LoT-NET

Low Temperature Heat Recovery & Distribution Network Technologies

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REFRIGERATION AIR CONDITIONING HEAT PUMPS

sirach

Strategies and Technologies for the Implementation of Low Carbon Heat Networks

A joint LoT-NET & SIRACH Half-Day Briefing, 12:00-16:00

WARWICK THE UNIVERSITY OF WARWICK

Ulster University

EST 1892 LSBU

Loughborough University

Welcome

Fire Exits & Toilets

Low Temperature Heat Recovery & Distribution Network Technologies

LoT-NET
Low Temperature Heat Recovery & Distribution Network Technologies

Agenda

1200-1210	Welcome
1210-1250	Session 1: Heat Sources and Perceptions
1250-1345	Lunch
1345-1445	Session 2: Keynote and Industry View
1445-1550	Session 3: Future Heat Network Technologies
1550-1600	Close

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Low Temperature Heat Recovery & Distribution Network Technologies

Welcome

Dr Stan Shire

LoT-NET interdisciplinary research project

- Funded by a 5-year EPSRC program grant
- Collaboration of four university teams
- Guided by an industrial advisory panel

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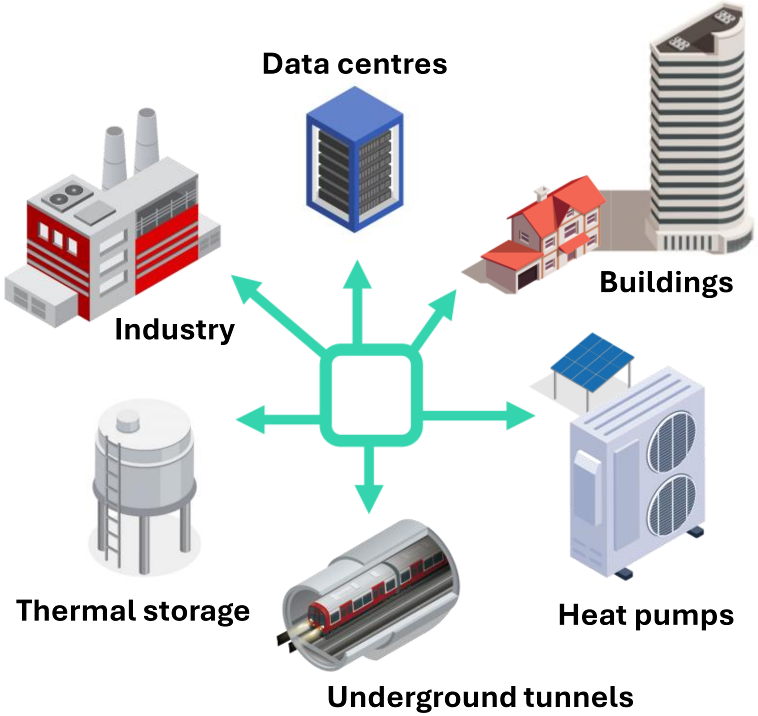
Low Temperature Heat Recovery & Distribution Network Technologies

The interdisciplinary research combines a **range of factors** contributing to the performance of energy systems:

1) **Insight** into end-user behaviours with respect to heat utilisation and new technology adoption

2) **Assessment** of recoverable heat streams

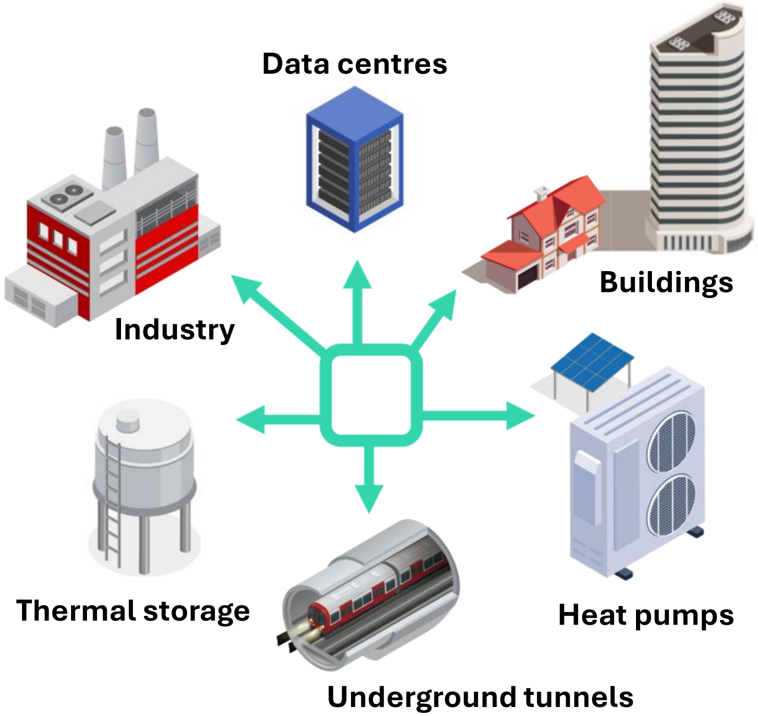


Low Temperature Heat Recovery & Distribution Network Technologies

The interdisciplinary research combines a **range of factors** contributing to the performance of energy systems:

3) **Evaluation** of the effects of market incentives and barriers influencing new technology take-up

4) **Innovation** in regulatory frameworks and market structures

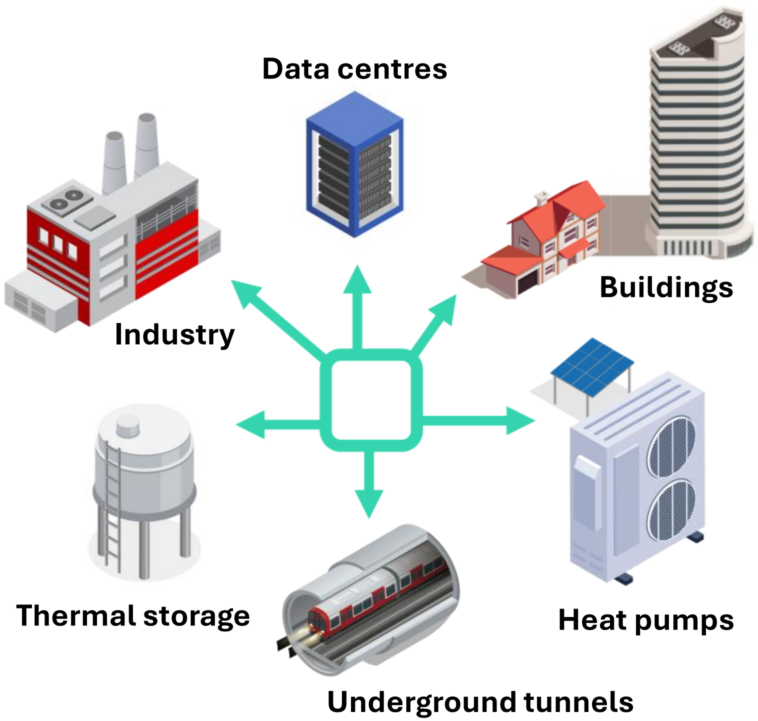


Low Temperature Heat Recovery & Distribution Network Technologies

The interdisciplinary research combines a **range of factors** contributing to the performance of energy systems:

5) **Development** of new technology:
   - high efficiency heat pumps to boost the temperature of waste heat
   - novel storage technologies for both intermittent heat and electricity

6) **Simulation** and demonstration of market situations at a range of scales



These topics map onto today's sessions:

Project Outline

1) Insight into end-user behaviours with respect to heat utilisation and new technology adoption
2) Assessment of recoverable heat streams

3) Evaluation of the effects of market incentives and barriers influencing new technology take-up
4) Innovation in regulatory frameworks and market structures

5) Development of new technologies
6) Simulation and demonstration of market situations at a range of scales

Session 1: Heat sources & perceptions

- End user behaviour
- Providing renewable heat

Session 2: Keynote & industry view

- Policy interventions
- Market development

Session 3: Future heat network technologies

- New technology (heat pumps, storage)
- System simulation/ optimisation

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Low Temperature Heat Recovery & Distribution Network Technologies

Session 1: Heat Sources and Perceptions

Chair: Dr Stan Shire, University of Warwick

Heat: A User's Perspective

Professor Vicky Haines, Loughborough University

Recoverable Heat Potential

Dr Catarina Marques & Dr Henrique Lagoeiro, London South Bank University

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Heat: A User's Perspective

Professor Vicky Haines, Loughborough University

Heat

A great opportunity!

