LoT-NET

Advisory Board Meeting 24th March 2021
Mid-term Report: Part 1

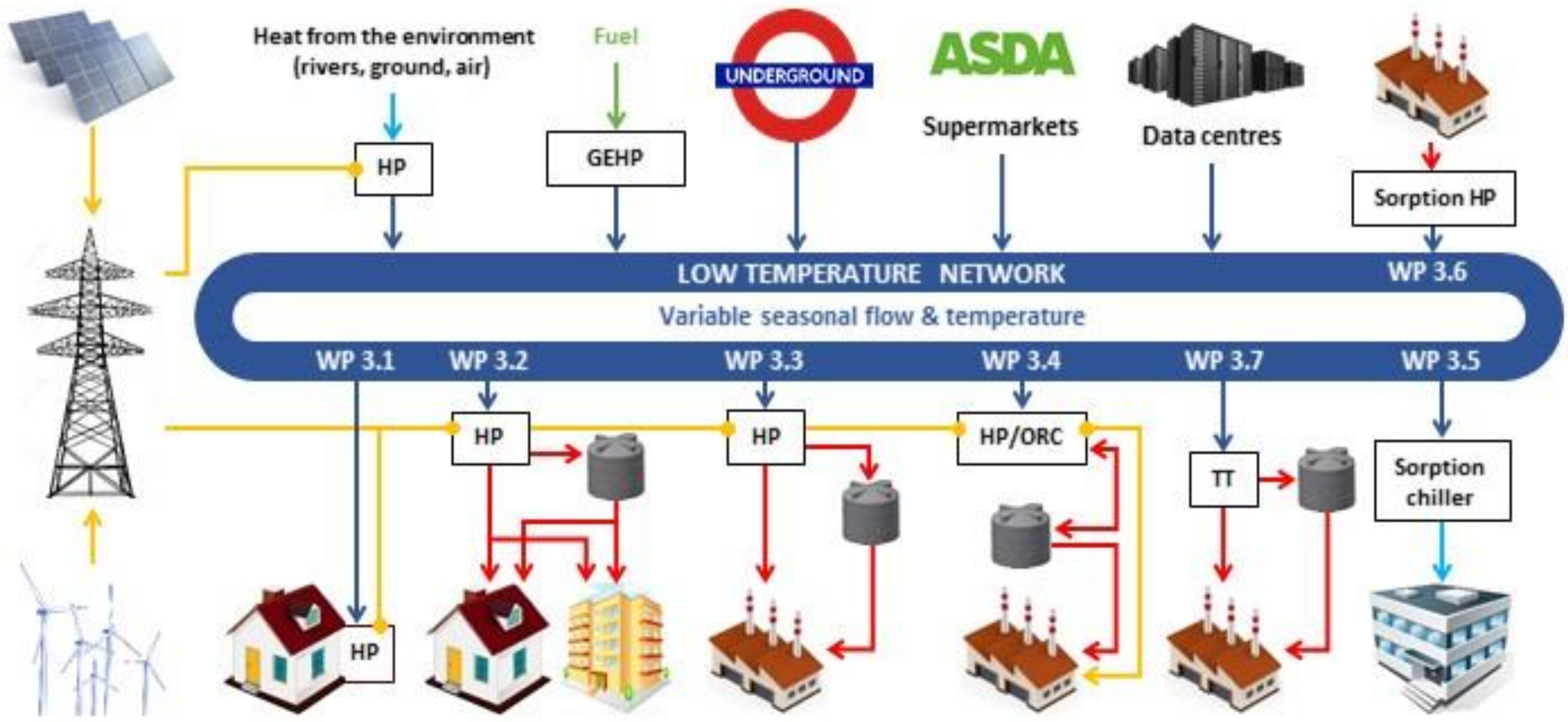
Low Temperature Heat Recovery and Distribution Network Technologies

1. Context
2. Original proposal
3. Original Work Packages
4. Dissemination and engagement
5. Equality, Diversity and Inclusion
6. Early career researchers
7. Risk assessment
8. Progress
9. Integration and future plans

1. Context

- LoT-NET is a 5-year, £5.5M FEC project, funded by EPSRC and commencing 1st January 2019
- The mid-term report to the AB report has two purposes:
    - inform the AB (as requested) how the separate research streams will be integrated and present the 'bigger picture'
    - to prepare for the mid-term review that will be required by EPSRC
- The report also has sections on, for example, Risk Management and EDI that will be requested by EPSRC

2. Original proposal



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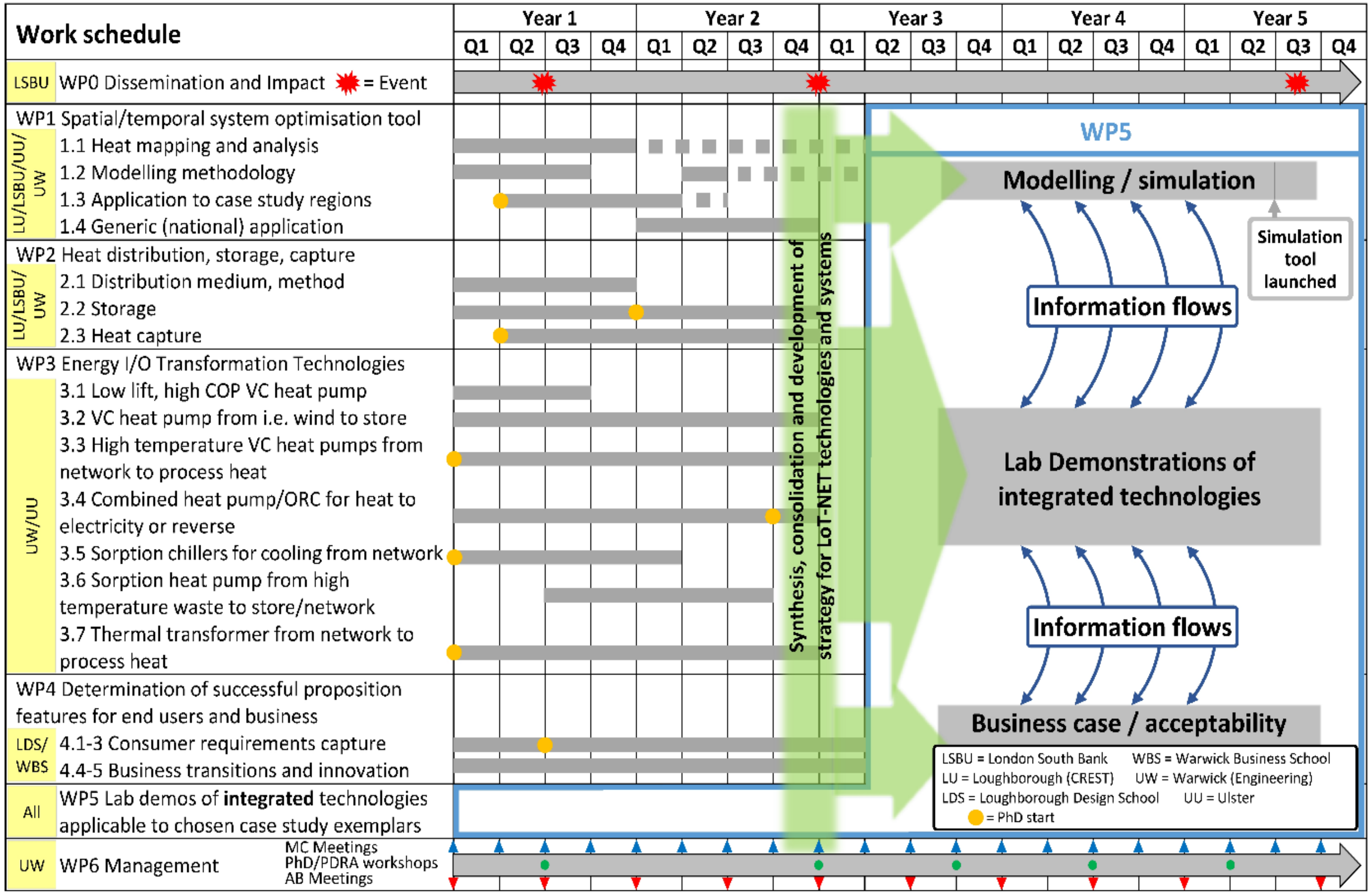
2. Original proposal

… to prove a cost-effective near-zero emissions solution for heating and cooling that realises the huge potential of waste heat and renewable energies by utilising a combination of a low-cost low-loss flexible heat distribution network together with novel input, output and storage technologies.

3. Original Work Packages



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4. Dissemination and Engagement

SIRACH (Sustainable Innovation in Refrigeration, Air conditioning and Heating)

