a variety of renewable energy sources into a fifth-generation district heating network (5GDHN)

Project outputs



Key Performance Metrics (KPMs)

Levelised Cost of Heat LCOH (£/kWh)

Carbon Equivalent (gCO2e/KWh)

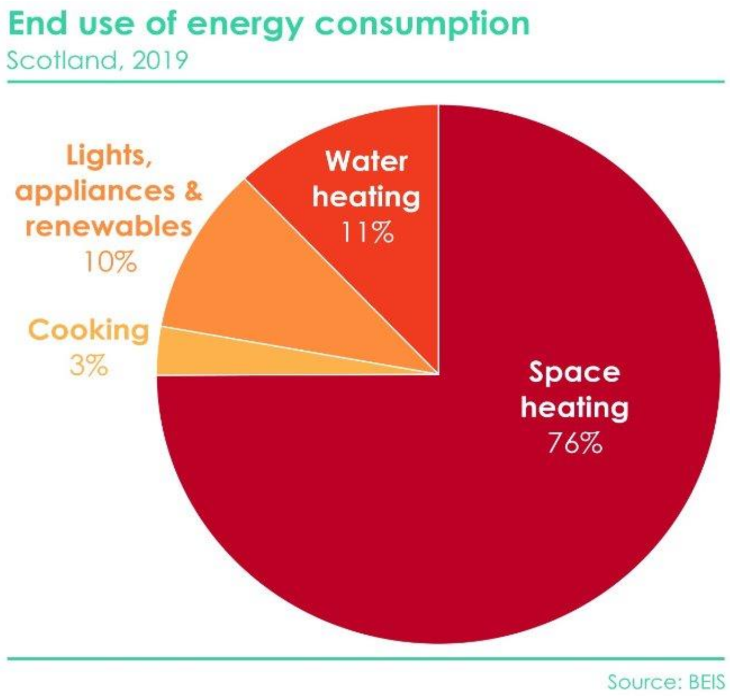
Capital Costs (£)

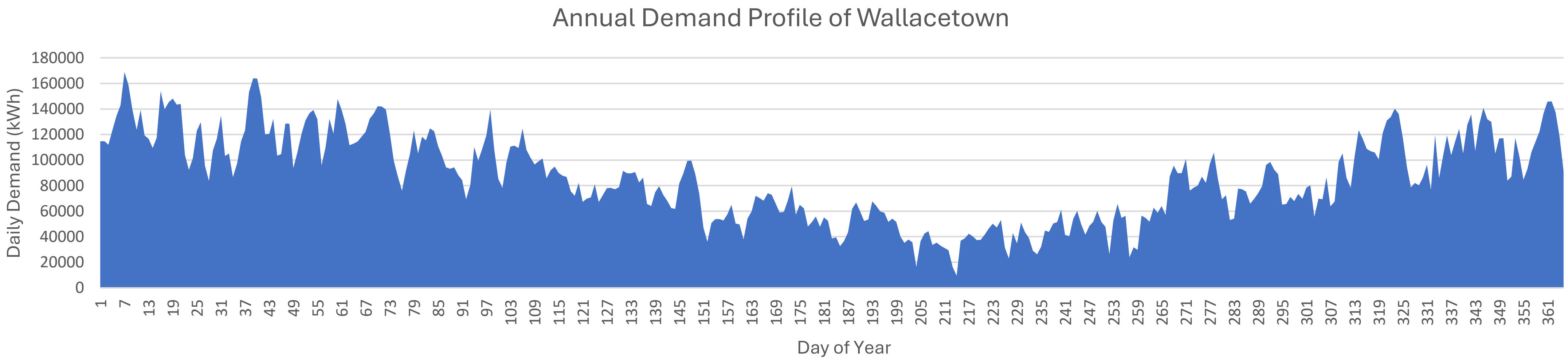
Wallacetown Current Demand Profile

No existing district heating network in Wallacetown

Uses conventional gas system

Total demand : ~31GWh per year





Solution Paths

Fabric Improvements

- Includes External Wall Insulation, Loft Insulation, Double Glazing
- Demand analysed in LHEES

District Heating

- Shared Heating System
- Many ways to implement, including recent 4^{th} gen & 5^{th} gen networks

Heat Pumps

- Transfers heat from one zone to another
- More efficient than direct electrical heat generation

Pathway to net zero 2045 will involve the integration of these solutions

DISTRICT HEATING

District Heating

In line with 2045 government targets, need to decarbonise heating (and cooling)

4th gen or 5th gen networks offer a way

15% of UK's greenhouse gas is space and water heating (CarbonBrief, 2019)

DHS have a lifespan of around 40 years

UK cooling demand projected to increase

~7000 deaths per year by 2050 (House of Commons, 2018; Kovats and Osborn, 2016)

Cooling must be taken seriously

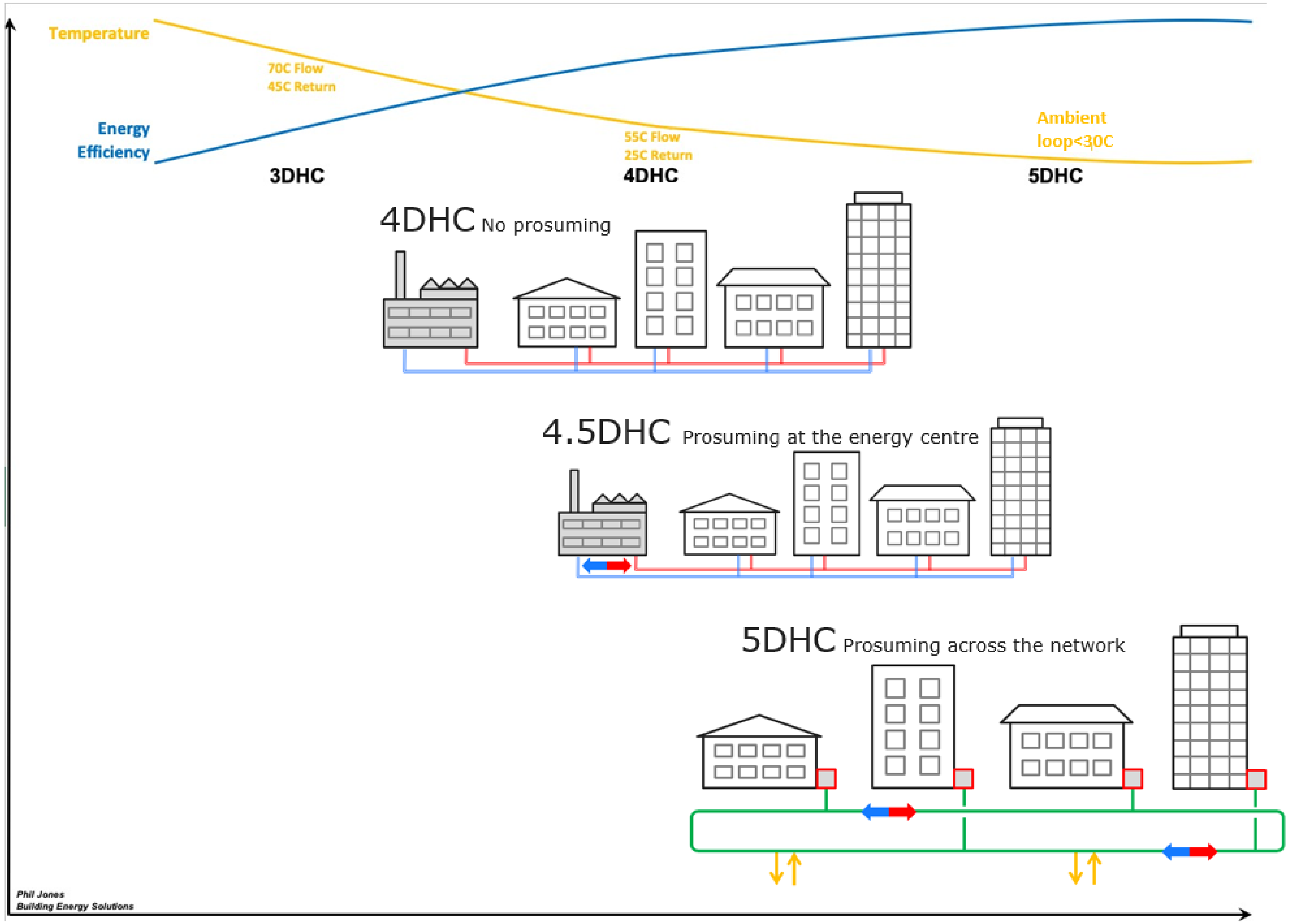
4th Generation DHN

Traditional centralised shape -energy centre supplying heat outwards to buildings.

Cooling would be a separate system

No interchange of heat between buildings is possible

Supplying at ~70-45ºC with a wider ΔT and return temperatures~25ºC.



Heat network progression: (Jones P, 2019; Lund et. al., 2014)

5GDHN for Wallacetown

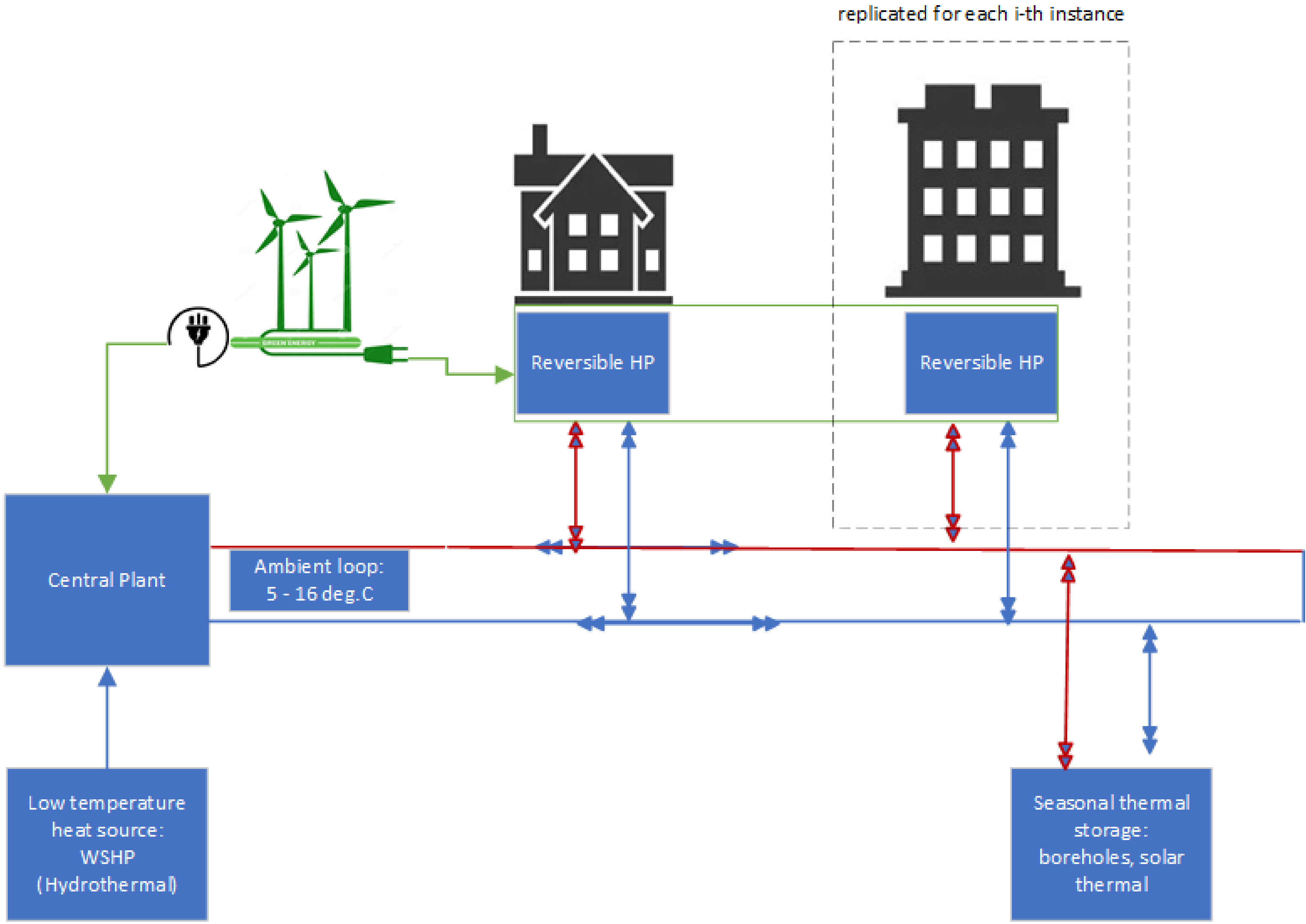
Bidirectional network

Central plant controls flow
- Central pump

Reversible heat pump

Four-way valves enable decoupling of evaporator/condenser from compressor

Different sources
- Boreholes, hydro & solar thermal.