Good focus on technical aspects

But we need to consider consumer attitudes towards use (and reuse) of heat

- to deliver maximum value
- to achieve community engagement and stakeholder support

Research at Loughborough University

Domestic heating in the UK is dominated by boilers, generating heat directly from gas

We will require a shift in attitudes and behaviours to move to new heating systems

(1) Acceptability of using heat released as a by-product from industrial processes for residential use

(2) Perceived impact of terminology and stakeholders on the adoption of this type of heat

Research at Loughborough University

In-depth research with 26 UK householders, varying in demographics and backgrounds:

- postal questionnaire
- In-depth semi-structured interviews including attitudinal rating scales
- thematic analysis of discussion

Researching UK householders' attitudes and perceptions of waste heat streams

Questionnaire Booklet

Loughborough University LoT-NET

Key topics identified from the research

- Economics
- Energy and sustainability
- Geography and location
- Health and wellbeing
- Safety
- Knowledge

Terminology

- A numerical rating scale was used to assess the attractiveness of five popular terms for the heat being recovered
- Participants were then asked to explain the reasoning for their ratings

Very unattractive term

Very attractive term

Waste heat

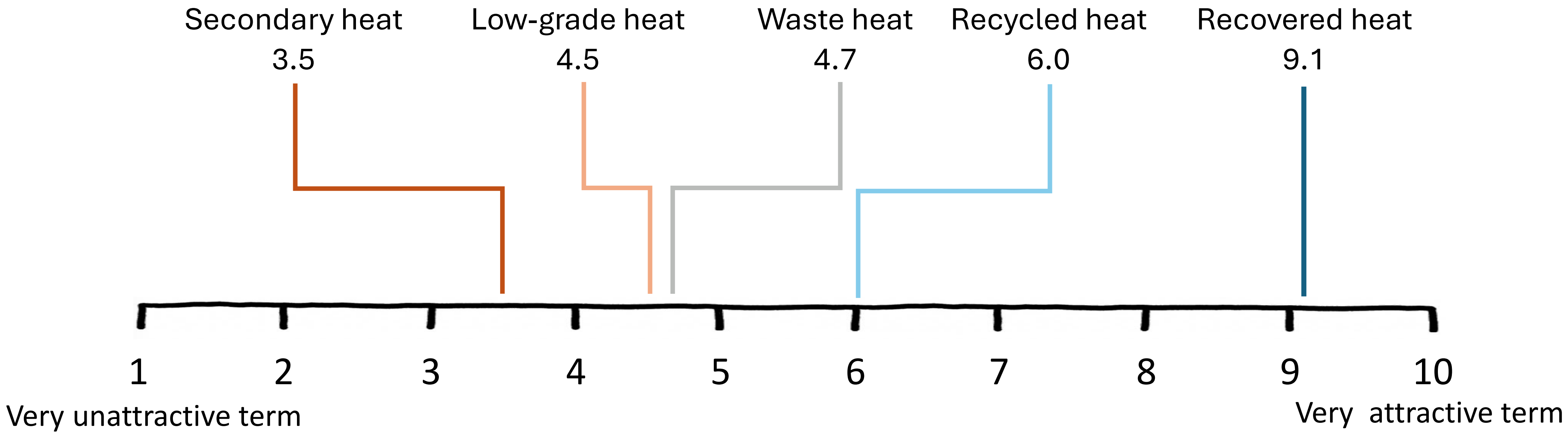
Recycled heat

Recovered heat

Secondary heat

Low-grade heat

Terminology



- *"if we can recover it to heat not only my home, but possibly hospitals or things like that, it's going to save the tax-payer money"*
- *"the environment is being safeguarded by being able to use the same energy twice in effect, or multiple times"*
- *"if you're giving me a low-grade product, I'll pay low-grade price"*
- *Secondary heat seems "second-best"*

Acceptability of recovered heat sources







Completely acceptable

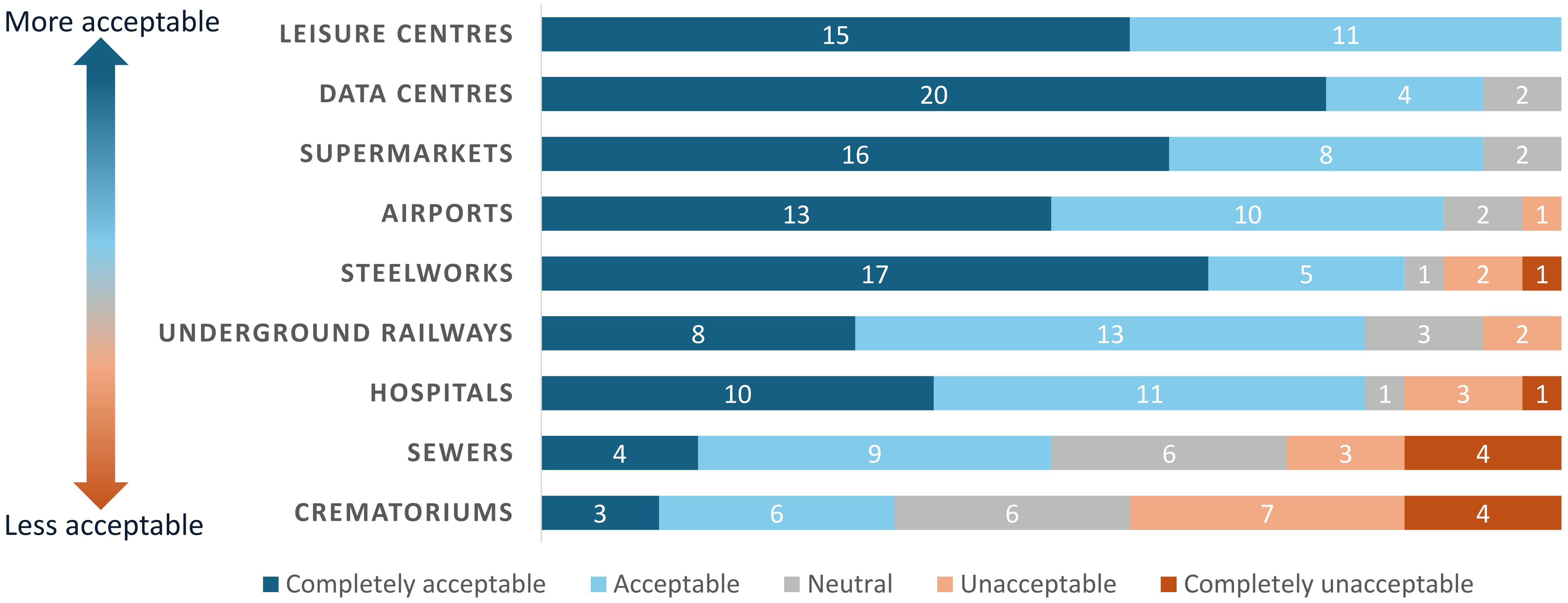
Acceptable

Neutral

Unacceptable

Completely unacceptable

Acceptability of recovered heat sources



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Acceptability of recovered heat sources

Poor understanding of heat transfer process by everyone!