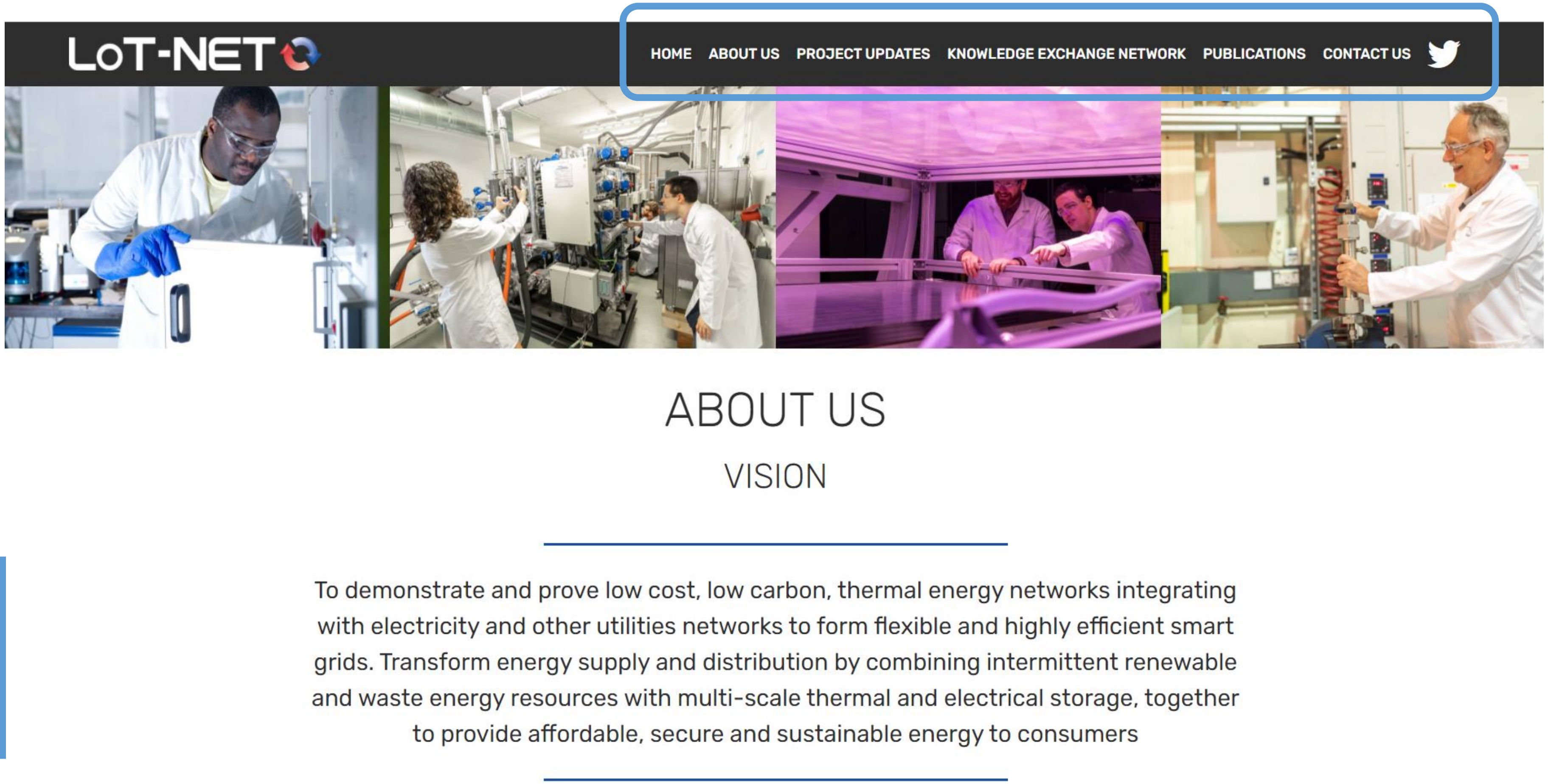
- Student event 9 June
- 3 minute thesis – 31 July
- Student event – 24th September 2020
- 17th February 2021- Energy Systems - Looking forward to 2050. Webinar broadcast. 11th May 2021 -Lessons learned from integration of heat pumps – The challenges and opportunities - details coming soon
- 21st September 2021 - Hydrogen for Heating and Cooling details coming soon
- Face to face 2021?

4. Dissemination and Engagement

New LoT-NET website

- New design
- New headings
- New content

Make sure to check it out and feel free to share your feedback!



4. Dissemination and Engagement: related projects and further successful research awards

- **EnergyREV:** David Elmes has the role of championing heating and cooling in the EnergyREV academic consortium that's part of the Industrial Strategy's Prospering from the Energy Revolution: (PFER) programme
- PFER Detailed Design Programmes. Team members supported the successful award of two Detailed Design programmes within PFER: the **GreenSCIES** project in Inslington, London (Resvesz, Maidment) and the **Regional Energy System Operator** project in Coventry (Elmes)
- Loughborough, Warwick, Ulster and LSBU are all involved in the EPSRC industrial decarbonisation project **DELTA PHI** (DEcarbonisation of Low TemperAture Process Heat Industry)
- Warwick, Ulster and Loughborough Design School are collaborating in an EPSRC 'Working with CREDS' project **HP-FITS** researching the combination of electric heat pumps with thermochemical heat stores in demand-side management

4. Dissemination and Engagement: related projects and further successful research awards

- **Mission Innovation Challenge 7** (Affordable Heating and Cooling) has funded two smaller projects via EPSRC. They are both required to report via LoT-NET:
    - **Sorption Heat Pump Systems** [UW] is an international collaboration on chemisorption heat pumps
    - **Comfort and Climate Box** [UU] (EPSRC EP/V011340/1 01/06/20 to 31/08/22) is a 26 month project aligned to IEA HPT Annex 55 CCB where global best practice in single family home air source heat pump and thermal storage integration is being assessed
- Loughborough is involved in the CREDS heat challenge providing inputs in relation to thermal energy storage and awareness of other key developments
- Loughborough is involved in the Active Building Centre (ABC) project being led by Swansea developing compact thermal energy stores for air source heat pump applications and gaining insight into other aspects of the ABC project

5. Equality, Diversity and Inclusion

- Developed an Equality, Diversity and Inclusion plan, using the template from CREDS
- Aim for an inclusive culture within LoT-NET
- Working group, led by Prof Neil Hewitt, includes early, mid and established career colleagues, including PGR
- Our four institutions support the gender equality Athena SWAN Charter and hold at least a Bronze award, with the lead University, Warwick, holding a Silver award
- Management Committee have all undertaken ED&I training within their institutions, including addressing unconscious bias and follow good recruitment practice when appointing new researchers to the project
- Establishing a reporting system for any individual associated with the project to report poor practice, e.g. bullying, harassment, lack of inclusion or opportunity relating to protected characteristics

6. Early Career Researchers

As part of LoT-NET, a Knowledge Exchange Network (KEN) has been established, focused on Early Career Researchers. The aims of the network are to:

- Publicise and to run event in topics related low-temperature networks
- Develop a scientific knowledge base by pulling together results from LoT-NET and sister projects
- Engage early carrier researchers and to provide them a platform which not only enables them to showcase their research but to collaborate with their peers both from academia and from industry

Thus far, we have successfully organised three KEN events with large number of attendees from both industry and academia. Our next event is currently being scheduled for April 2021

7. Risk assessment

Process:

1 risk identification

2 risk analysis

3 risk evaluation and ranking

4 risk mitigation/treatment

5 risk monitoring and review

Review of the risk register is a standing agenda item at each management meeting

7. Risk assessment

COVID-19:

- Staff have been redeployed from lab-based work to work packages not based in labs
- Work has shifted from experimental to modelling/theoretical within work packages
- Researchers have worked closely with staff to implement limited-access schedules.
- The management team have also shifted the schedules of work to reflect long term sickness and constraints in recruiting appropriate staff
- Regular Teams meetings are proving to be reasonable in terms of staff interactions, research meetings and supervision

7. Risk assessment

COVID-19:

- Lab work is now more able to continue although numbers of staff in labs is again subject to restrictions
- Dissemination of findings and progress at national/international conferences over the last year was very limited though our SIRACH dissemination activities have continued online
- The ability to achieve successful creative, collaborative and interdisciplinary work is harder without in person meetings
- On the positive side of opportunities, the programme has moved ahead in developing or confirming involvement in larger-scale, smart energy systems than the “lab demonstrations of integrated technologies” proposed at the start

8. Progress
Overall

- The Y1-2 focus on capture, storage and conversion technologies and individual work packages has progressed broadly as expected in Y1-2
- In addition, we have developed the modelling environment that will enable the various technologies to be assessed for use and integration into energy systems
- We also have the intention to expand the modelling capability to include electrical energy demand
- Overall strategy and phasing as proposed but added research on larger scale real world energy systems in place of the 'lab demonstrations of integrated technologies' initially proposed for Y3-5

8. Progress (WP1 – WP3)

WP1

- WP 1.1: Heat Mapping and Analysis
- WP 1.2: Model Development
- WP 1.3: Application to Case Study
- WP 1.4: Generic (national) application