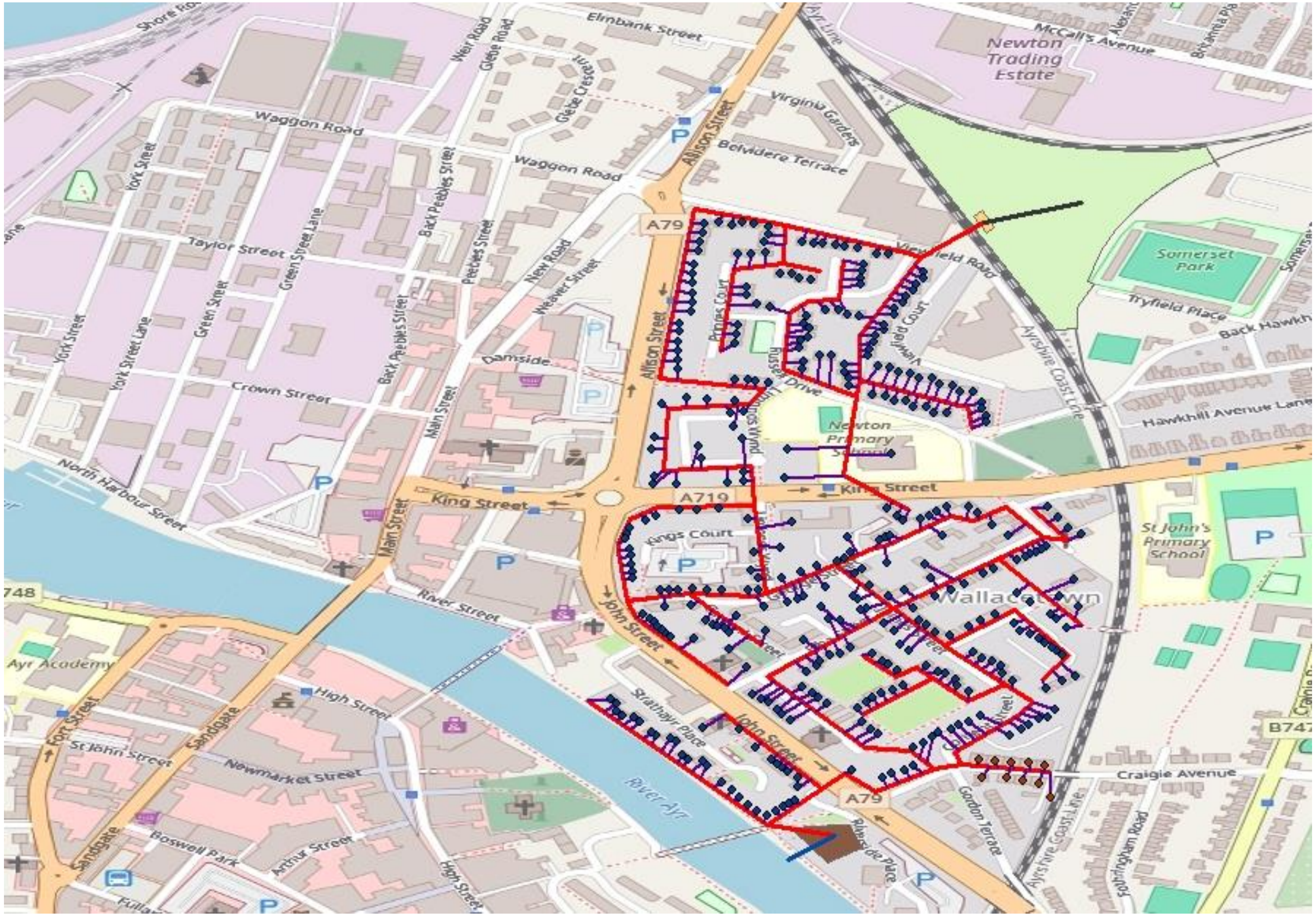
Schematic diagram for Wallacetown 5GDHN

Network overlay

- Overview of the 5GDHN design
  - Network stretching ~10km

Legend

- buildings with traditional walls
- buildings with solid walls
- river water pipe
- proposed pathway for main network
- pipes to substations
- WSHP central plant
- Solar panel+borehole control plant
- proposed place for solar panels and boreholes



Basemap: openstreetmap

THERMAL SOURCES

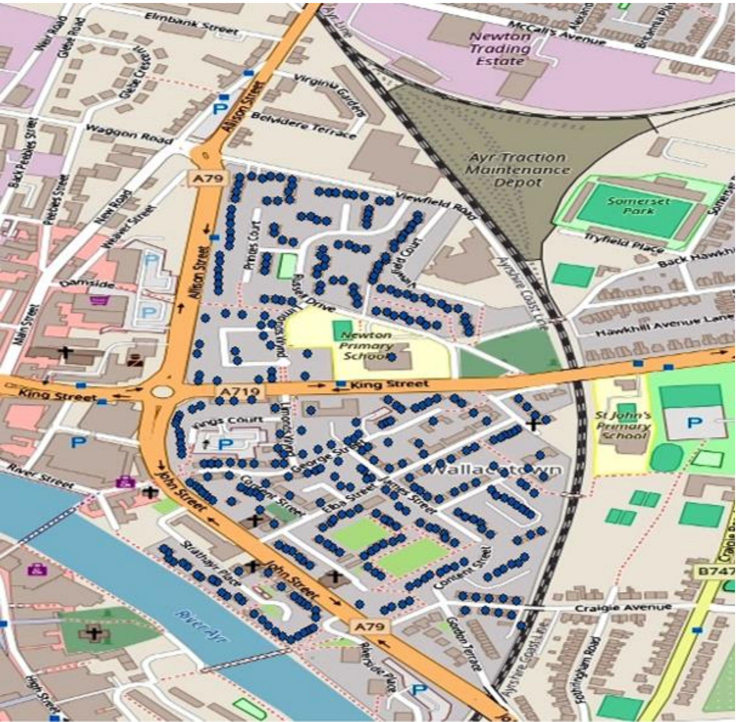
- ❖ Waste Water Heat Recovery System
- ❖ Water Source Heat Pumps
- ❖ Solar Thermal
- ❖ Boreholes Thermal Storage
- ❖ Mine Water Heat Pumps

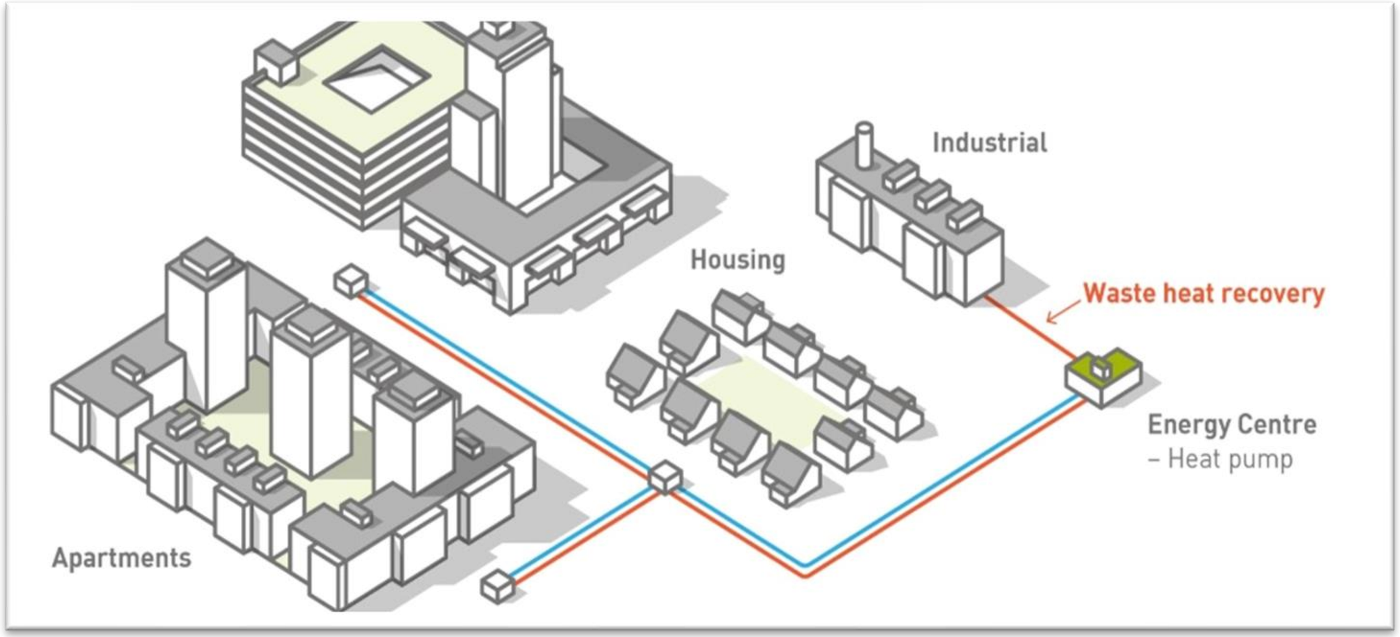
Waste Water Heat Recovery Systems (WWHRS)

- Individual or communal options available
- From shower, washing machines, dishwasher, sinks…
- 150l wastewater per head per day (Scotland)

- Wastewater inputs into system at average 15°C in winter and 25 °C in summer
- ~4.6l/s flow rate from Wallacetown

Location of Resource in Wallacetown





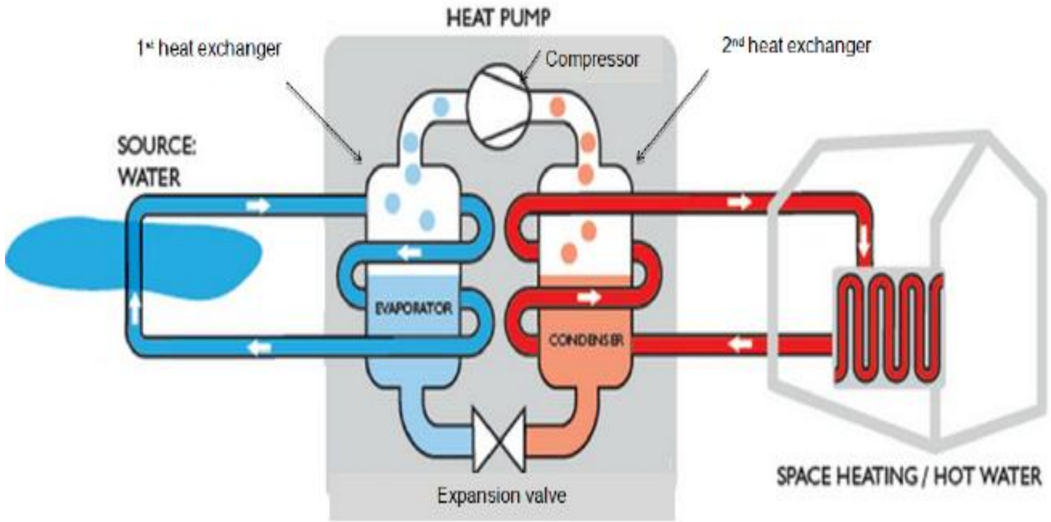
Source: storymaps.arcgis.com

Water Source Heat Pumps (WSHP)