Most thought heat would mimic the characteristics of source environment

- ‘Clean’ heat – machine made e.g. data centres
- ‘Dirty’ heat – transmission of odours, germs and even bad spirits

Clear environmental benefits; Reliable and dependable supply

“If we’re having heat sources from anywhere, it’s going to be safe and it’s going to be processed properly…it’s just heat”

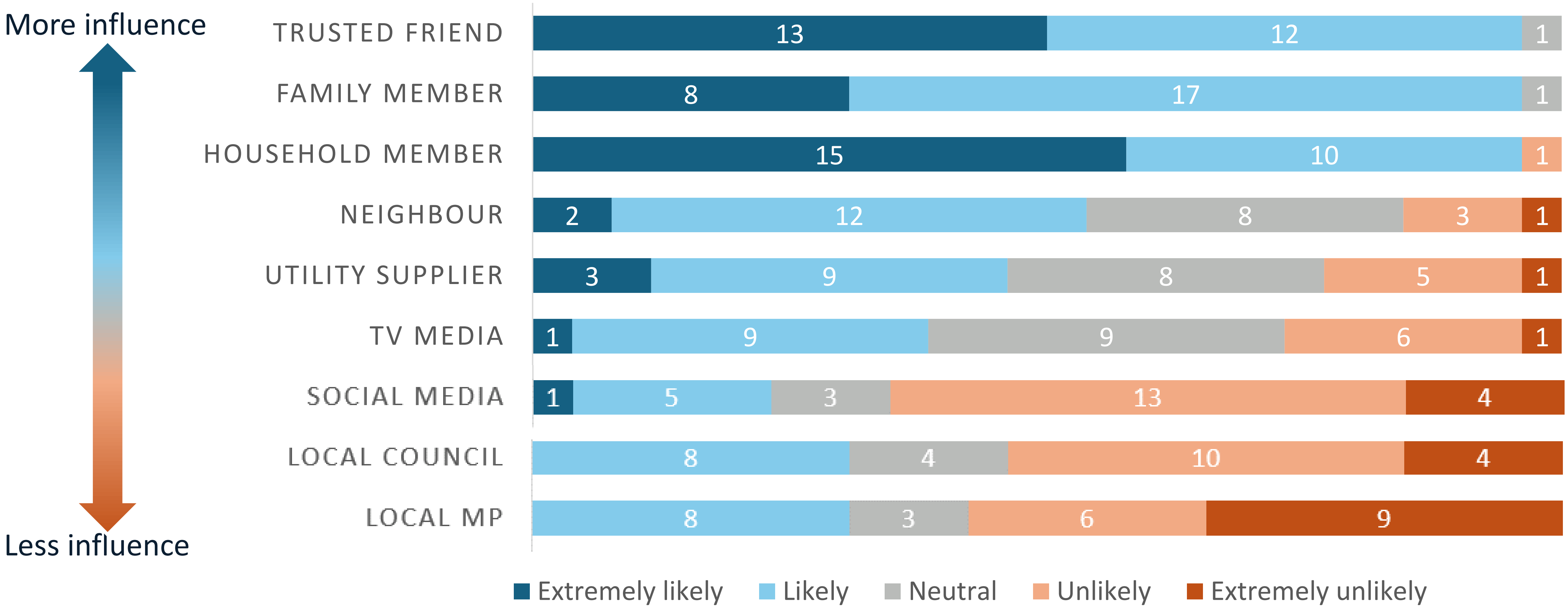
Influence of stakeholders

Participants rated how likely they felt different stakeholders would be able to influence them to adopt the use of recovered heat in their home

1) Family members
2) Householders
3) Local Council
4) Local MPs
5) Neighbours
6) Social Media
7) Trusted friends
8) TV media
9) Utility suppliers

- Extremely likely
- Likely
- Neutral
- Unlikely
- Extremely unlikely

Influence of stakeholders



Summary...

Recovered heat can be seen as a positive option if users know that its clean and safe

Poor heat transfer knowledge leads to unhelpful householder beliefs

Terminology used with householders may not be the same as that used with industry / academia but 'recovered heat' could work well for all audiences

Promoting recovered heat in an acceptable way is needed to engage users

Trustworthy stakeholders are required to encourage widespread UK acceptance.

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Questions?

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Recoverable Heat Potential

Dr Catarina Marques and Dr Henrique Lagoeiro
London South Bank University

DECARBONISING HEAT

District heating can unlock the potential for heat recovery in cities

Decarbonising heat will be crucial on our path towards **net zero** in 2050

Heating represents **1/2** of energy consumption

Accounting for **1/3** of carbon emissions in the UK

Electrification Opportunity

Average **grid carbon intensity** fell by **66%** from **2013** to **2020** (nationalgridESO, 2021)

- Heat pumps and district heating: economies of scale
- Green Heat Network Fund and zoning policy

From **2% to 20%** of demand

Is the potential growth for heat networks by **2050** according to the UK Government, reaching up to **95 TWh** annually (DESNZ, 2021)

- Recoverable heat: higher efficiencies and local
- Reduced demand and higher energy security

THE LOT-NET STRATEGY

Addressing the big questions to identify the recoverable heat potential

- Underground Railways
- Data Centres
- Mine water
- Supermarkets & Cold stores
- Substations
- Wastewater
- Crematoria

What is their size and location?

How to capture and what is the benefit?

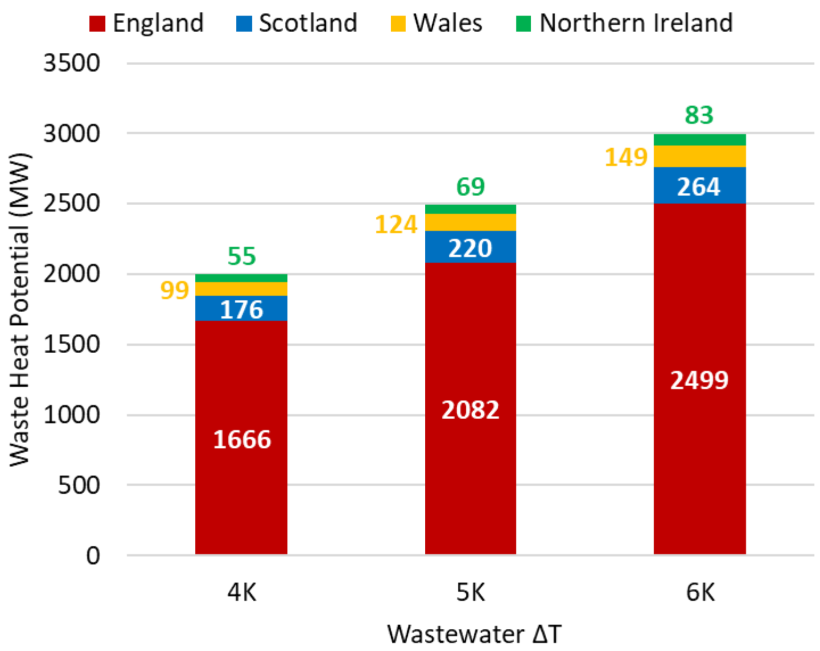
How do they compare?