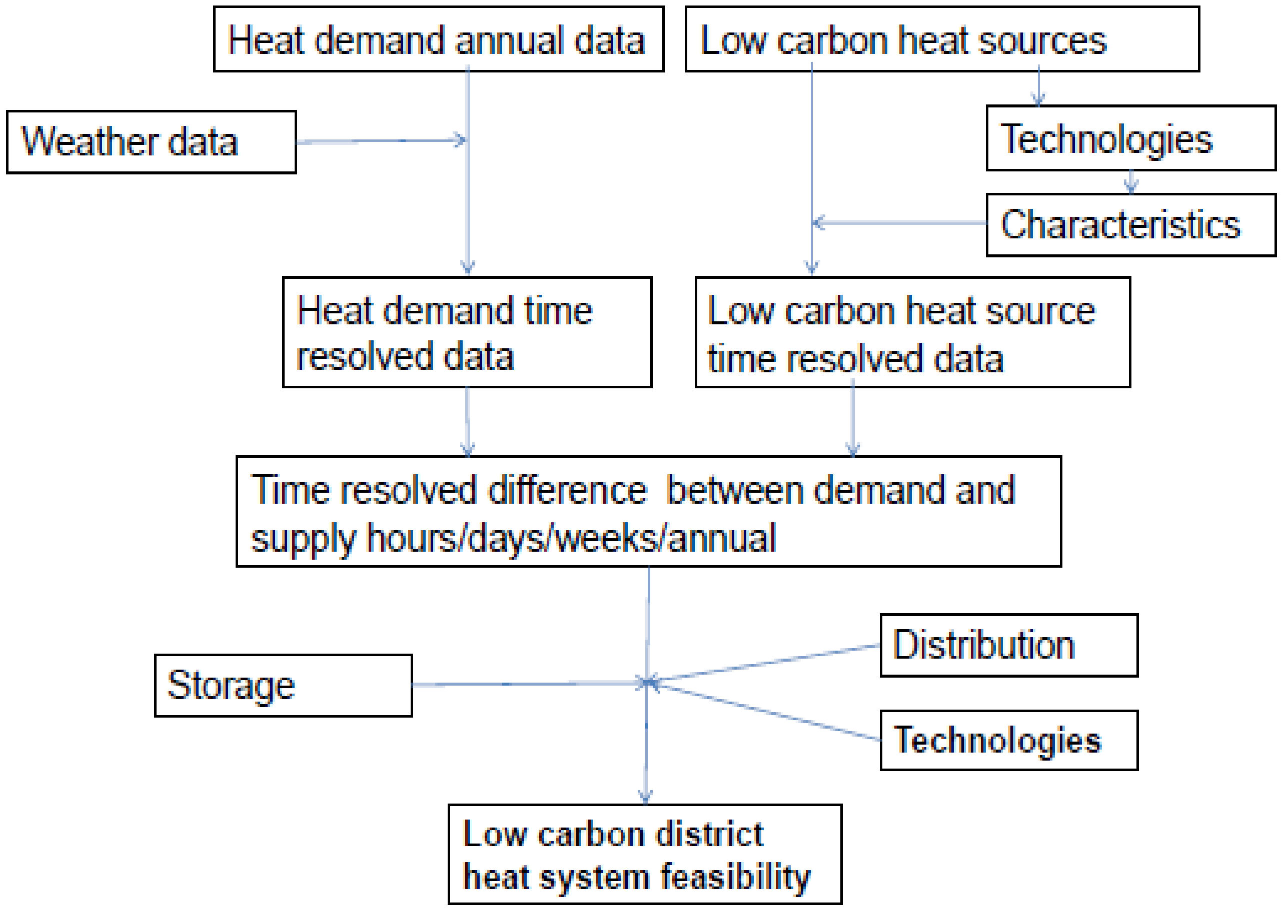
WP2

- WP 2.1: Distribution medium
- WP 2.2: Storage
- WP 2.3: Heat capture

WP3

- WP 3.1: Low temperature lift, high COP VC heat pump
- WP 3.2: VC Heat pump for demand side management
- WP 3.3: High temperature VC heat pumps from network to process heat
- WP 3.4: Combined heat pump/ORC for heat to electricity or reverse.
- WP 3.5: Sorption chillers for cooling from network (commercial use)
- WP 3.6: Sorption heat pump from HT waste to network.
- WP 3.7: Heat transformer from waste heat to process heat and output to network

Work Package 1 – Modelling tool



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Work Package 1.1 – Heat mapping and analysis

- Define building types and number in an area
- Define typical building occupancy
- Use hourly weather data and building form and orientation to generate heat gains and heat loads
- Include domestic hot water

Type of dwelling [1]	
Detached	22.94%
Semi-detached	35.29%
Terraced	23.20%
Flat	18.58%
Number of dwellings in Loughborough	23478
Number of adult women living in dwellings (average)*	1
Number of adult men living in dwellings (average)*	1
Number of children living in dwellings (average)*	1

Table 1. U-values of dwellings' fabric and air changes per hour [24][10].

	Basic U-value (W/m^2K)	Improved U-value (W/m^2K)
External wall	0.45	0.11
Floor	0.60	0.10
Ceiling	0.25	0.13
Glazing	2.94	0.70
Infiltration (air changes per hour, N_{air})	0.50	0.06

Table 1. Basic dwelling geometrical data.

	Floor area (m^2)[10]	Heated volume (m^3)[10]	Total windows area (m^2)[1]	Width (m)[1]
Detached	136	286	34.00	10
Semi-detached	87	186	21.75	10
Terraced	57	142	14.25	10
Flat	56	140	14.00	10

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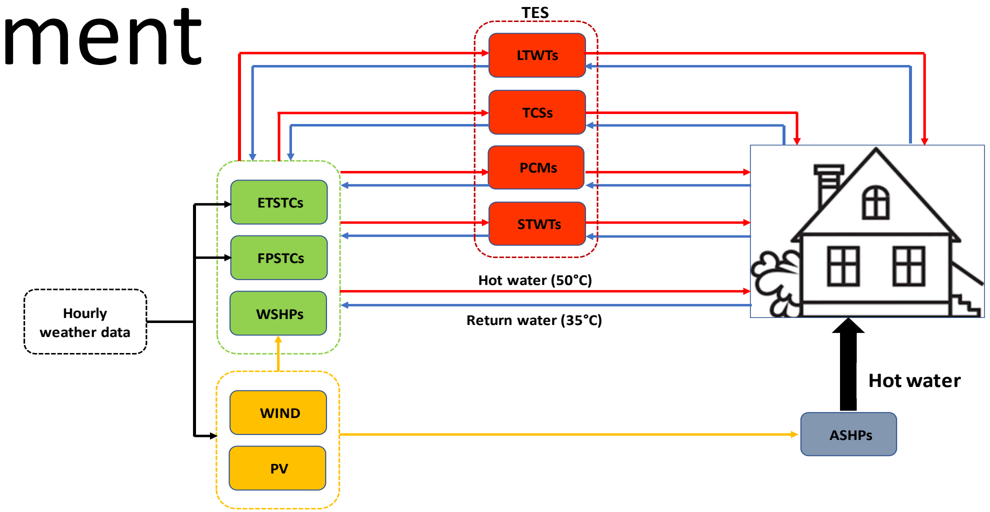
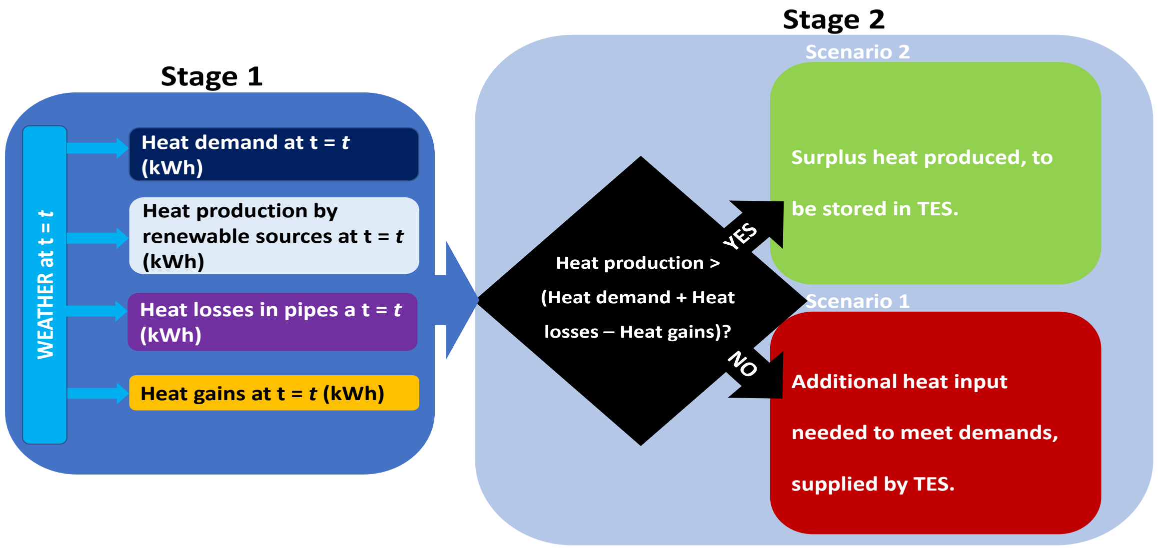
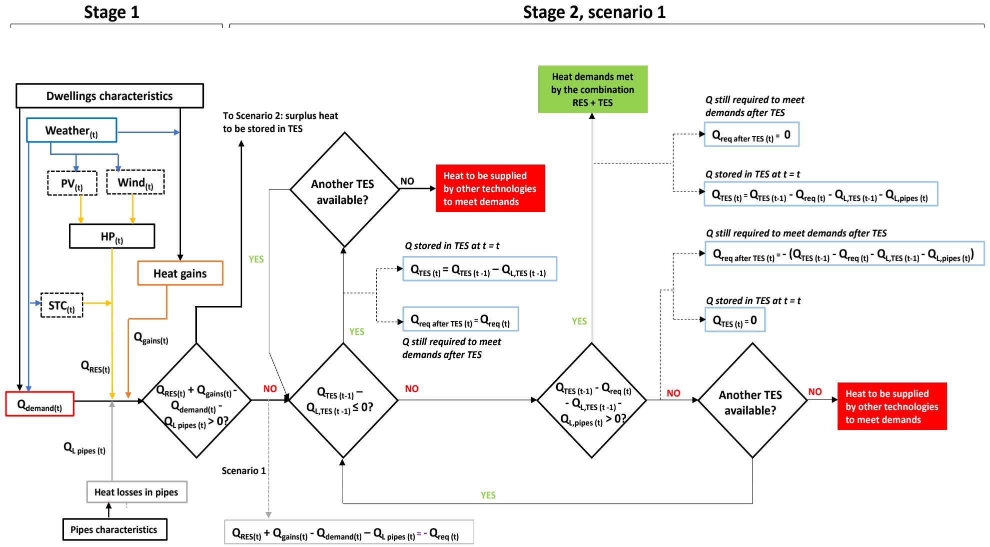
Work Package 1.2 – Model development



Calculate time varying heat loads.
Calculate time varying heat production for different mixes of renewable heat generation.
Specify type and distribution of storage.
Specify general operational mode, temperatures, storage priority.
Specify optimisation parameter for example, cost, efficiency.