Water passed through heat pumps to extract thermal energy

Closed loop system abstracting water from the River Ayr

WSHPs can achieve high efficiencies of 300-600% in normal use



Discharged water returned to the river at a lower temperature

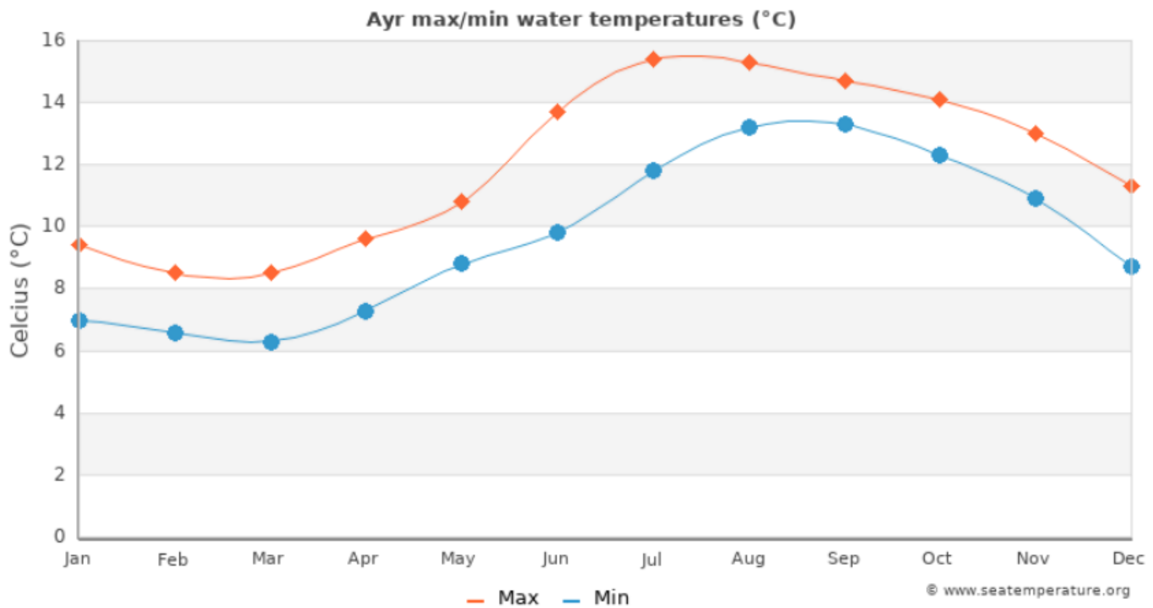
WSHPs can deliver water temperatures up to 85°C for district heating applications

Generates less CO_2 emissions than traditional systems.

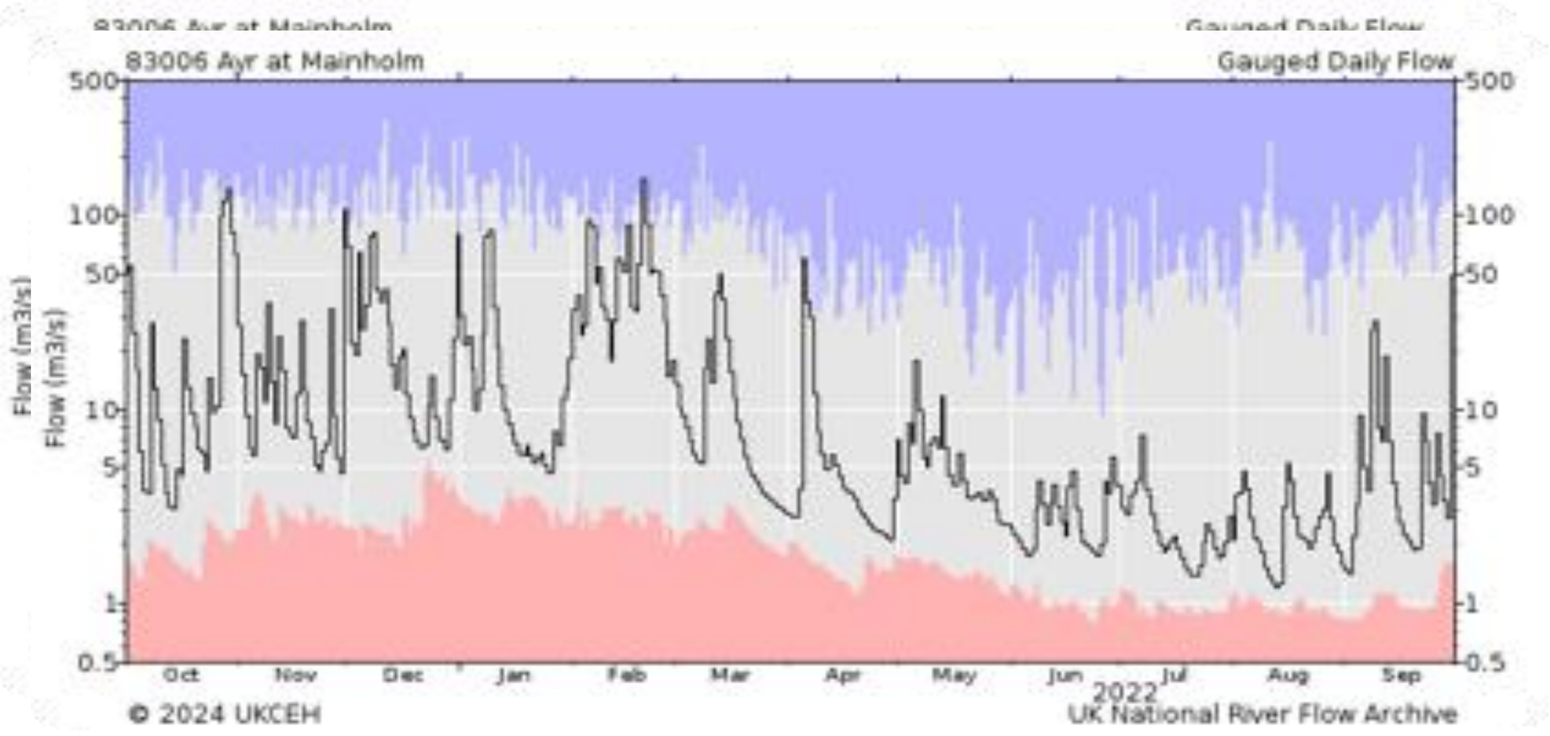
Location of Resource in Wallacetown

WSHP River Ayr Properties

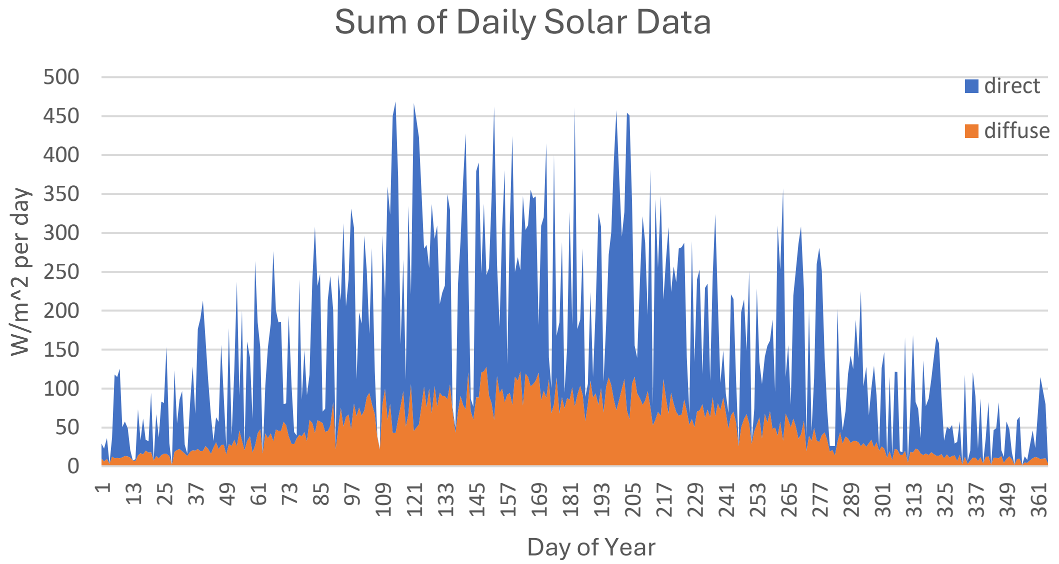
The river Ayr has a catchment area of 574km2.
Water temperature for river Ayr is 6.5°C in February and 16°C in August
Q= m*Cp*ρ*ΔT
ΔT=3°C



Location of Resource in Wallacetown

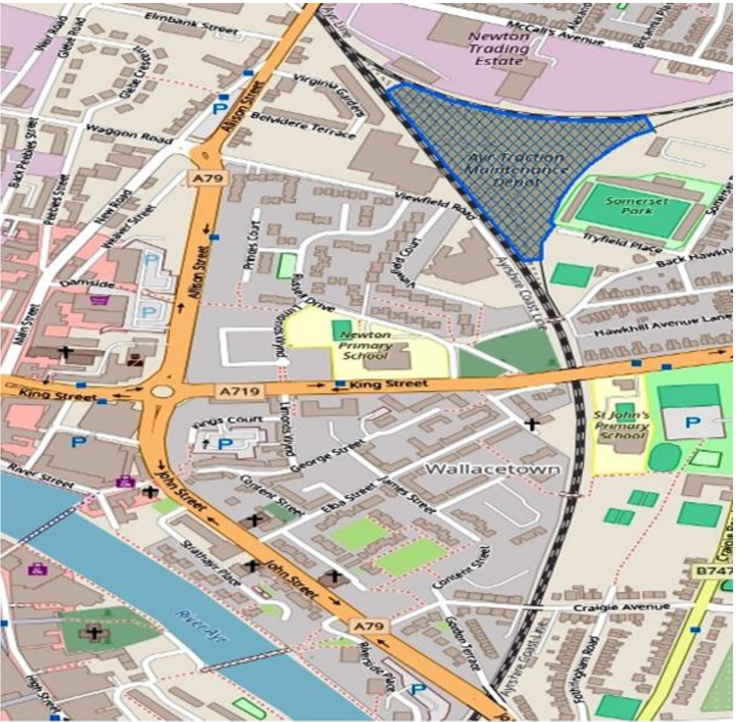


Solar Thermal



Source: Prestwick TMYx 2007-2021

Location of Resource in Wallacetown



Solar collectors would be installed on a selected site same as the boreholes area

Excess heat will be stored in thermal storage (Boreholes)