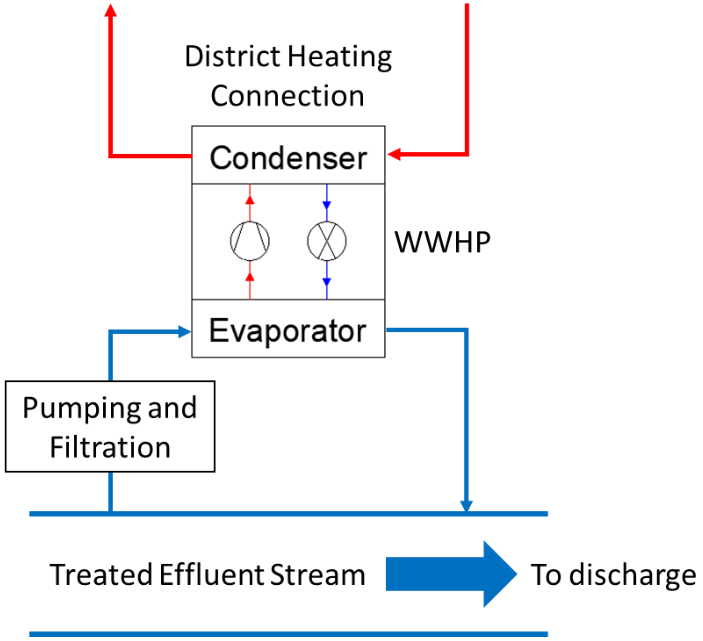
- PhD projects
- Case studies
- Demonstrations
- Partnerships
- Sister projects
- Publications

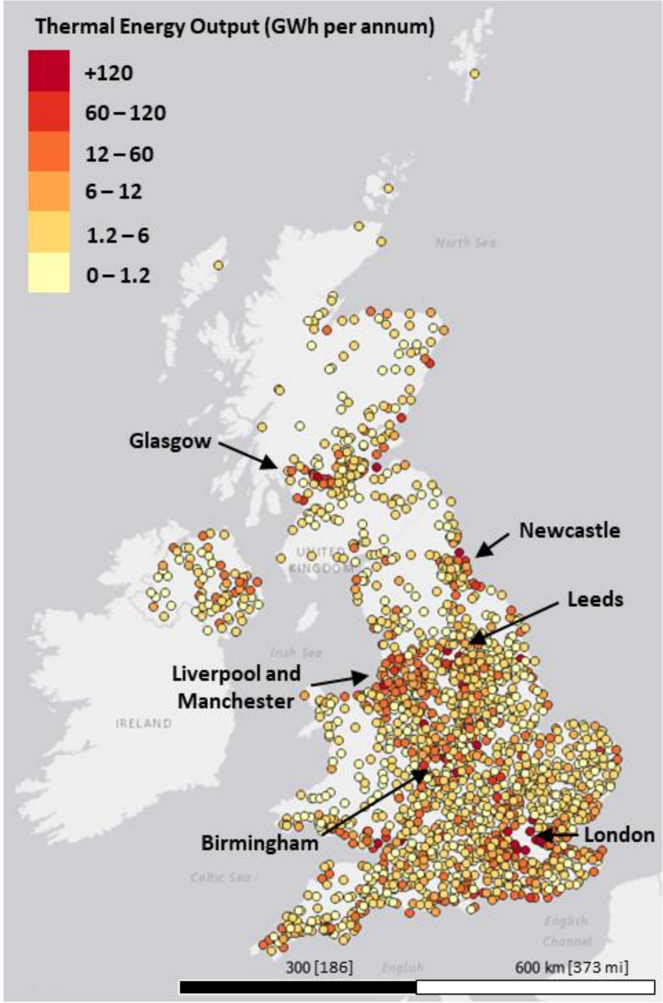
WASTEWATER TREATMENT PLANTS

A large and stable heat source, suitable for meeting base-loads

- 1,876 WWTPs in the UK serving agglomerations > 2,000 PE
- Typical effluent temperatures from 13 to 22°C (average 15°C during winter)
- 22.5 TWh per annum of potential for effluent ΔT of 5 K (64% in urban areas)







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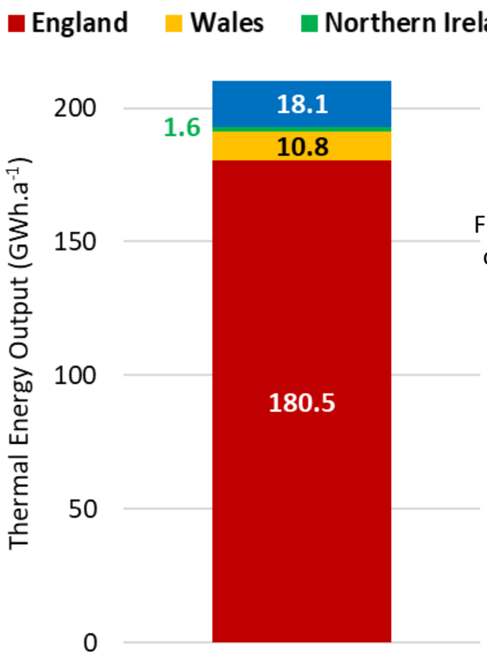
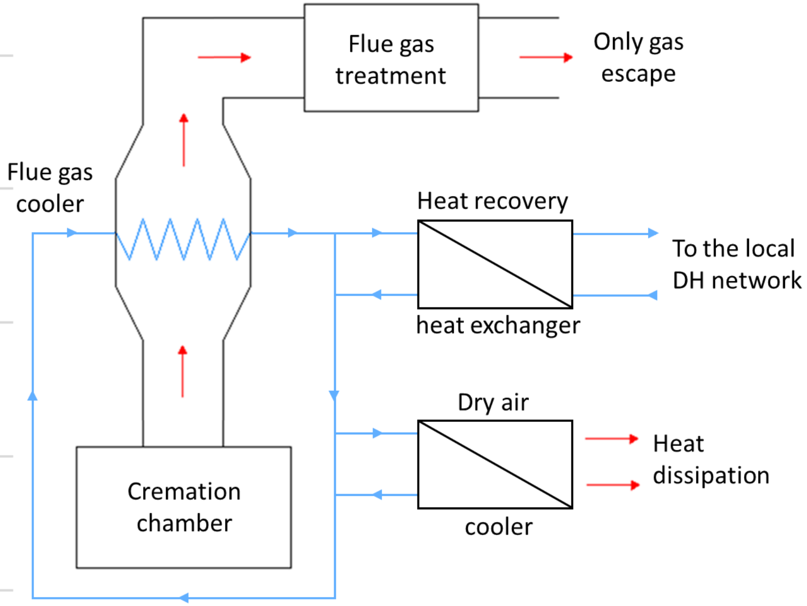
CREMATORIA