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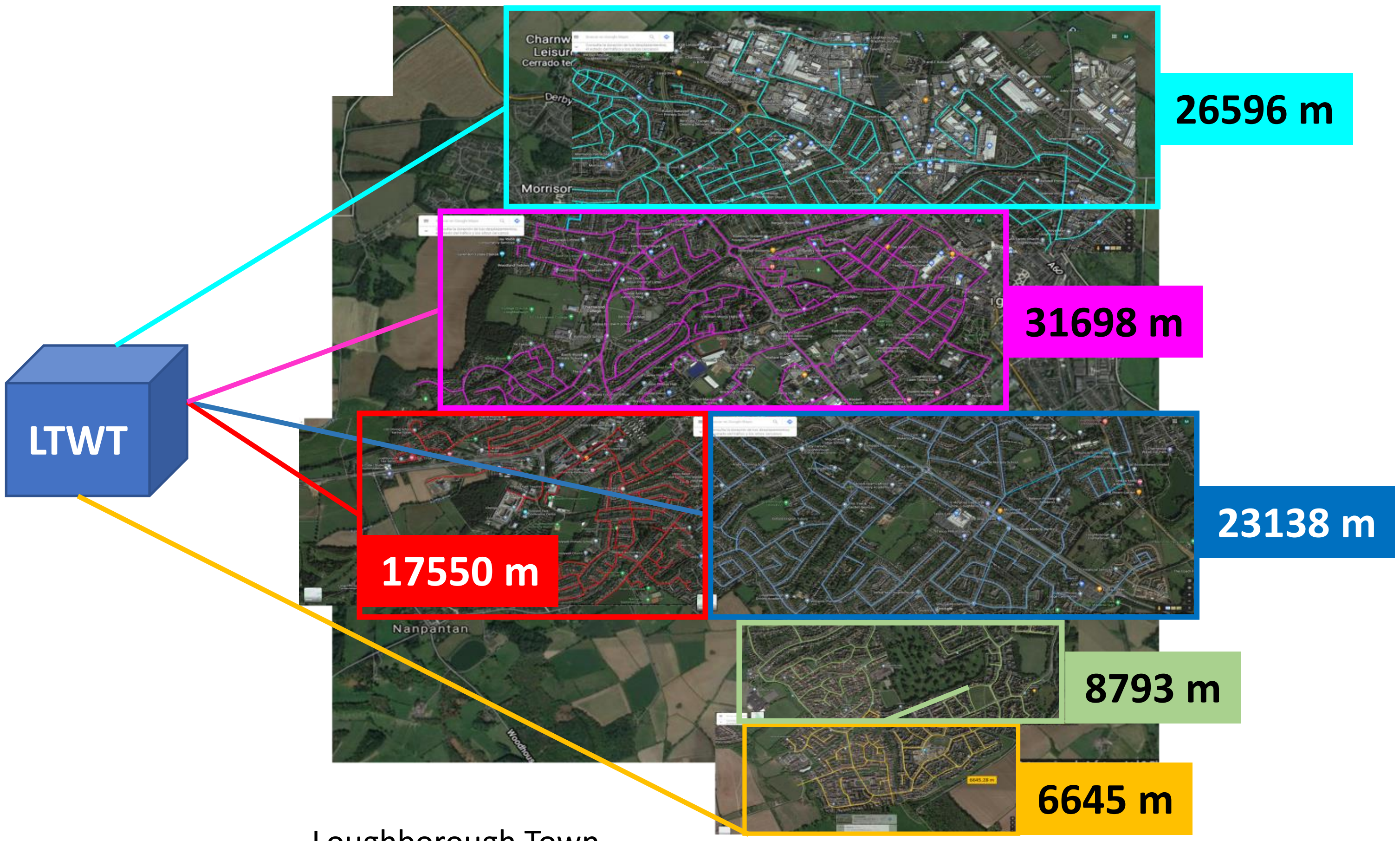
Work Package 1.3 – Application to case study



Loughborough Town

Initial simulations for the Loughborough area have been performed over a two year period with the condition that the heat source for domestic space and water heating should be 100% renewable with heat demands met for each hourly time period.

Key findings are that air source heat pumps using power generated from wind turbines with large scale thermal storage (125,000m^3) with a storage temperature of 80-90° C is likely to deliver a least cost system.

Work Package 1.3 – Application to case study

- Wind turbines are favoured in the costs analysis compared to PV since generation aligns better with demand.

- Air source heat pumps although with lower COP are significantly cheaper than ground source heat pumps.

- Boosting the storage temperature using high temperature heat pumps greatly increases the heat storage capacity.

- The large store SA/Vol ratio makes long term storage effective due to low heat losses.

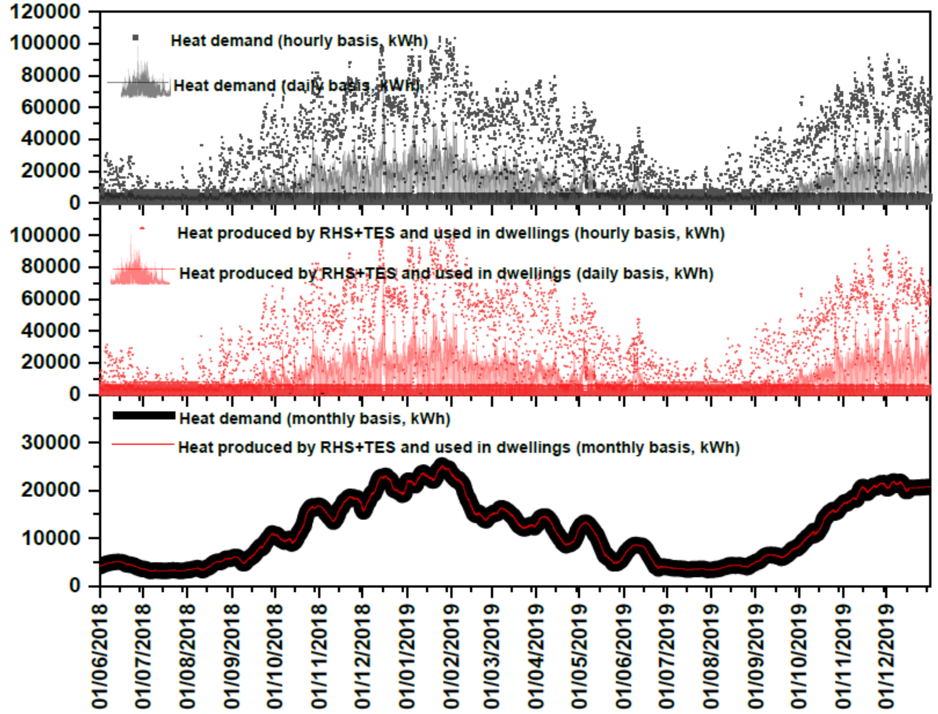


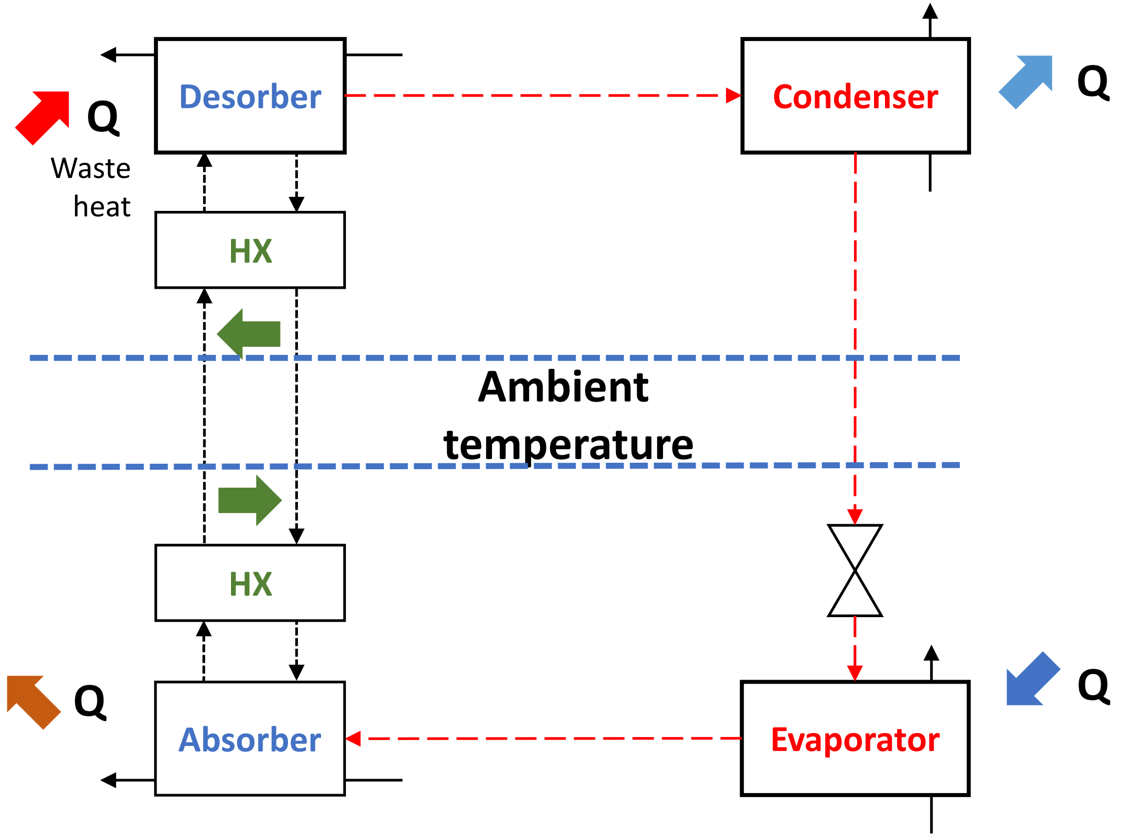
Fig. 1. hourly, daily and monthly total heat demand and heat delivered by a combination of RHS+TES for the town of Loughborough.