~1000kWh/m^2Annual g lobal horizontal irradiance in Ayr

Literature suggested over 1000m^2 per 50 houses for feasibility

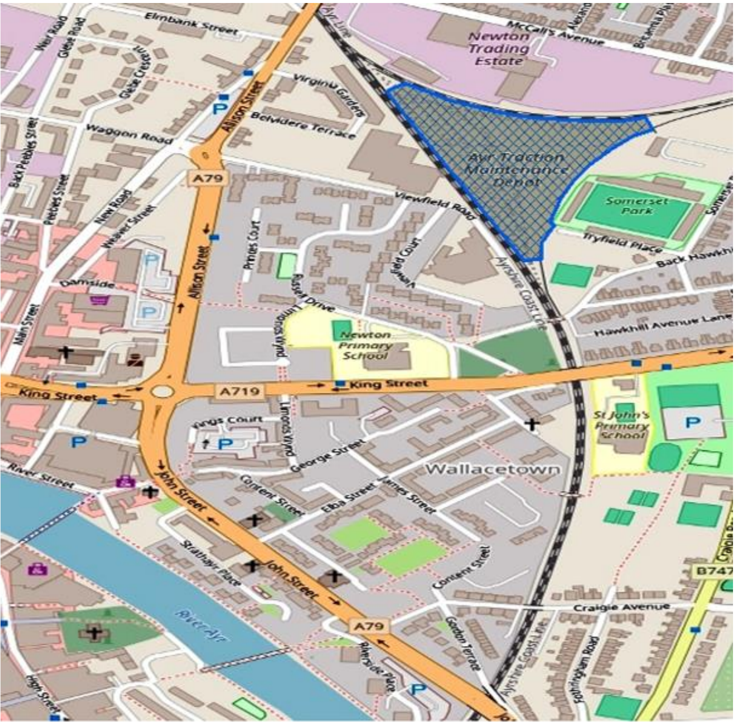
Boreholes Seasonal Storage

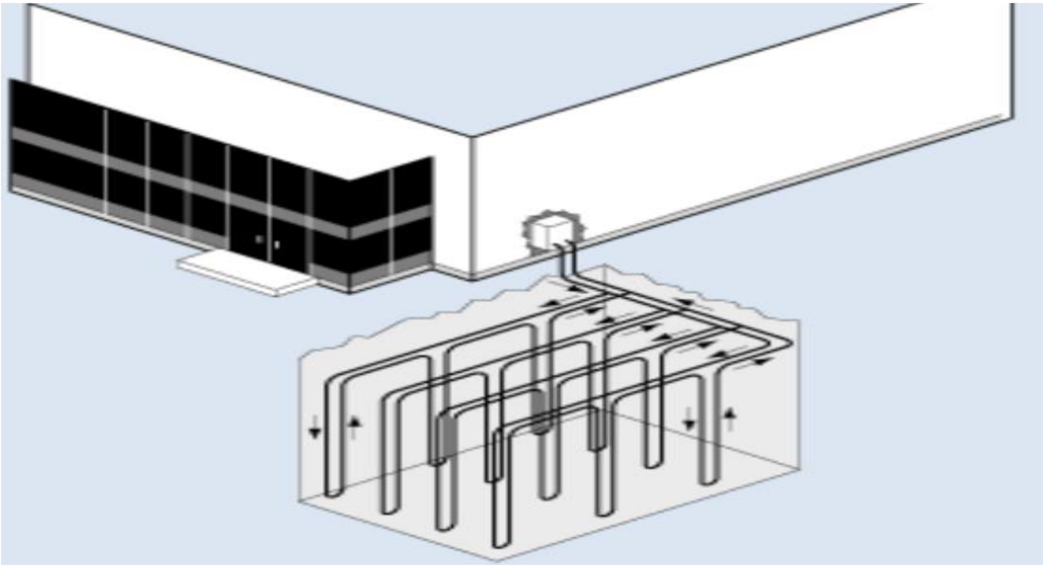
Help to balance the demand and supply

Typical storage temperatures: 40.0°C at 1024 m depth (Halo project)

The soil type
in Wallacetown is carboniferous
K=1-2.5 W/m·K

Location of Resource in Wallacetown





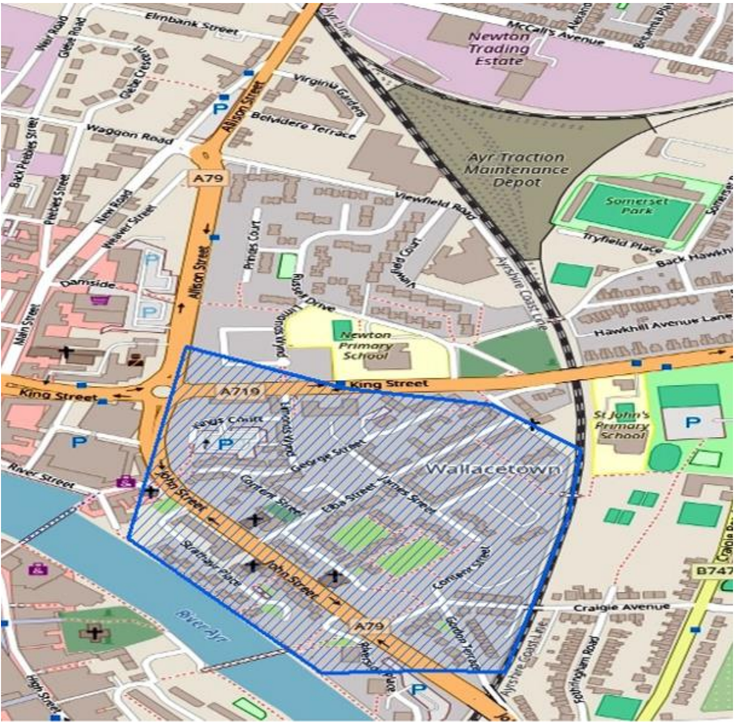
Source: underground-energy.com

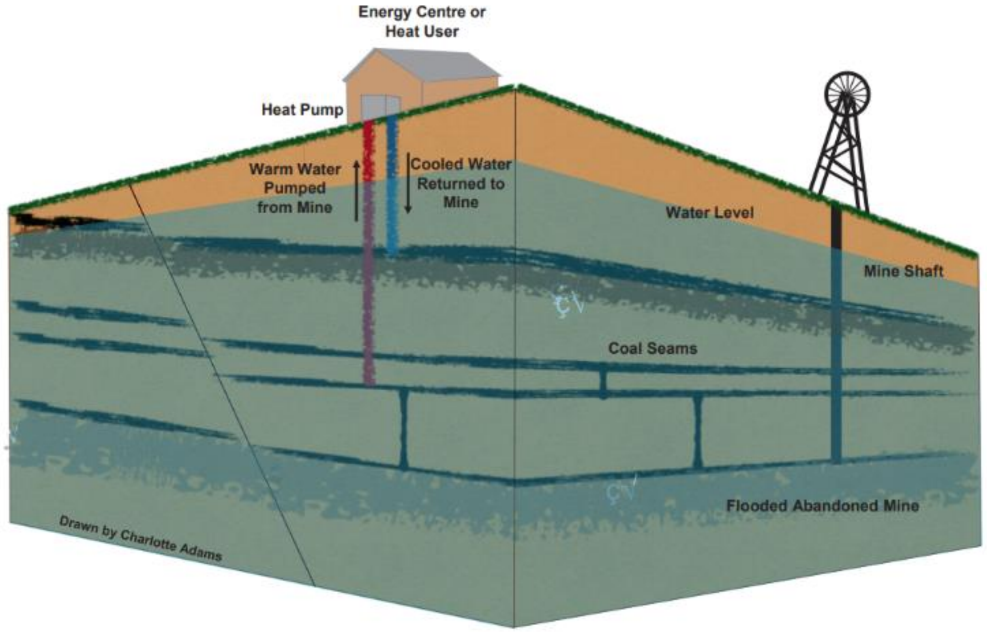
Mine Water Heat Pump

Water in abandoned mine works which could be used to provide a source for heating and cooling

Mine water maintains stable temperatures (10°C - 40°C @1km)

Location of Resource in Wallacetown





Source: Geolsoc.org.uk/Geoscientist

- Wallacetown has flooded abandoned mines with the volume of around 100,000m3

They can be used as both energy supply source and for storage

Thermal Sources Selection

Source	Reason	Outcome
Solar Thermal	Compatible with Wallacetown, provides enough energy	Scoped in
River WSHP	Provides extra energy needed, dispatchable	Scoped in
GSHP STES	Provide enough storage	Scoped in
Mine WSHP	Not easy to access, limited data, Risk of failure	Scoped out
WWHRS	Provides too little energy, treatment site outside scope area	Scoped out

MODEL RESULTS

Thermal Storage Capacity

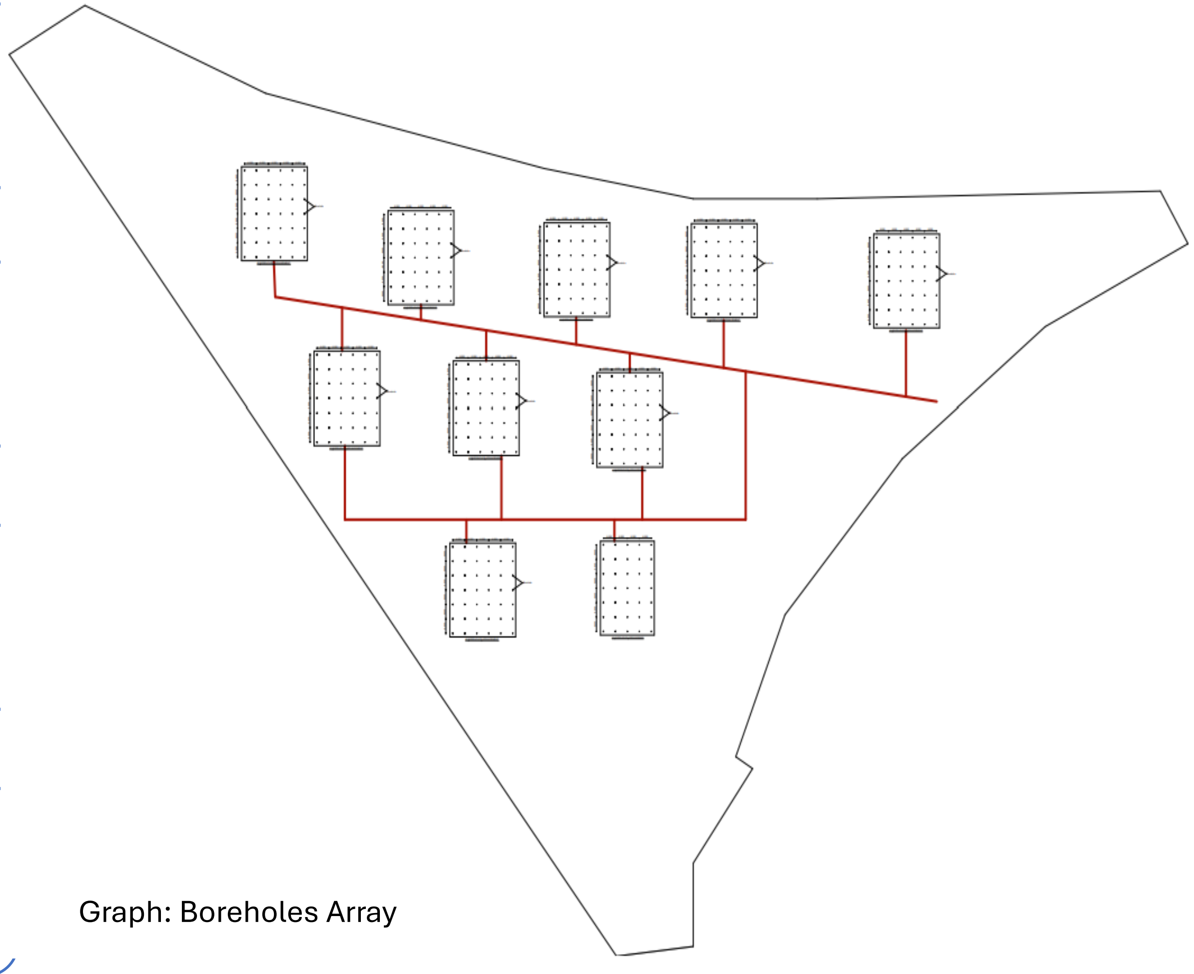
- 413 boreholes
- 0.075m radius
- 110m deep at 12.8°C

- Efficiency= 61.53%
- The efficiency will increase up to 80% at the end of 30 years

- 6m boreholes spacing
- Arranged in a 6*7 array
- Thermal conductivity 1.75W/m.K
- Storage capacity of 7.3 GWh