Small potential, but higher temperatures suggest a lower cost for heat





From **35%** to **78%**

is the percentage growth of cremation as the chosen post-funeral rite since 1960

From **200** to **400 kW**

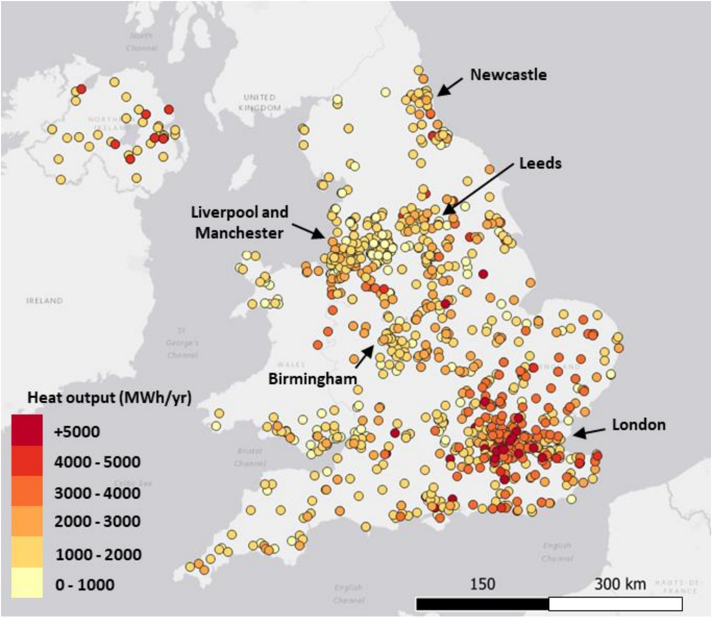
is the range of heat released during a typical 80-minute cremation process

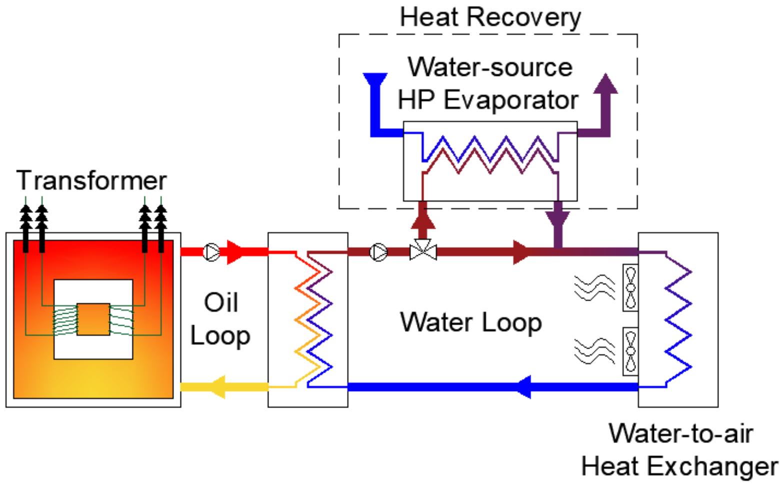
- All UK crematoria had to eliminate mercury emissions by 2020, and flue gas treatment process involves cooling
- Flue gas temperatures reduced from over 800°C to around 150°C, leading to water temperatures from 80 to 90°C
- Warwick case study showed local crematorium could only meet 1.5% of demand, but reduce peak gas use by 33%

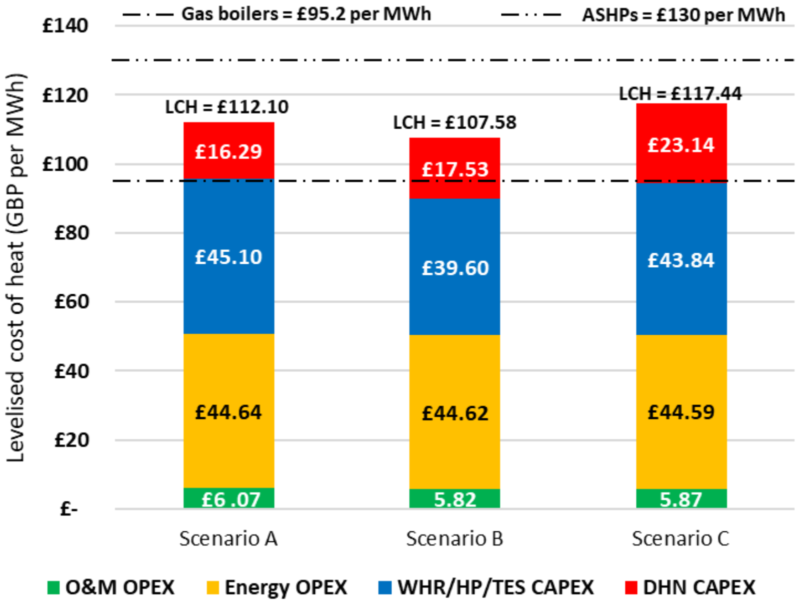
ELECTRICAL TRANSFORMERS

Higher temperatures, but significant variations in output

- 1,391 sites >60 MVA, temperature ranging from 20 to 70°C (load dependent)
- Concept for heat recovery from a water-cooled substation transformer
- Levelised costs dependent on peak coincidence and linear heat densities
- Heat recovery system could achieve a SCOP of 3.40 and 80% carbon savings





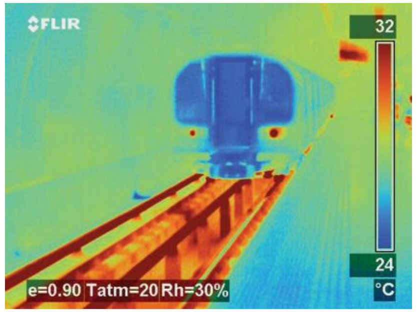


Country	Number of sites >60MVA	Recoverable heat (TWh)
England	1,181	3.52
Wales	78	0.18
Northern Ireland	77	0.30
Scotland*	55	0.32
Total	**1,391**	**4.32 (58% urban)**

*Obtained from an investigation by Sinclair & Unkaya (2020)

UNDERGROUND RAILWAYS

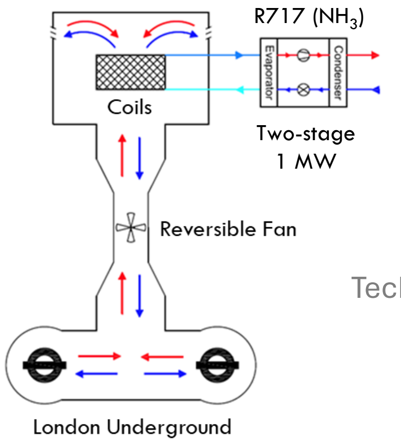
Opportunity to integrate heating and cooling via district-scale heat pumps