Work Package 2.1 – Distribution medium

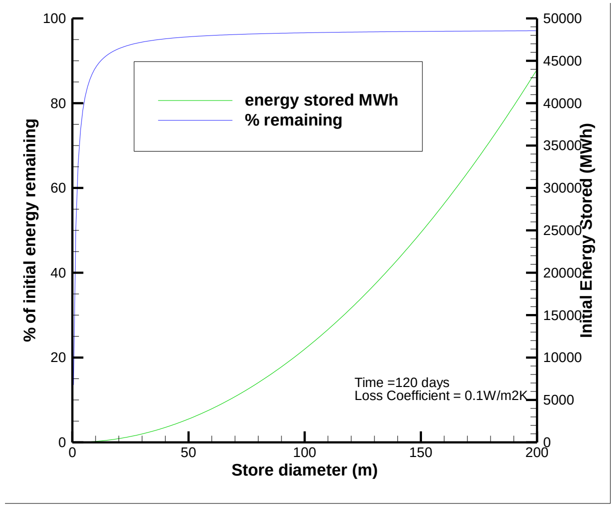
- TC options use fluids at ambient temperature (~zero loss).

  e.g. absorption of water vapour in NaOH
- 'Low temperature' (55/45°C) and 'Ambient' (14/4°C) loops.
- Characterised both by simple efficiency and by 'DeltaT H_2O'

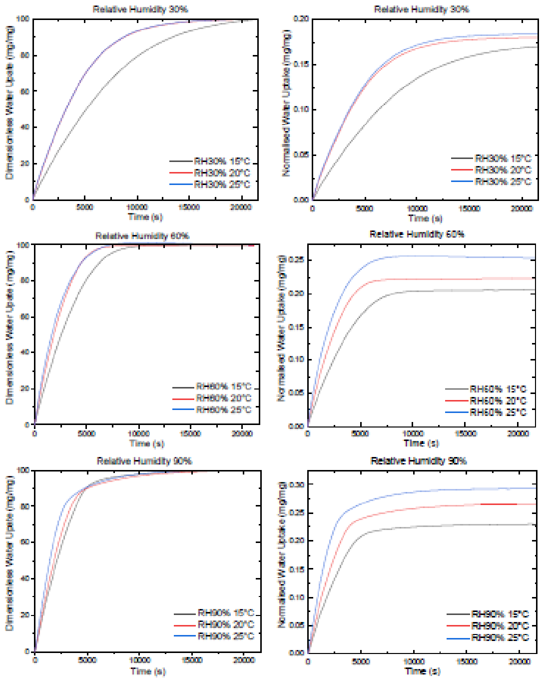
  10°C would correspond to a normal LT system with a drop from 55 to 45°C and 100°C would require only 10% of the flow to be pumped compared to a conventional system.
- The main value of a reduction in the flow rate is in the reduced capital cost of trenches etc.
- For LT loops the TC systems could not achieve more than about 75% efficiency with a DeltaT H_2O of around 70°C.
- For ambient loops the efficiencies > 95% and DeltaT H_2O in '00s - pipe diameters reduced by a factor of four.



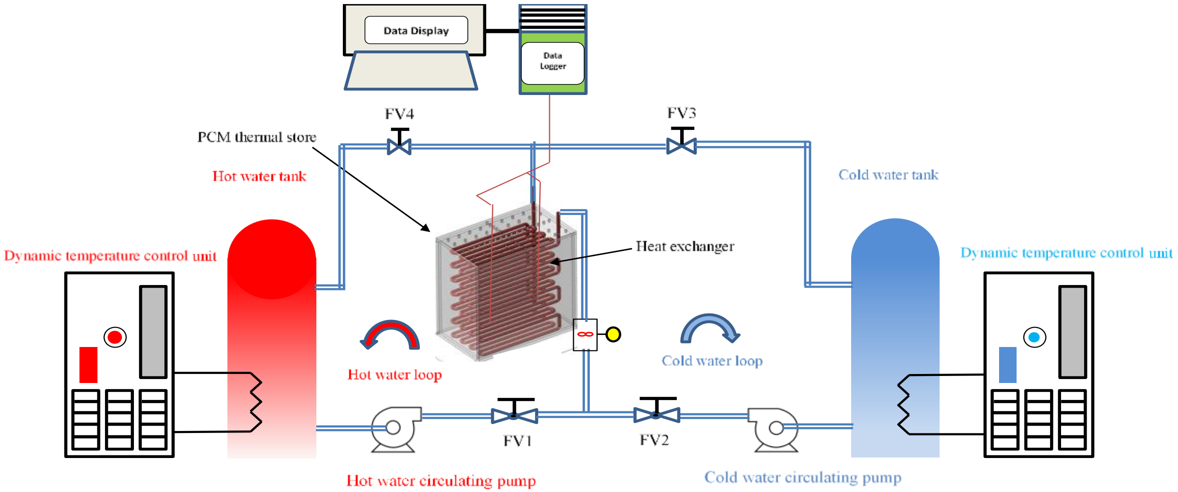
Work Package 2.2 – Storage



Sensible water based heat storage.
The importance of store size:
H = 20m
Initial store temperature 80°C

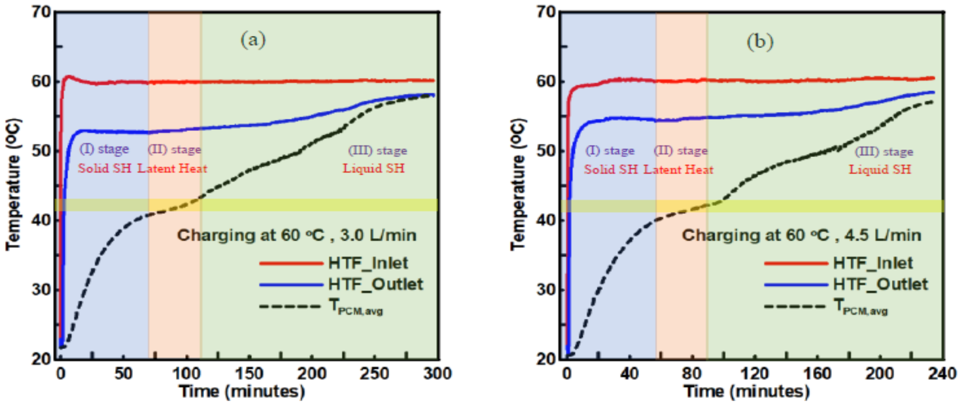


Measurement of hydration of Silica Gel impregnated with 15% MgCl2 for different hydration conditions



Schematic of lab based latent heat thermal storage test rig (Above)

Examples of experimentally measured store charging process (Below)



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Work Package 2.3 – Heat capture opportunities

The different waste heat sources investigated to date are including the following categories:

- Electricity substations, Cable tunnels (Estimated 479 MW)
- Supermarkets (Estimated 959 MW)
- Cold stores (Estimated 416 MW)
- Crematoriums (Estimated 75 MW)
- Data centres (Estimated : 1939 MW)
- Cement/Iron & steel industries (Estimated : 68/195 MW)
- Paper and pulp (Estimated :10 MW)
- Wastewater treatment plants (Estimated : 2929 MW)
- Underground Railways (Estimated : 38 MW)

Work Package 2.3 – Heat capture opportunities

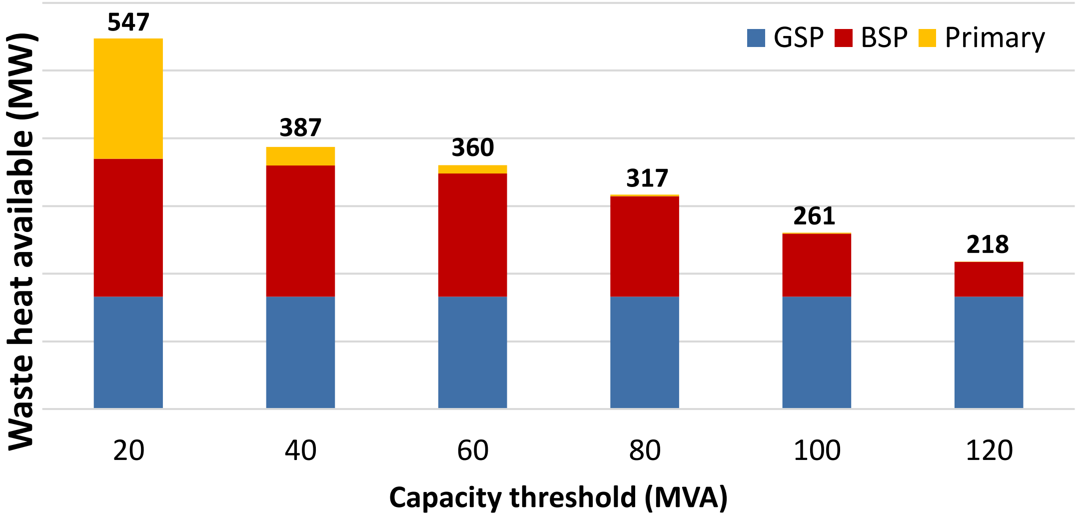
EXAMPLE - SUBSTATIONS

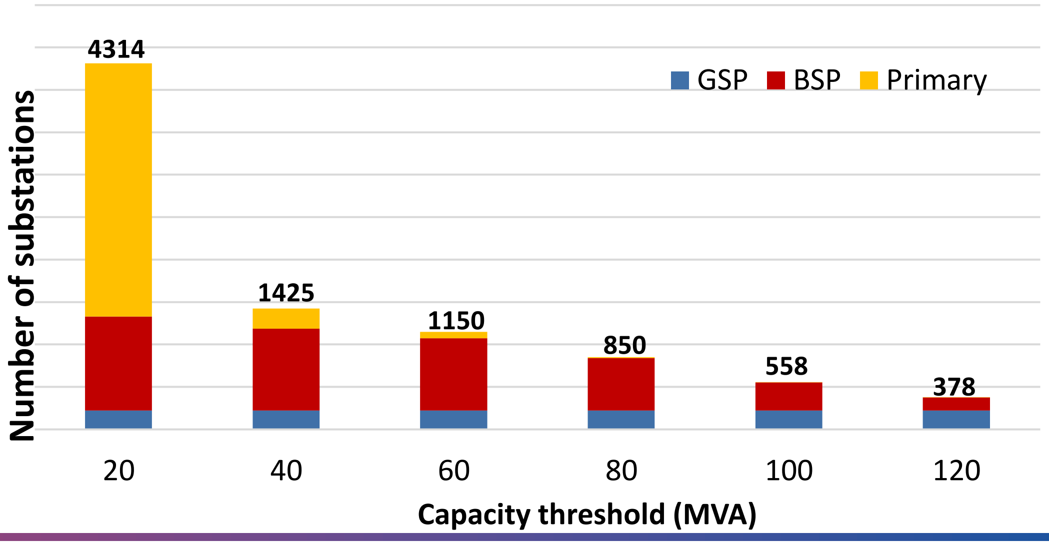
Headline numbers (considering only substation with capacity ≥ 60 MVA) :

1150 substations in England, Wales, N Ireland (excl. sites in Scotland)