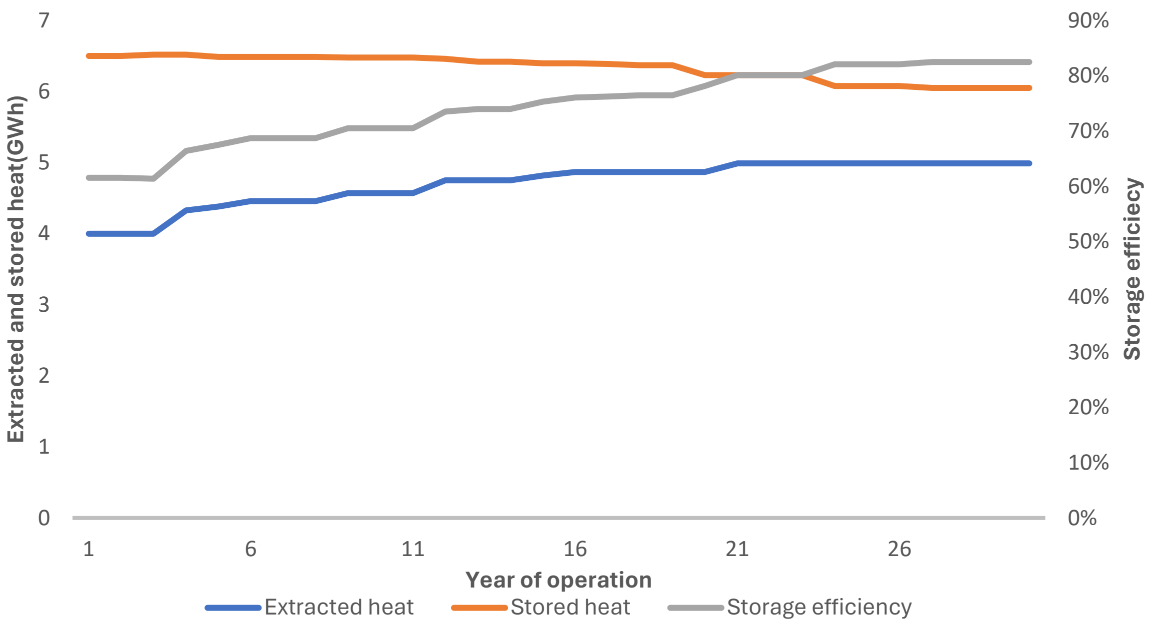
- Stored energy QS=6.5GWh
- Extracted energy QE= 4GWh

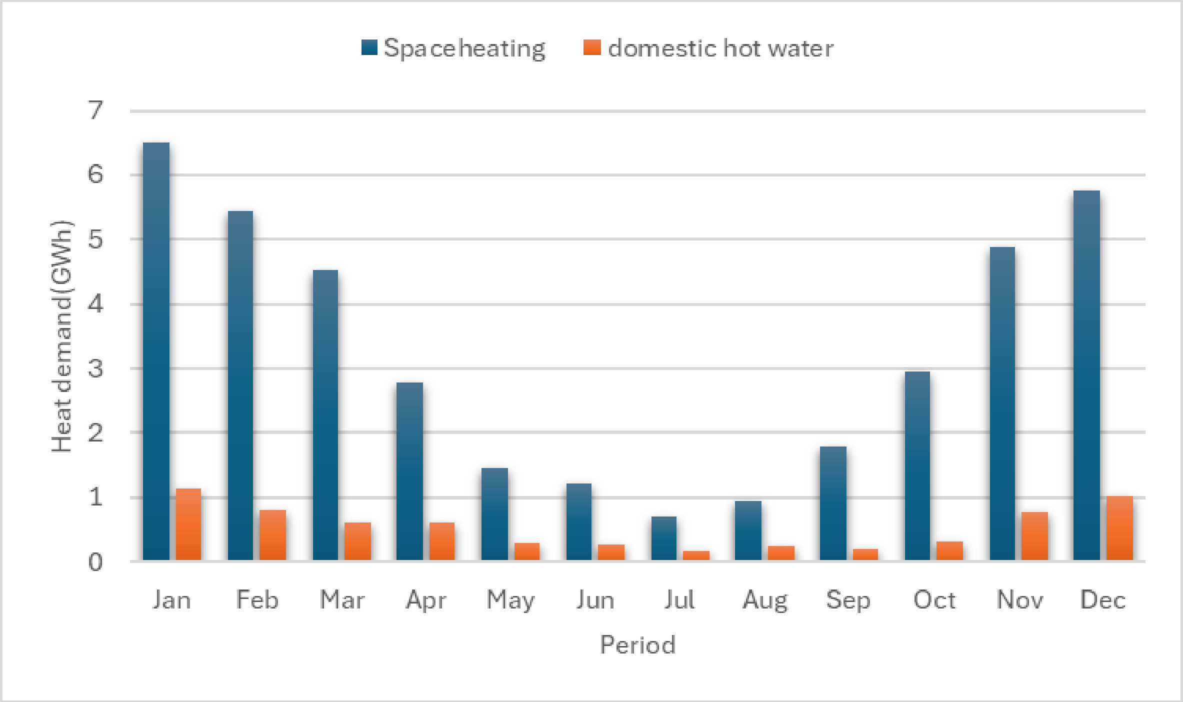
Efficiency $\eta = \left| \frac{Q_E}{Q_S} \right|$



Graph: Boreholes Array

Efficiency and Demand





Dynamic nature of BTES Systems stored heat gradually decreases as it is used.

- Improved efficiency and optimised operation lead to increase in heat extraction over time
- Thermal losses are negligible

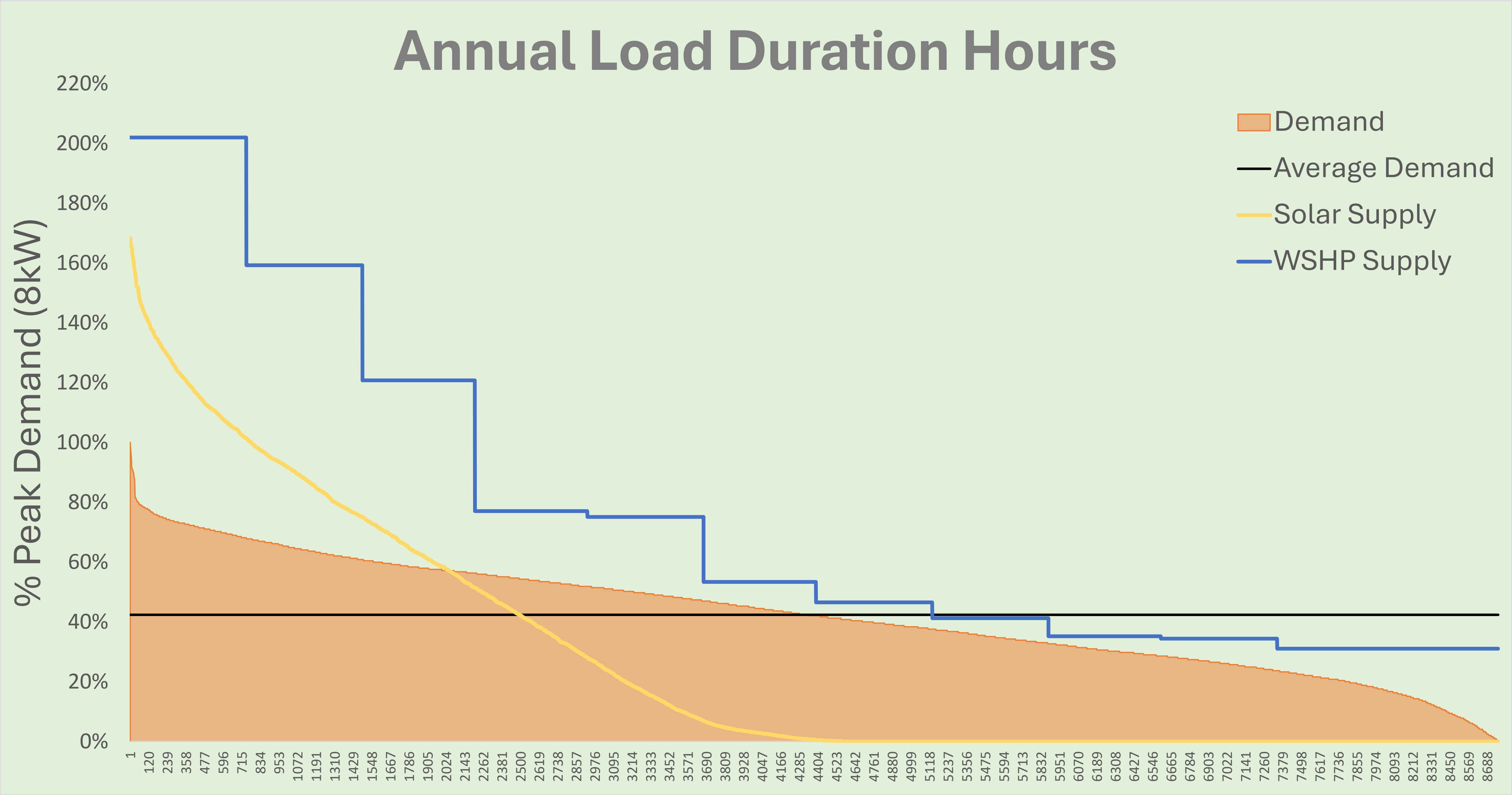
$$v_1 = \sqrt{\frac{P_2 + pgy_2 - P_1 - pgy_1}{0.5p - 0.5p\left(\frac{A_1}{A_2}\right)^2}}$$