40°C

highest temperature ever recorded in the UK

Overheating: growth in cooling demand and heat recovery potential

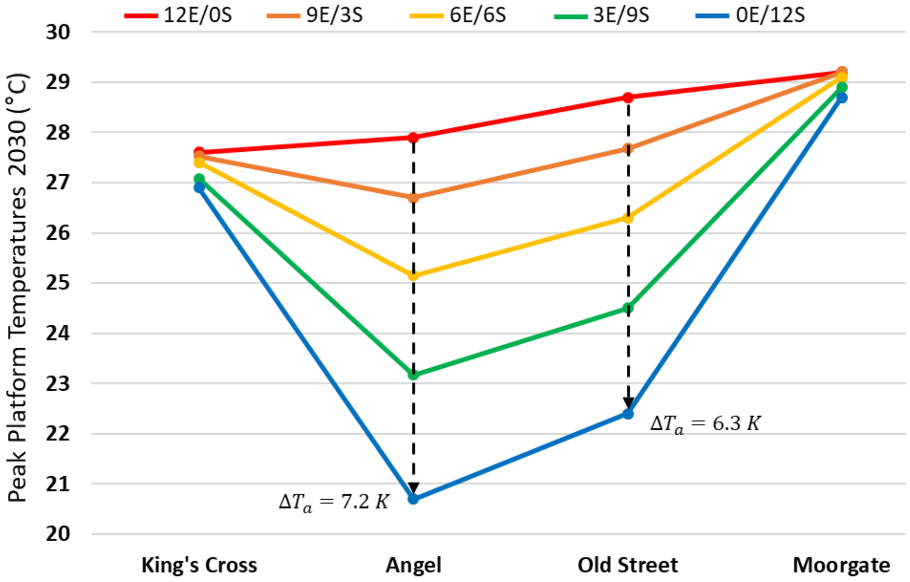


Extract vs Supply

Energy modelling

Technology comparison

Cooling potential

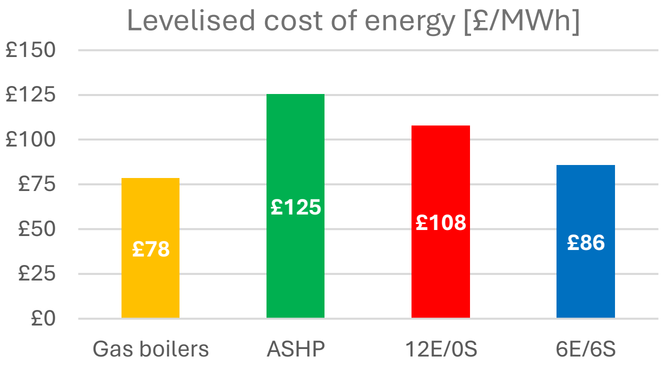


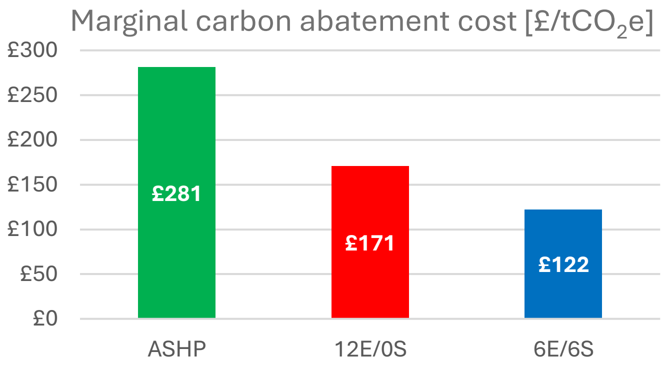
3 K

ΔT for Angel Station in a 6E/6S condition

5.4

bivalent SCOP
May - October
(3.4 for heating only)





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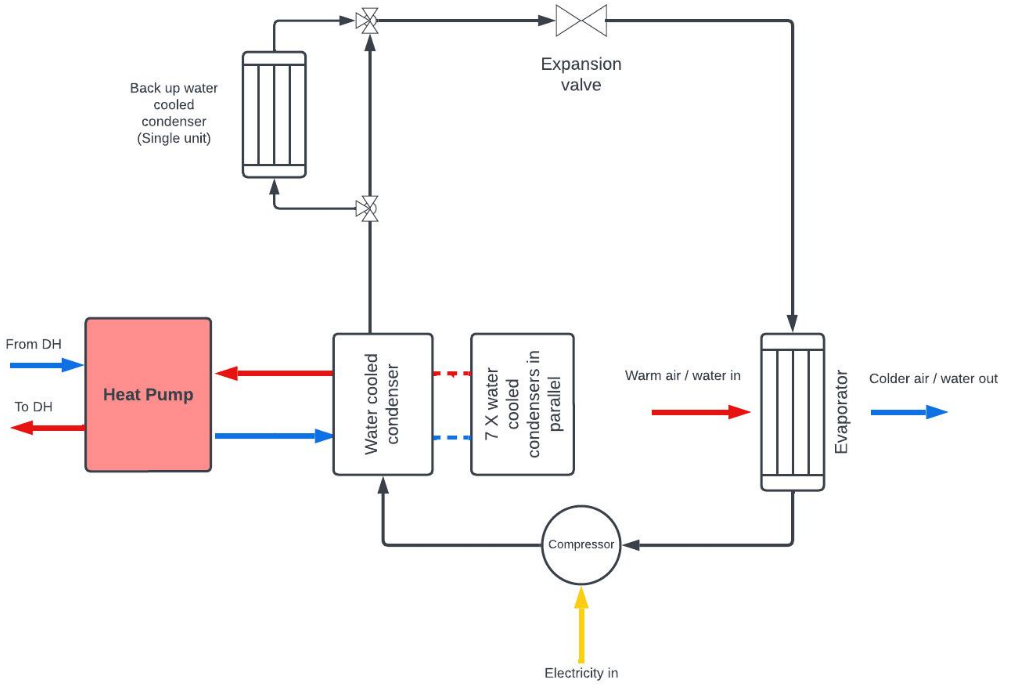
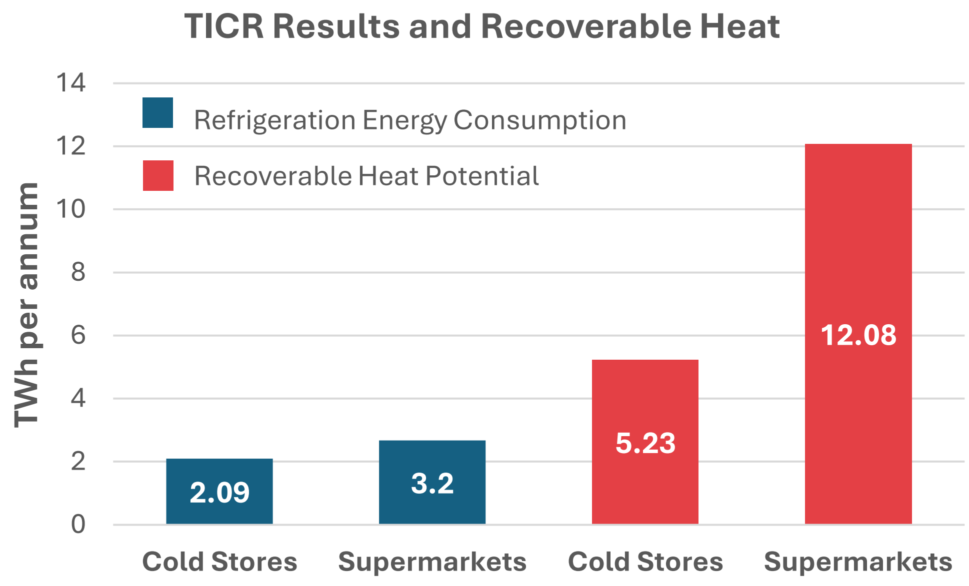
COLD STORES AND SUPERMARKETS

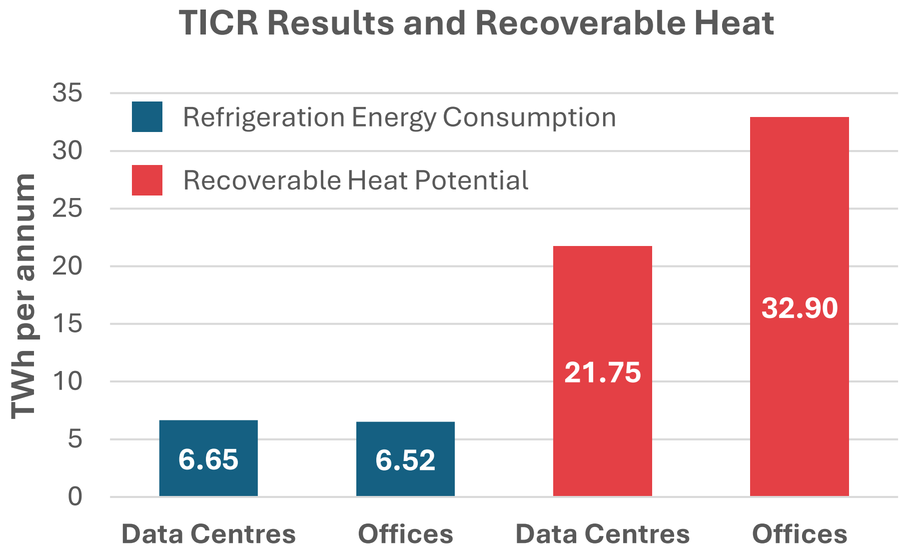
- Data gathered for 7,400 supermarkets and 607 cold stores
- Analysis suggest greater number of sites in the UK
- Energy figures can be used to assess waste heat potential
- Assuming SCOPs of 1.5 for cold stores and 3.52 for supermarkets