Energy: 3.2 TWh/year for substations ≥ 60 MVA

Average heat output per site: ca. 313 kW for substations ≥ 60 MVA





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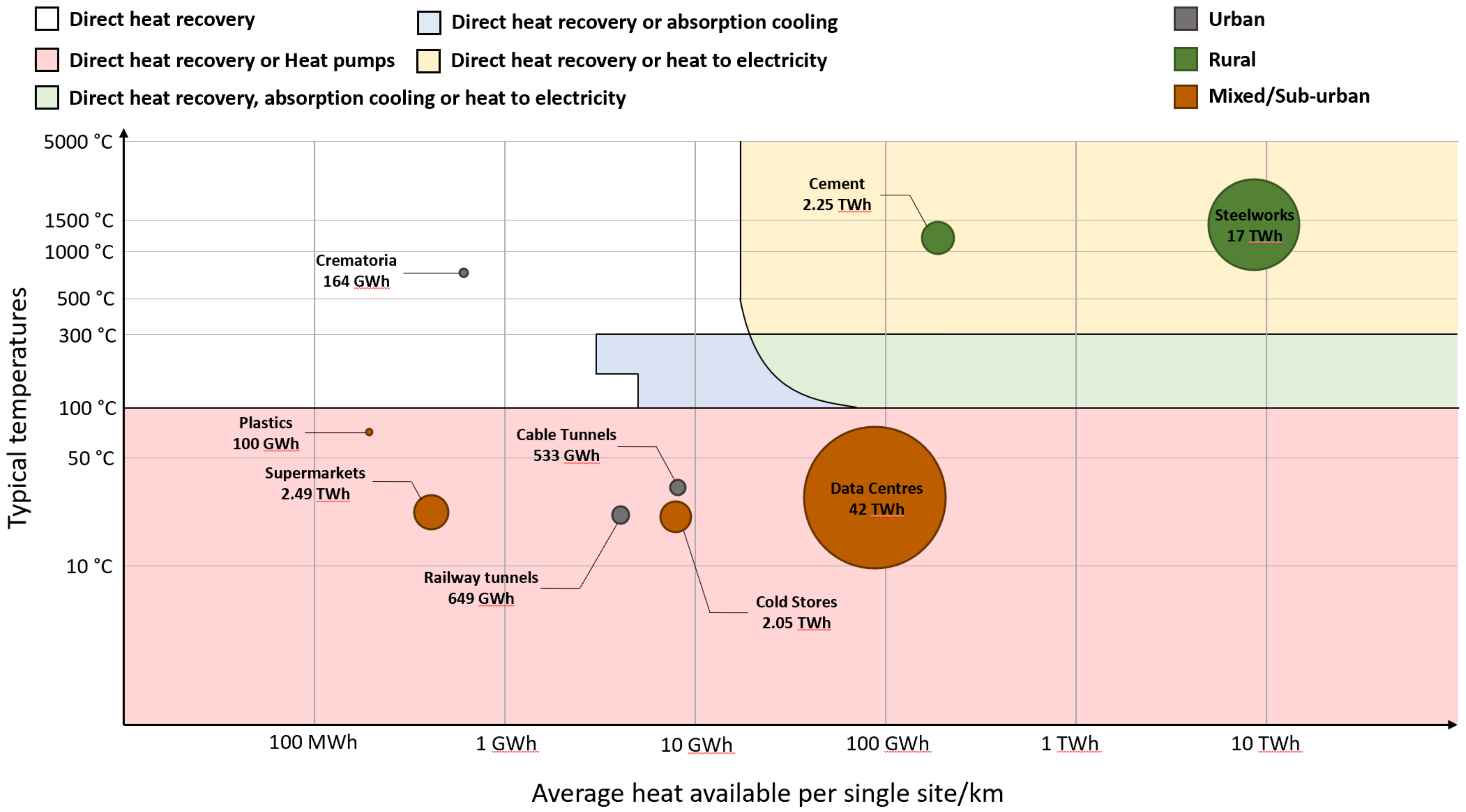
Work Package 2.3 – Heat capture opportunities



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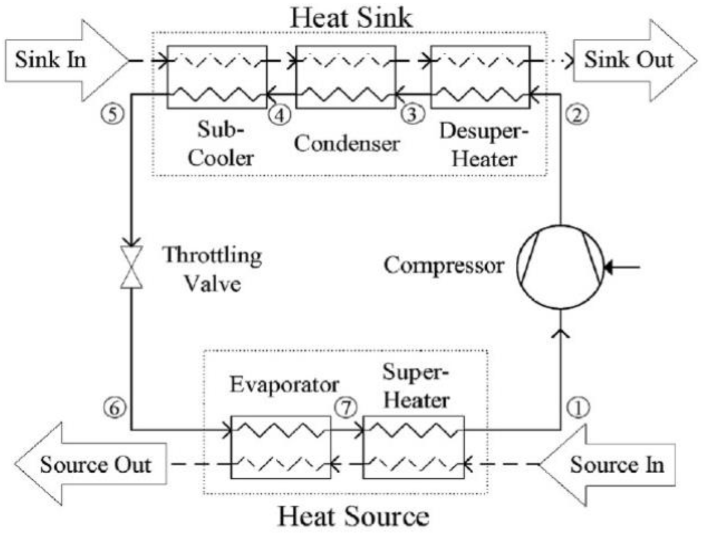
Work Package 3.1 – Low temperature lift, high COP Vapour Compression Heat Pump

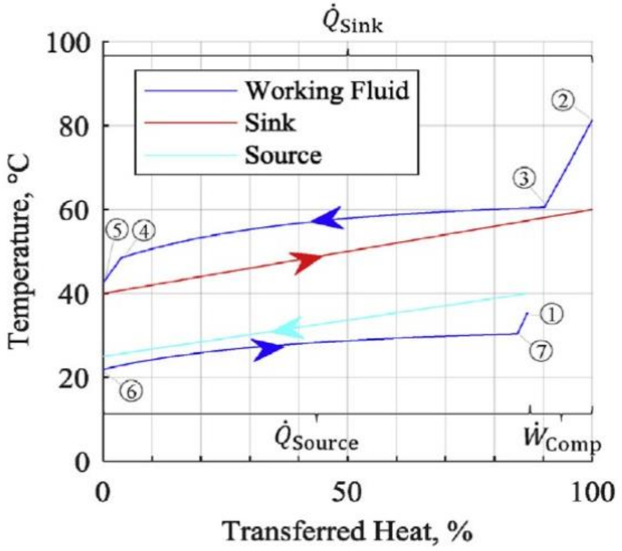
Standard Heat Pump configuration => COP = 6.5 for temperature lift of 50°C to 70°C

New configuration suggested by Zuhlsdorf et al (2018) with subsequent models leads to COP =9 for 50/50 mixture of R1234yf/R1233zd(E). Progress delayed by pandemic restrictions

Lubricant Investigation for High Temperature Heat Pump Application, N Shah, D Cotter, M Huang, N Hewitt (2019) 2nd Symposium on High-Temperature Heat Pumps, 249

Refrigerant Lubricant Interaction in High-Temperature Heat Pump and Organic Rankine Cycle Systems (2020) Donal F. Cotter, Nikhilkumar N. Shah, Ming J. Huang, Neil J. Hewitt, IIR International Rankine Conference - Heating, Cooling and Power Generation – 27-31 July 2020, Glasgow, UK, PAPER ID: 1198





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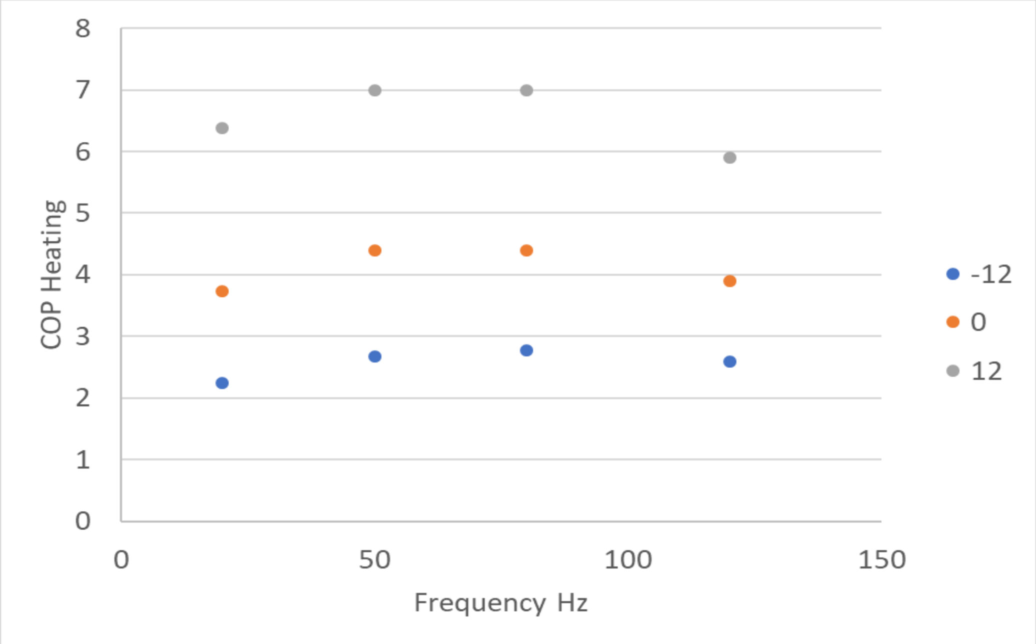
Work Package 3.2 – Vapour Compression Heat Pump for Demand Side Management

- Variable Speed Drive Compressor tested across a range of inlet and outlet temperatures
- Definite peak in performance at 50Hz-60Hz representing design origins at these frequencies
- Loss in performance becomes more pronounced at lower temperature lifts
- Work was carried out using R410a
- Replacement of R410a by R466A provided 5% greater performance
- R466A GWP > 150 (733) compared to R410A of 2,088



Domestic Demand-Side Response: The Challenge for Heat Pumps in a Future UK—Decarbonised Heating MarketNJ Hewitt, N Shah, D Cotter, C Wilson, K Le, R Byrne, P MacArtain (2020) Renewable Energy and Sustainable Buildings, 735-745