Velocity

Storage volume

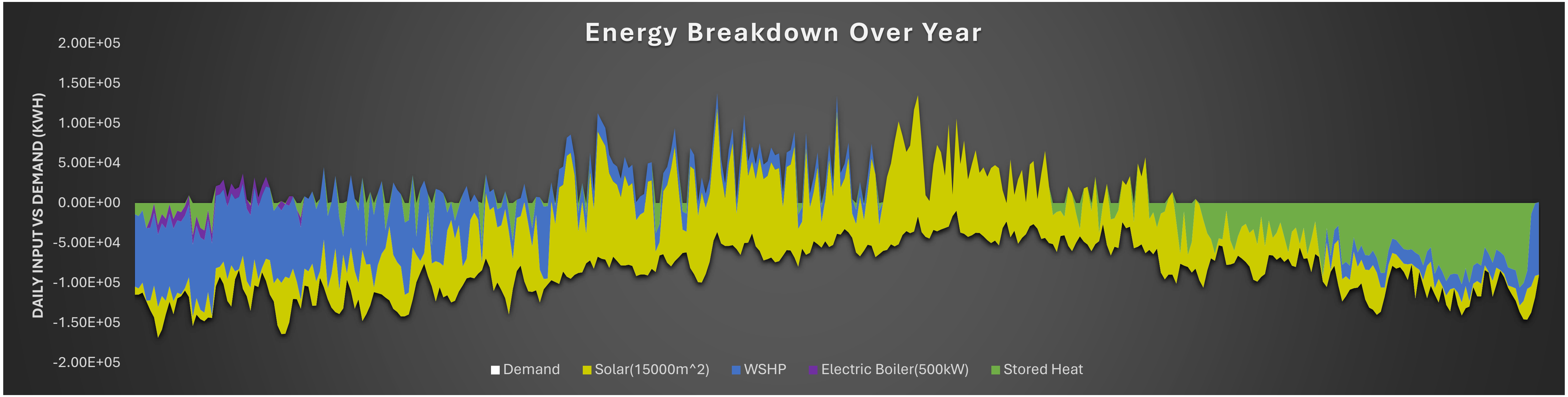
$$V = \frac{E_+}{\Delta T \cdot C}$$

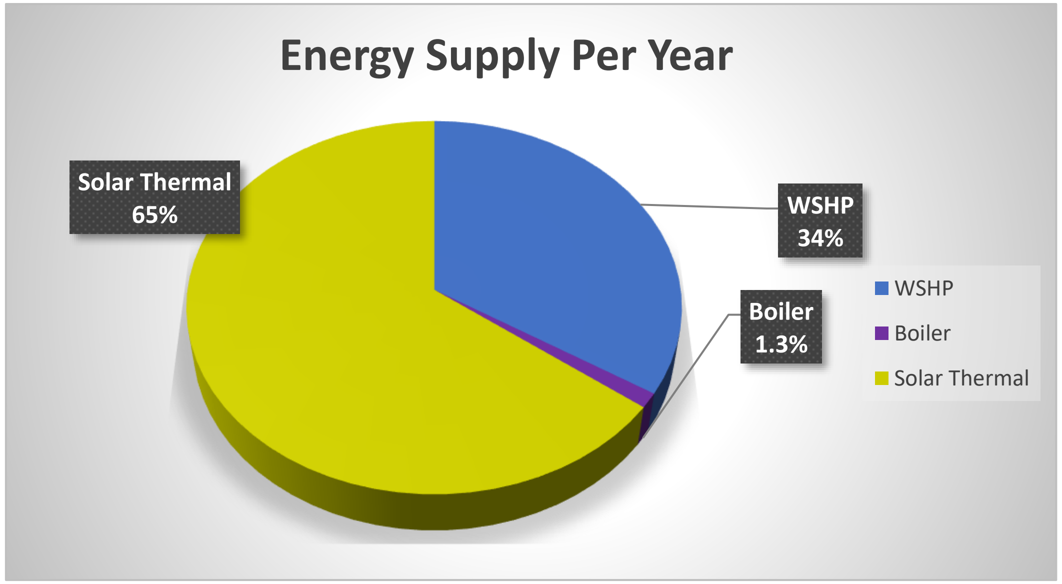
Power

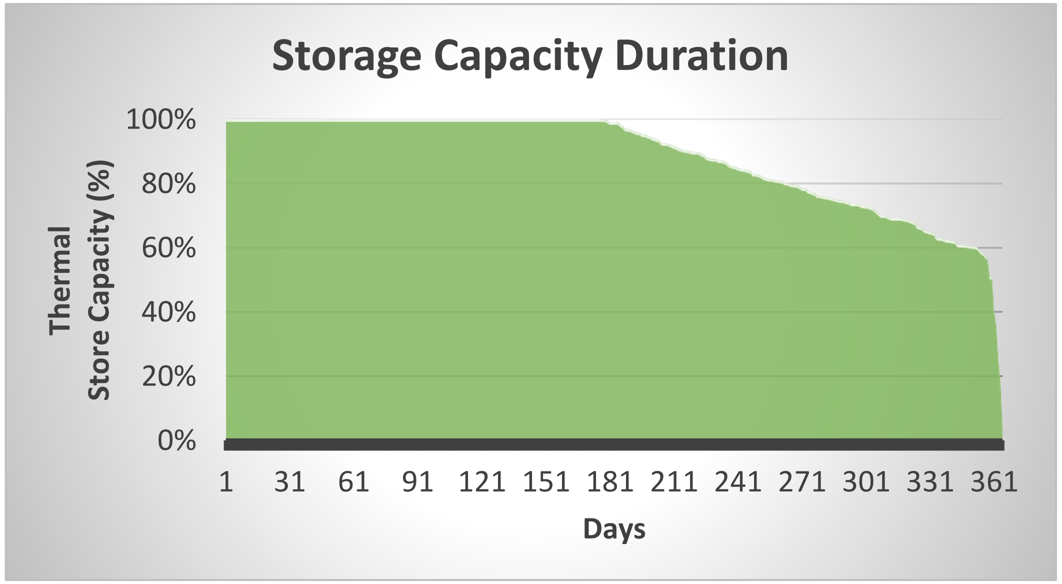


Source: Calculation, Scottish Government, Prestwick Climate Data 2007-2021

Network Model Outputs







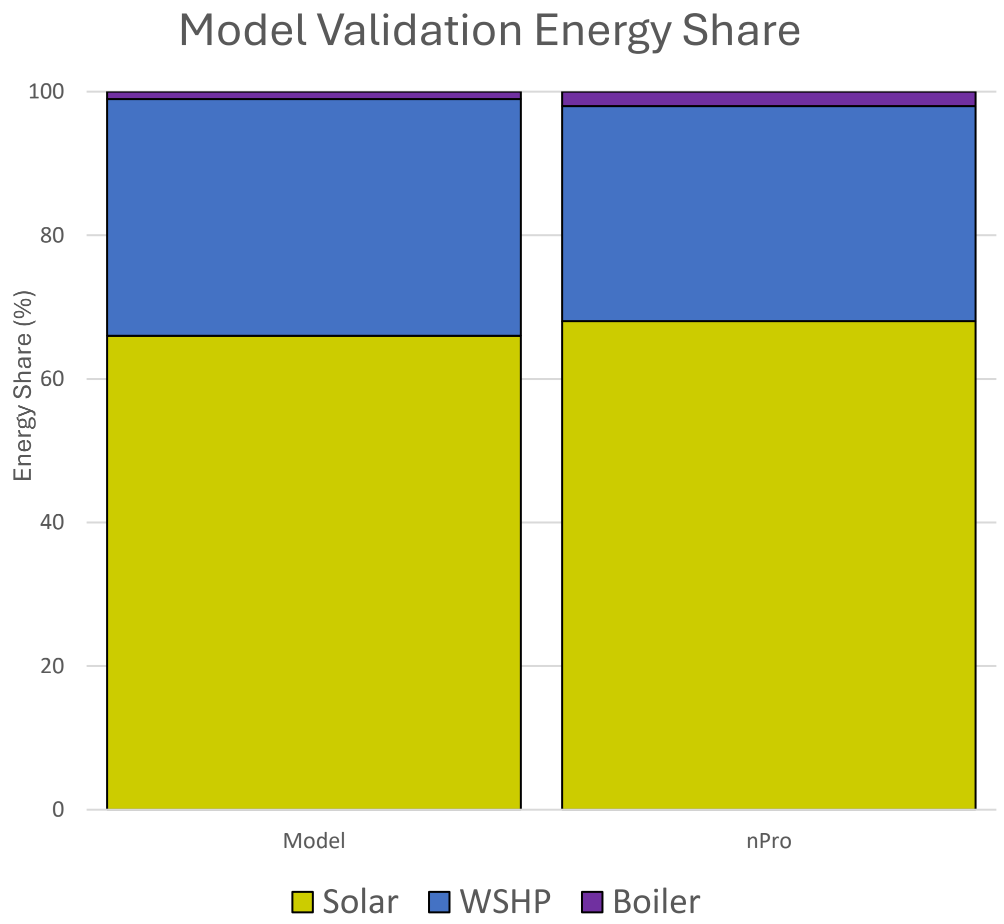
Validation

Validated with nPro, less than 3% deviance in energy share

Peak Energy Demand varied <10% with all demand profile estimations

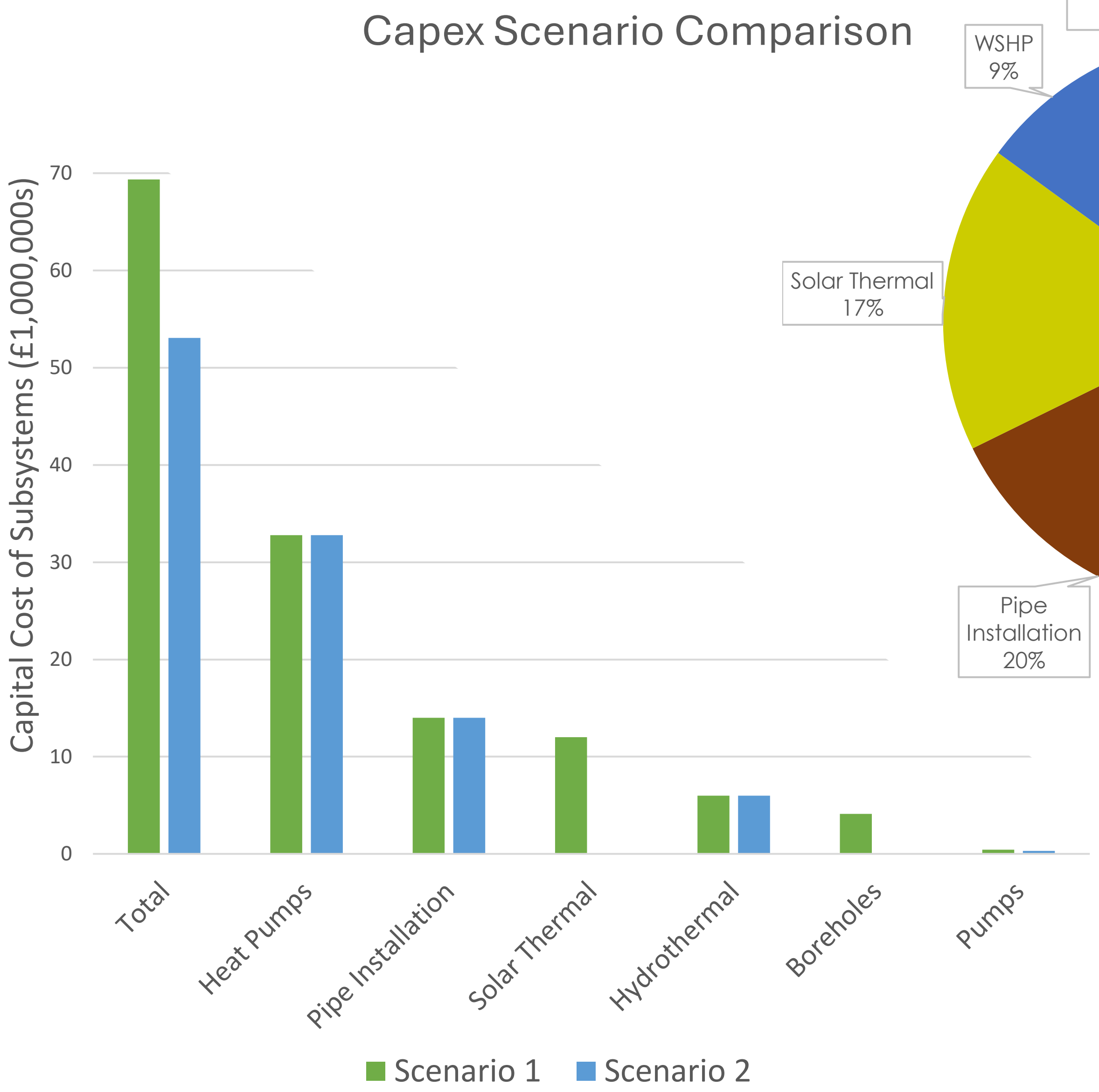
Capital Costs taken from nPro

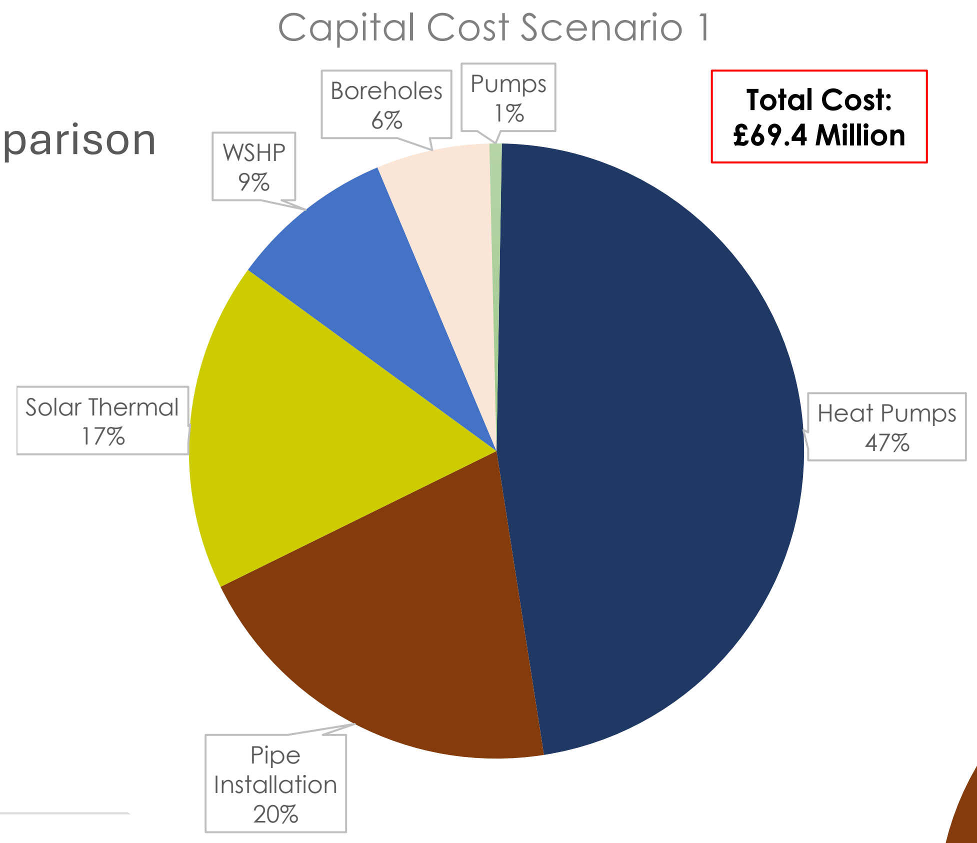
<10% variation of capital costs in comparison to economic case study†