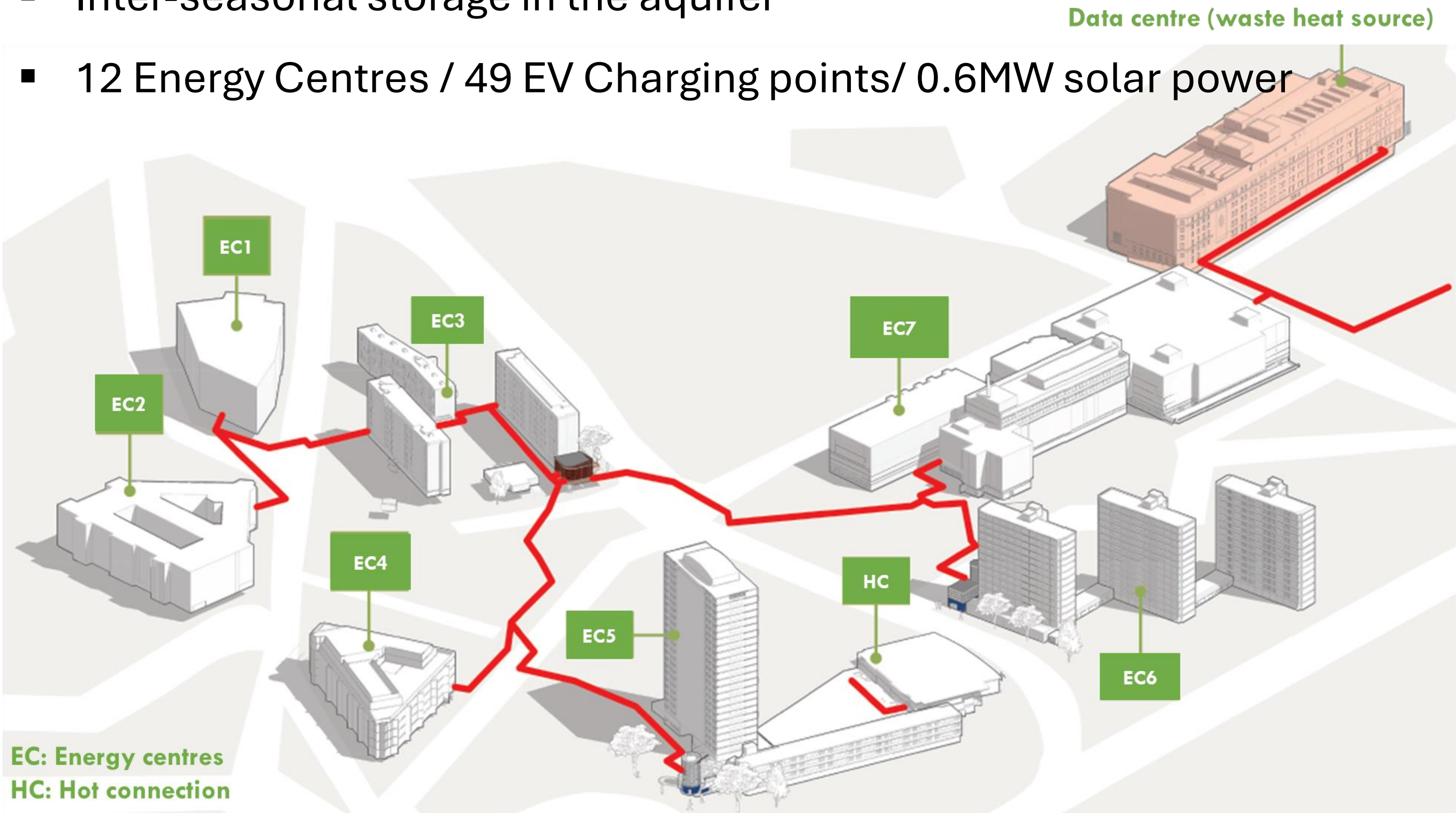
DATA CENTRES

- Data gathered for 521 data centres and 1584 office buildings
- Main datasets are the VOA rating lists and CCAs
- Energy figures can be used to assess waste heat potential



Ambient Loop Network : Heat, power, e-mobility integration

- Prosuming (sharing heat); 3 Social Housing Estates / University/etc.
- Inter-seasonal storage in the aquifer
- 12 Energy Centres / 49 EV Charging points/ 0.6MW solar power