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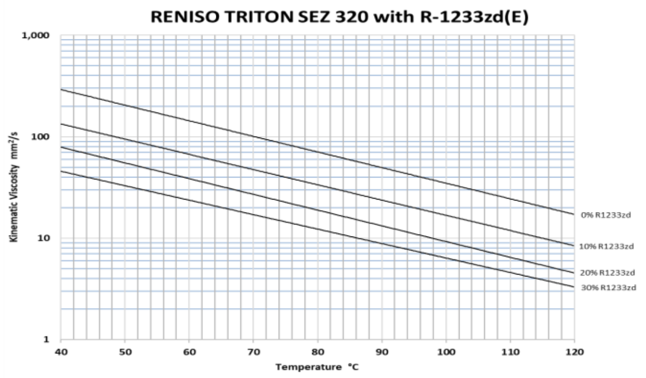
Work Package 3.3 – High Temperature Vapour Compression Heat Pump for Industrial Process Heating

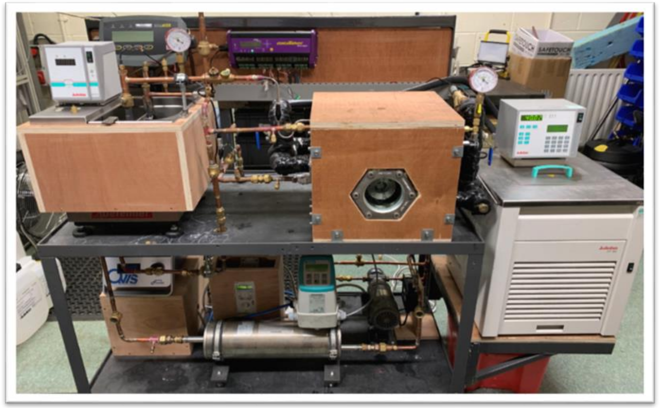
Temperatures up to 140°C can be delivered for R1233zd(E) as a replacement for R245fa

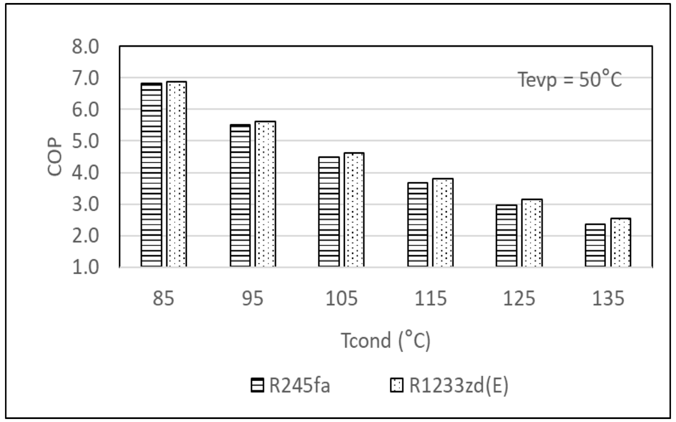
Compressor lubricants have been tested for solubility and miscibility meets the minimum kinematic viscosity of 20mm²/s

Test best tested both R245fa (baseline) and R1233zd(E) with R1233zd(E) having a superior performance.

Combining with WP3.1





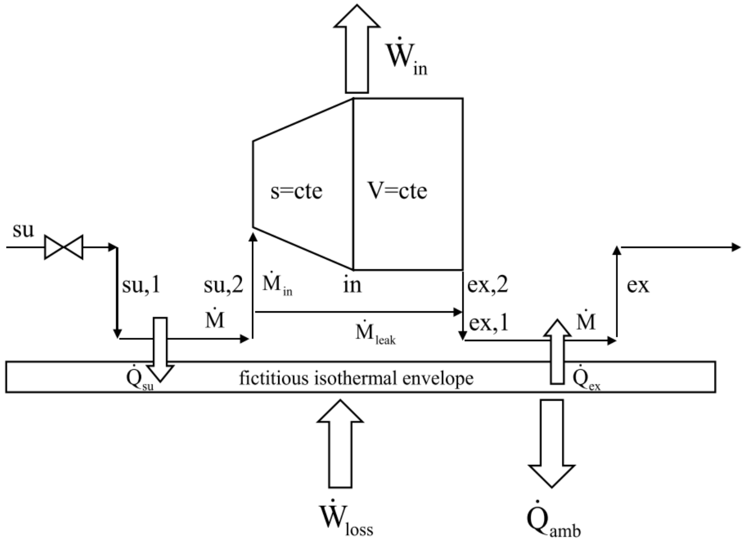


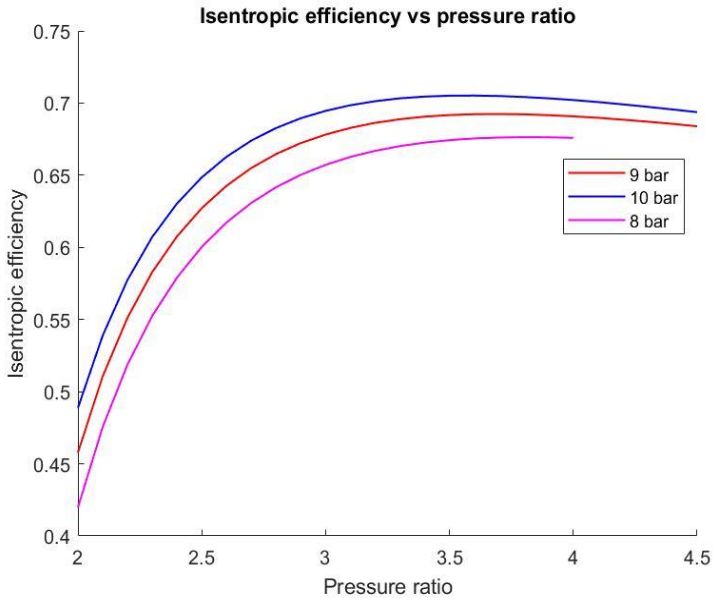
Work Package 3.4 – Combined Vapour Compression Heat Pump/Organic Rankine Cycle for Heat or Electricity

Originally modelled around R245fa and redesigned for R1233zd(E)

Focus has been around the development of the Organic Rankine Cycle Turbine

Starting Construction





Work Package 3.5 – Sorption chillers for cooling from network (commercial use)

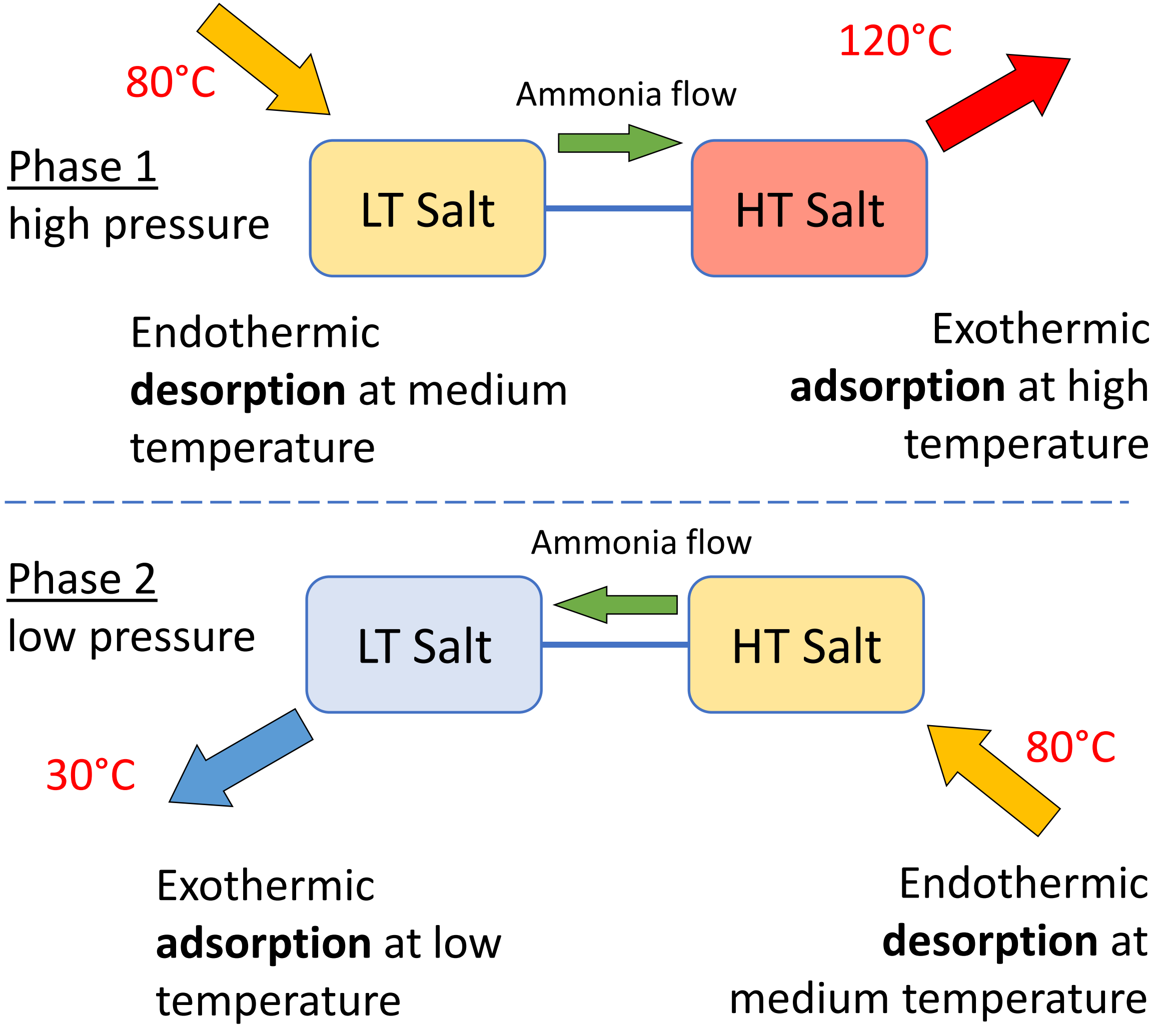
A few systems available commercially and characteristics known – no research needed prior to application.