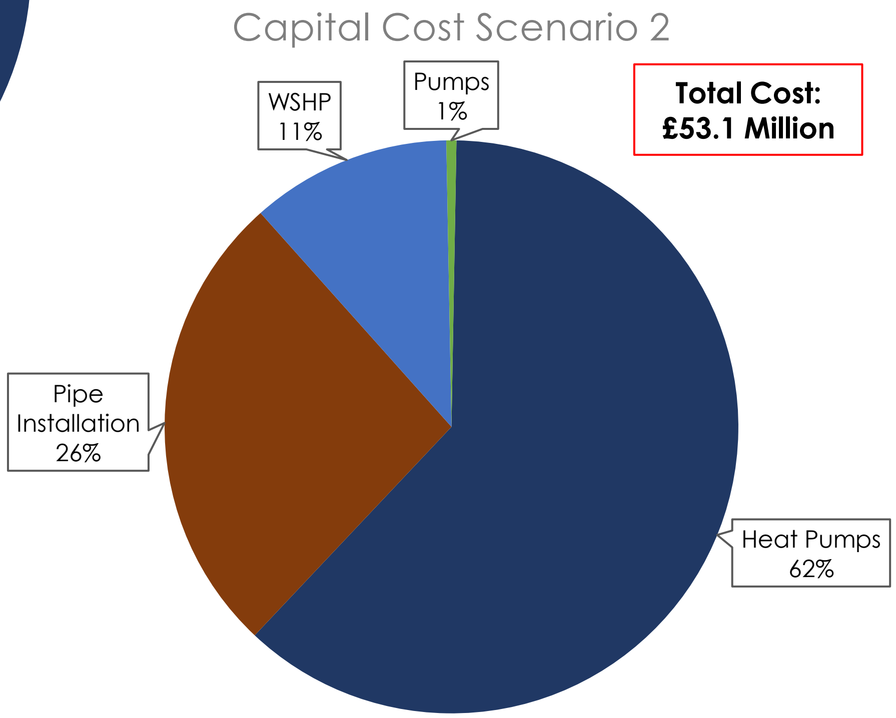


†:'*Techno-economic analysis of fifth-generation district heating and cooling combined with seasonal borehole thermal energy storage*', 2023

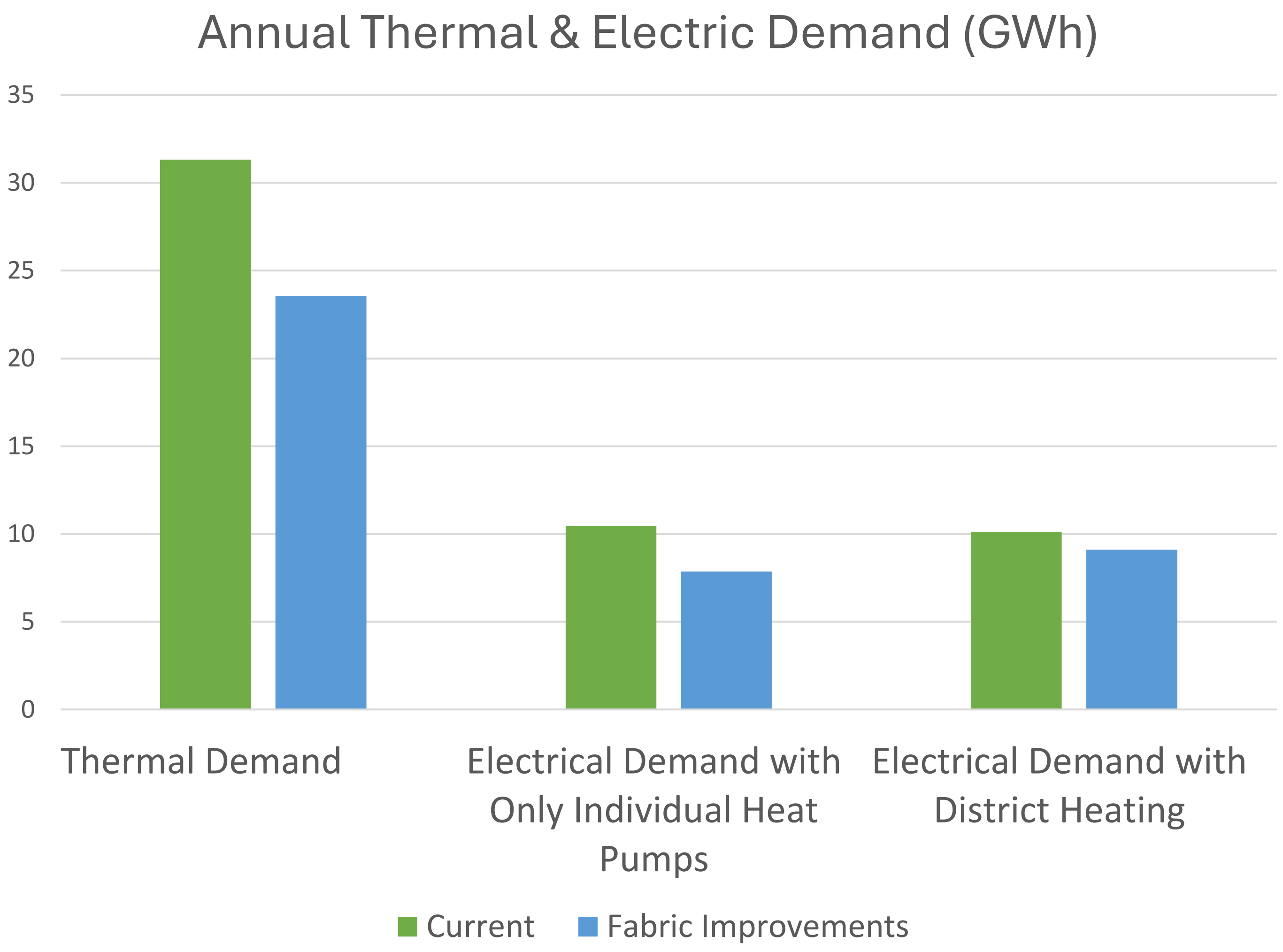
Capital Cost

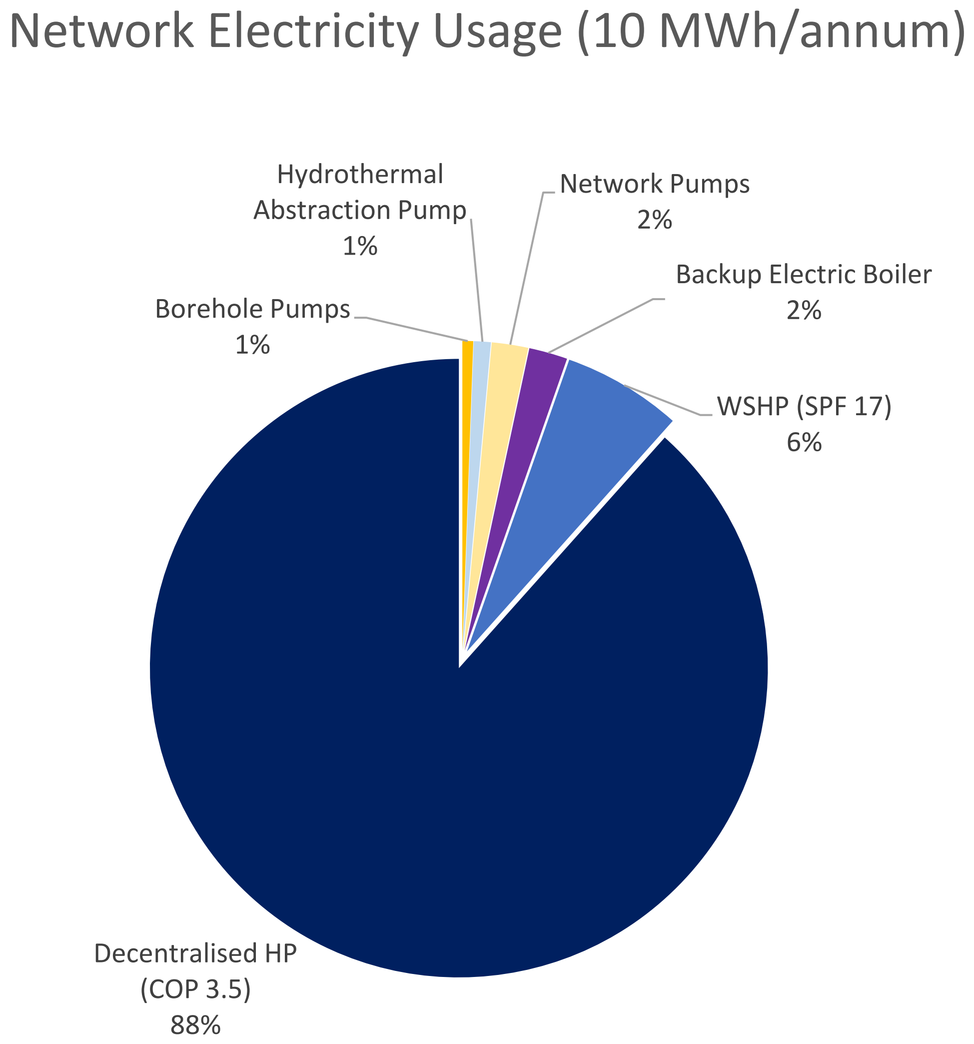






Energy Usage



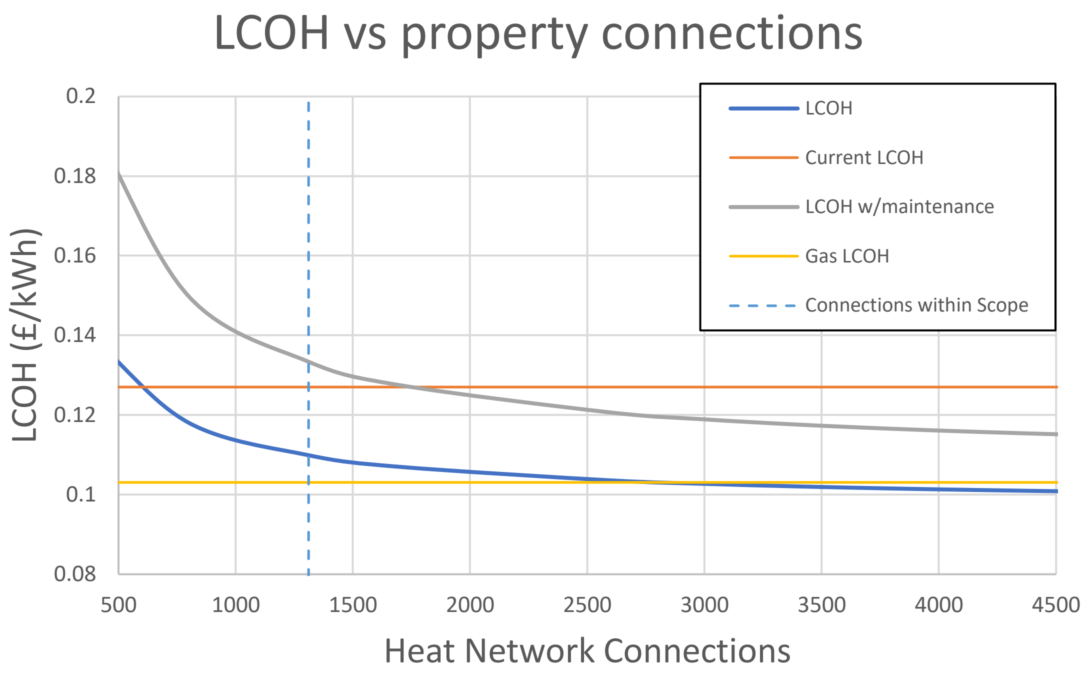


Consumer Cost

£400 a year saved per property if capital and maintenance costs covered

Cost exceeds current LCOH if maintenance costs are considered at 1% of Capital Cost

This doesn’t consider government incentives or tariffs



Source: Calculation, South Ayrshire LHEES

	LCOH (£/kWh)	Consumer Energy Cost (£/annum)	average household savings over current (£/annum)
Current	£ 0.127	£ 3,970,000	£ -
100% Gas	£ 0.103	£ 3,230,000	£ 570
Direct Electric	£ 0.340	£ 10,650,000	-£ 5,100
Scenario 1	£ 0.110	£ 3,440,000	£ 400
Scenario 1 w/ maintenance	£ 0.133	£ 4,180,000	-£ 160
Fabric Improvement	£ 0.127	£ 2,990,000	£ 750
Scenario 2	£ 0.131	£ 3,100,000	£ 670
Scenario 2 w/ maintenance	£ 0.155	£ 3,650,000	£ 240

Environmental Analysis

Zero Gas Heating

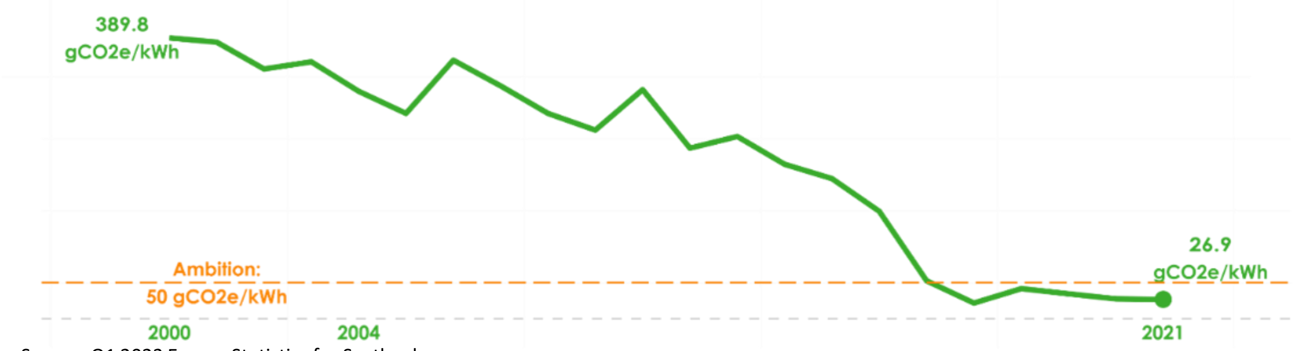
+

Heat Pumps

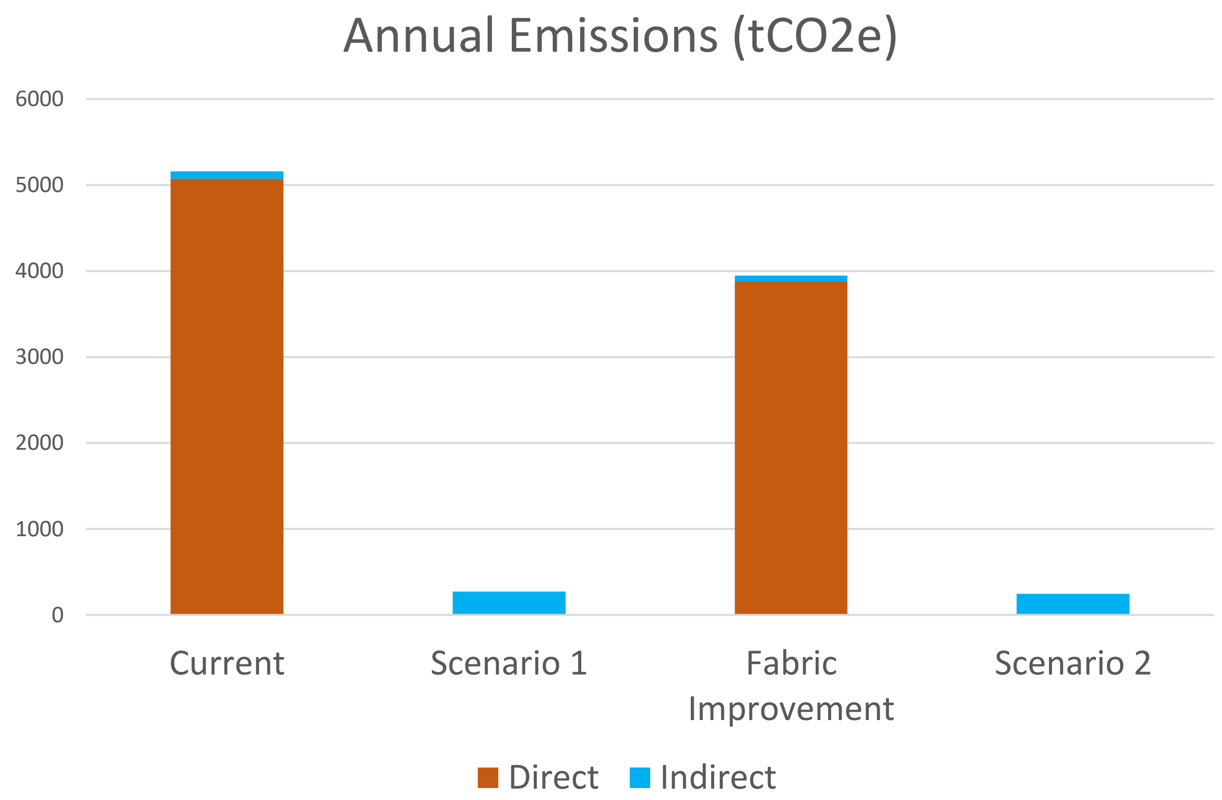
>94% Reduction in Heating Emissions

	Direct	Indirect	Total	% Reduction
	Annual Emissions (tCO2e)			
Current†	5100	100	5200	-%
Scenario 1	-	300	300	94%
Fabric Improvement	3900	50	3950	24%
Scenario 2	-	250	250	95%

Source: Model
†: Scottish Government



Source: Q1 2023 Energy Statistics for Scotland



Source: Model

Conclusions

A 5GDHN is feasible in Wallacetown reducing emissions and fuel poverty in the Area

Fully Subsidised District Heating could save residents £400 a year in energy bill

Fabric Improvements could save residents £750 a year in energy bills

Despite raising the LCOH, Combining these improvements could save residents £665 a year in energy bills

Significant Reductions in emissions of over 94% for district heating

Fabric Improvements will reduce emissions by 23.5%

High upfront cost

Maintenance cost and complexity

Further Work

Support through the Scottish Heat Network Fund could be utilised to investigate further

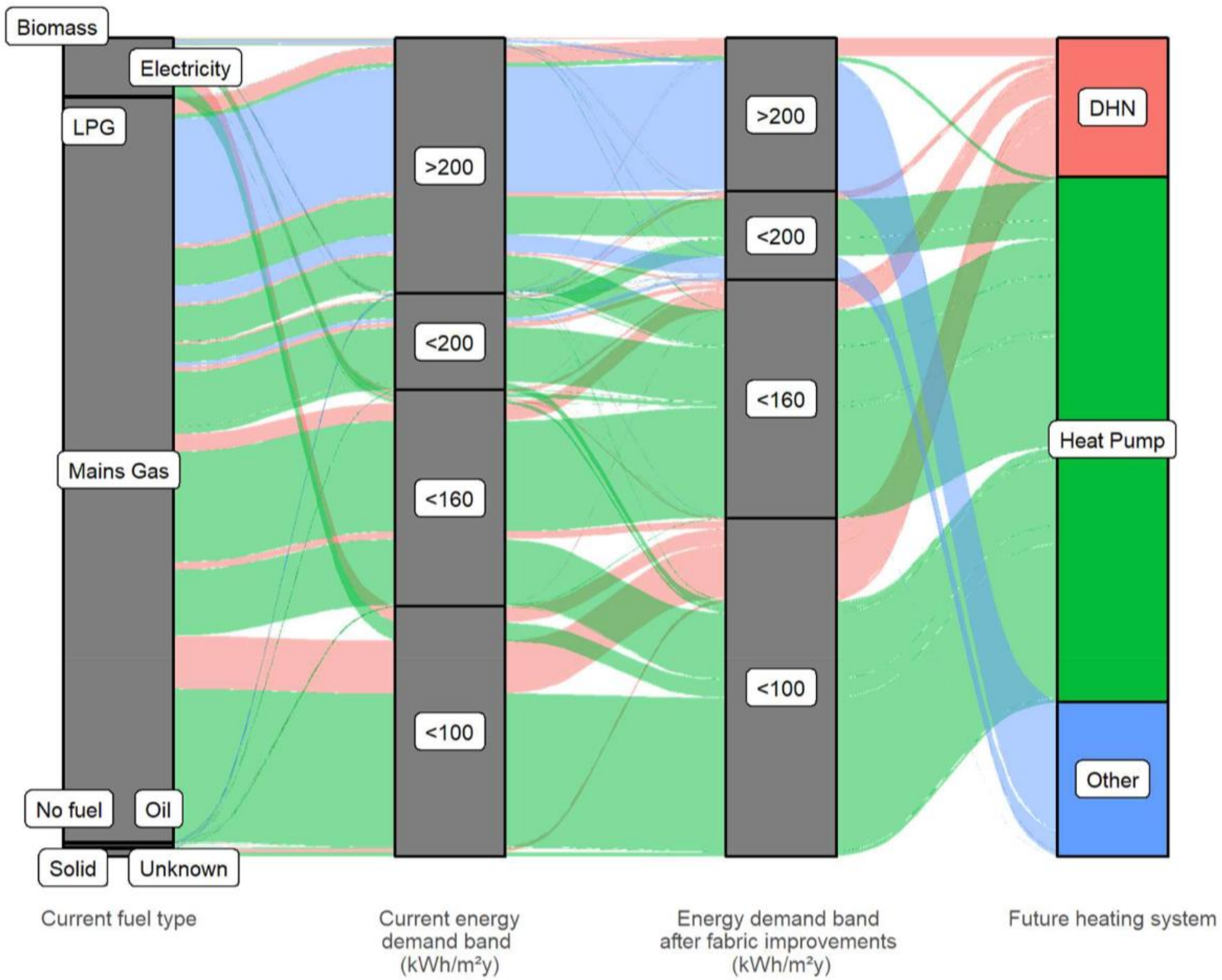
Visualise comparison of model against real systems

Integration of Anchor/non-domestic loads

Refining economic analysis for Scotland, with specific subsystem & quoted installation costs

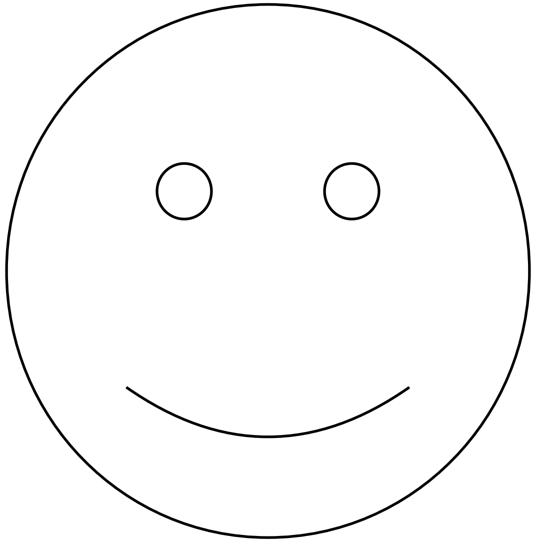
Ground Stability Analysis

Figure 40: Decarbonisation pathway for domestic properties in Ayr



Source: South Ayrshire LHEES

Thank You for Listening



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Royal Charter since 1964

Useful Learning since 1796