Work Package 3.6 –Sorption heat pump from HT waste to network

Similar technology to domestic gas heat pump research already underway at Warwick (BEIS and MI) and can receive results from those projects.

Work Package 3.7 – Heat transformer from waste to process heat and output to network

- A 2-stage process adsorbing/desorbing ammonia into salts impregnated into ENG
- Typically $MnCl_2$ and $CaCl_2$
- Potentially very simple construction
- ‘LTJ tests’ on small samples have been characterised and a model validated.
- Final power densities of up tp 1kW/litre are feasible.
- A kW scale laboratory version should be in operation by the end of 2021.



WP1-3 Summary and plans for future work

Broadly, all the technologies (WP2 and 3) must be characterised such that they can be modelled and put as technical options in the modelling environment being developed. Tasks may be summarised as follows:

WP 1: Extend modelling capability to new technologies and to other (case study) areas [LU]

WP2.1: Continued research on PC and TC storage technology [LU]. Possible absorption storage research coming out of WP2.2[UW].

WP2.2: Laboratory proof of concept of TC heat distribution [UW]

WP2.3: [LSBU]

- Identify the costs associated with capturing the waste heat sources
- Decide how to connect them to a low-temperature energy network
- Map the size, scale and location

WP1-3 Summary and plans for future work

WP 3.1: Adapting test facility to push COP to 9

WP3.2: Completion of tests on R410a replacements, then watching brief

WP3.3: Aligning with WP 3.1 for higher temperature applications

WP3.4: Starting building programme for laboratory reversible heat pump/ORC

WP3.5: Watching brief only.

WP3.6: Watching brief only.

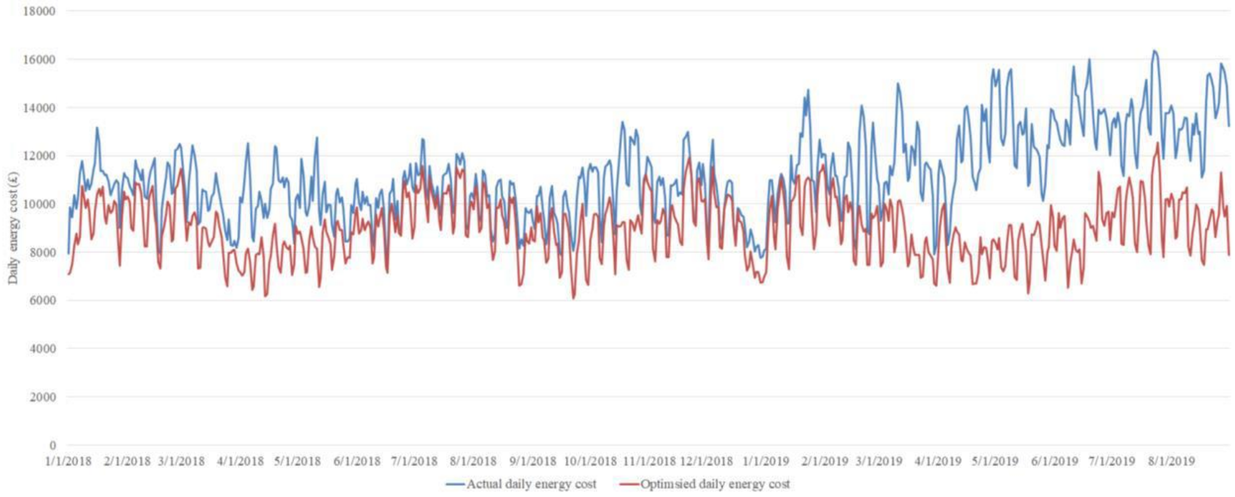
WP3.7: Build and test thermal transformer at kW scale

Work Package 4 – Determination of successful proposition features for end users and business

- WP 4.1: Understanding household priorities [Loughborough Design Year 2-3, now 3-4]
- WP 4.2: From user requirements into technology design [Loughborough Design Year 3-4]
- WP 4.3: Consumer engagement with low carbon heating and cooling [Loughborough Design Year 4-5]
- WP 4.4: Energy transitions and competing for investment [WBS Year 1, 4]
- WP 4.5: Low temperature heat networks in Smart Local Energy Systems [WBS Year 2-4, now 2-5]

Work Package 4.5 – Low temperature heat networks in Smart Local Energy Systems

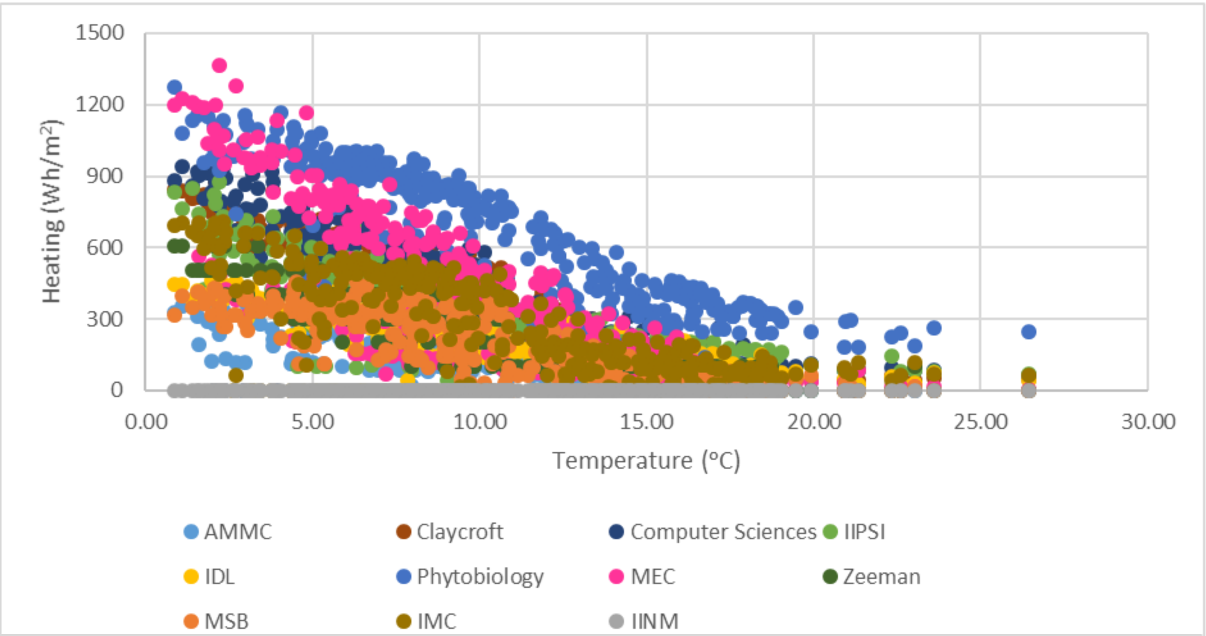
- Transactive Energy Demonstrator
  - UoW CHPs, thermal stores and demand for heat and power
  - 200,000 data points sampled hourly
- Illustrates a model-free, machine learning AI approach
- Suggested energy costs could be reduced by 13-18% vs existing controls
- Needs good, granular data on demand and significant work to characterise energy assets

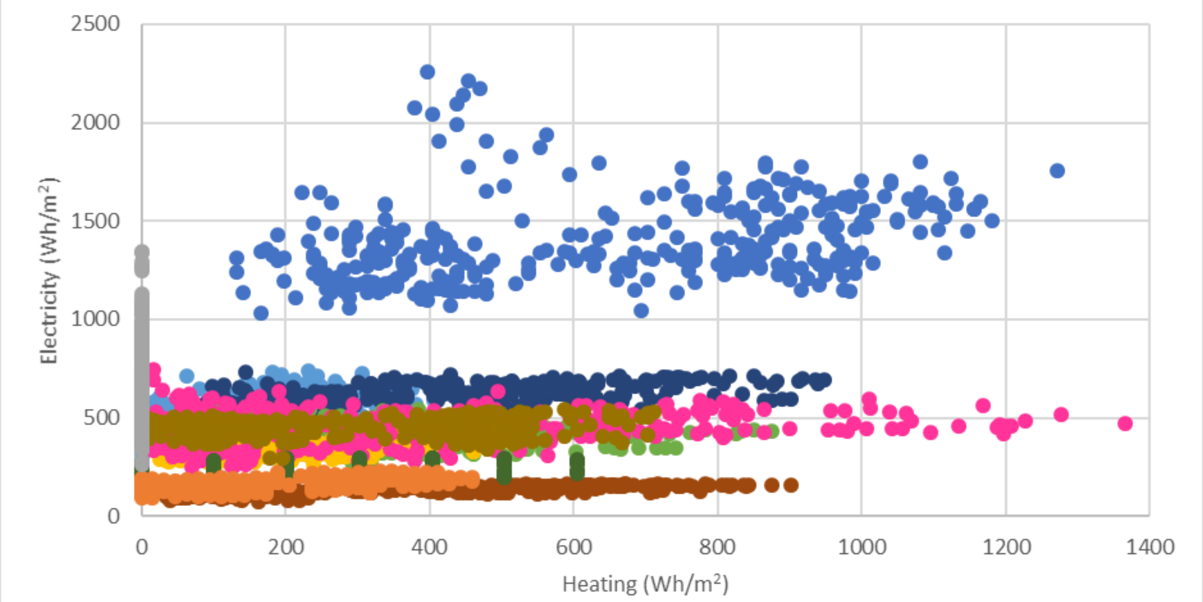


Daily cost of energy for selected assets on the University campus comparing actual (blue) with the cost from model-free, machine learning agents working on a virtual, transactive energy platform (red). Analysis carried out in collaboration with Fetch.AI

Work Package 4.5

- Smart Square in the University of Warwick Campus
  - 17 buildings, mixed use, 1992-2019
  - 50:50 heat and power use, ~£1Mpa spend
  - Candidate for a LoT-NET
- Understanding building performance
  - Seasonal profiles: heat, power, PV, EV
  - Heat use vs temperature
  - Heating use vs electricity use
- Some buildings are "in control" with tight spreads for heating and electricity. Some are "out of control" - harder to integrate
- Now comparing performance with benchmarks and building network view





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Coffee / Comfort break, then over to David for Future Plans