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MINE WATER

CIBSE JOURNAL

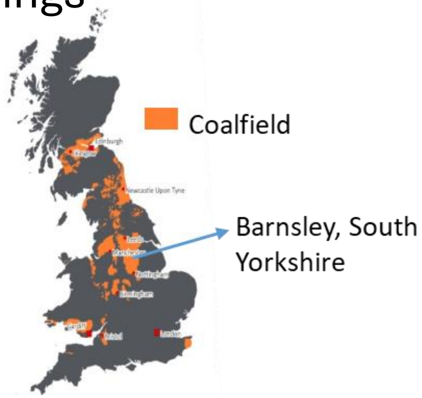
Minewater study wins symposium prize

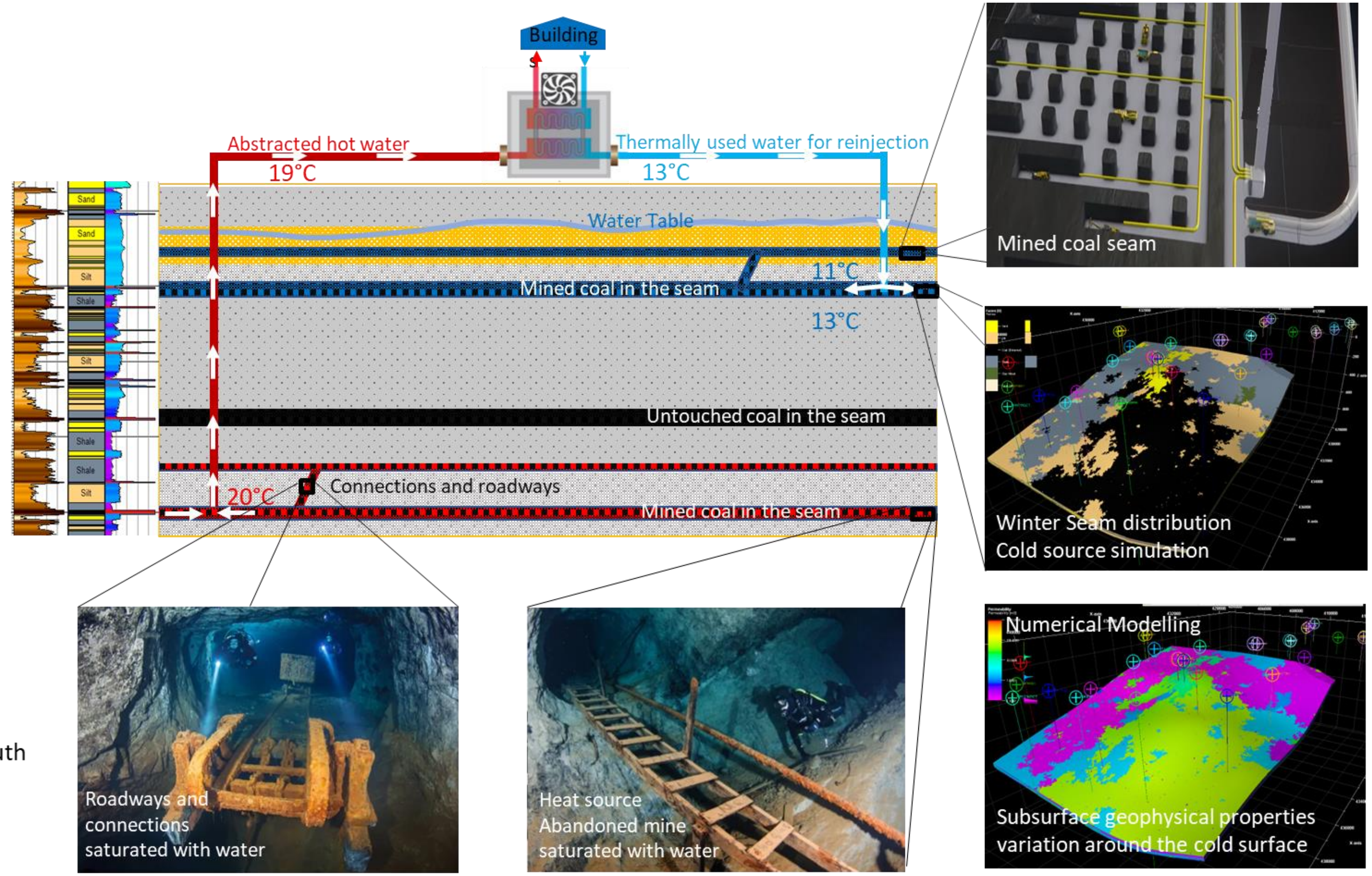
The presentation of a case study on the integration of minewater into smart cooling and heating network systems has been voted the 'Most significant contribution to the art and science of building services engineering' at the annual CIBSE ASHRAE Technical Symposium.

- 23,000 abandoned coal mines in the UK beneath 25% of UK buildings

Integration of waste heat and mine water:

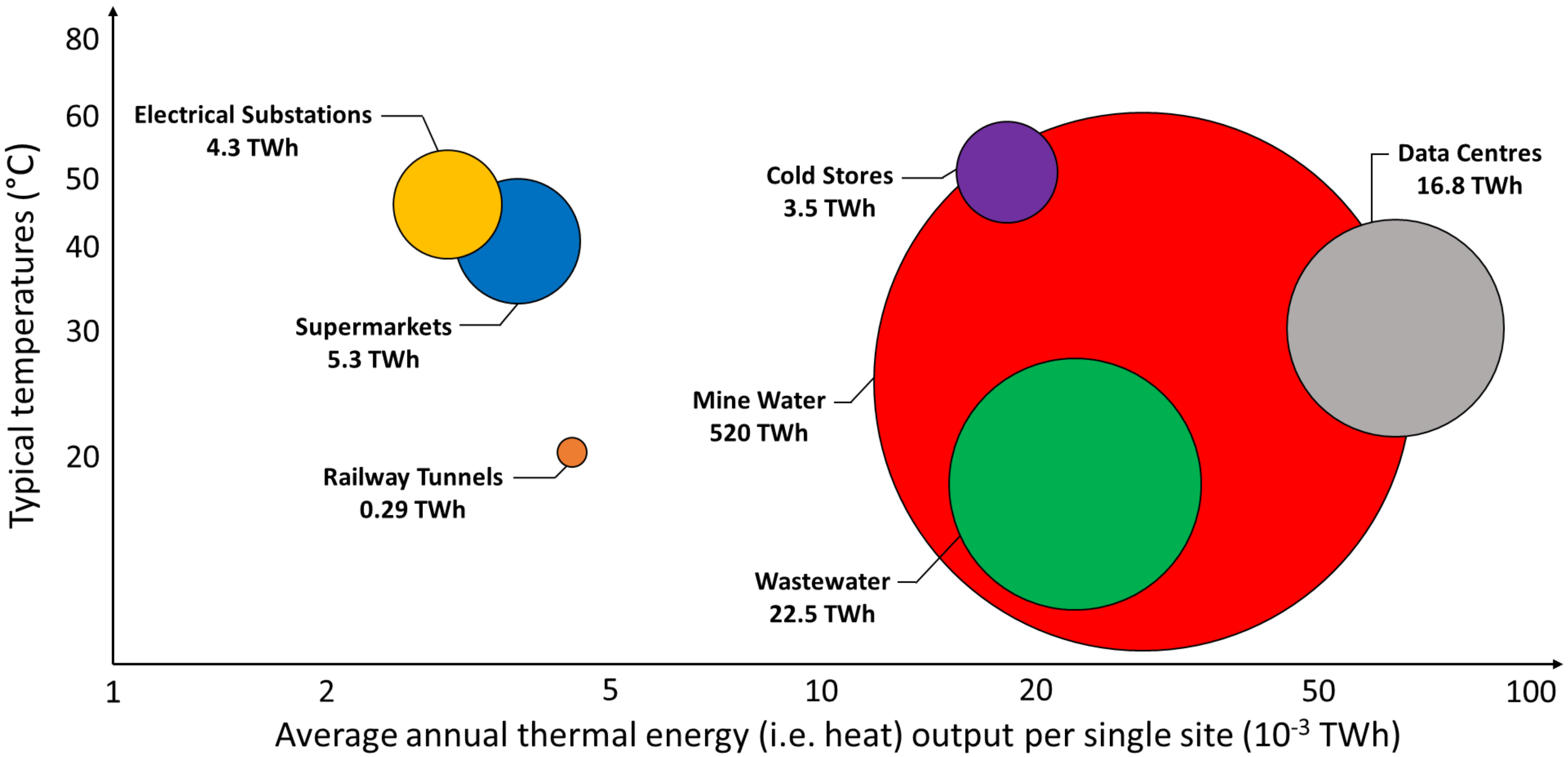
- Saving 7MW of waste heat.
- Heating nearly 2000 buildings.
- Inter-seasonal heat storage.
- Economically efficient.





LOW-GRADE RECOVERABLE HEAT

Overall, significant opportunities for efficient capture and reuse across the UK



53 TWh

released annually from low-grade heat sources

65%

of the projected increase in annual heat demand for district heating in 2050

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CONCLUSIONS AND FURTHER STUDIES

Recoverable heat is a valuable resource for the energy system, but there are still challenges

Recoverable Heat

Widespread resource in the UK
Diverse merits and applications
Can support DH development
Lower decarbonisation costs

Benefits

Additional value streams
Integrating heating & cooling
Wider impacts (grid, pollution)
Unlocking the full potential

Challenges

Electrification: higher costs
Highest spark gap in Europe
Align levies/taxes and reforms
Policies such as zoning are key

Further Studies

Analysis of levelised costs
Behaviour and practicalities
Business/commercial models
Industrial collaboration

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Low Temperature Heat Recovery & Distribution Network Technologies

Session 2: Keynote and Industry View

Chair: Dr Joel Hamilton, HermeticaBlack

EU Policy Context on DHC and its Impact on Industry

Gabriele Pesce, Euroheat & Power

Heat as a Service

Klara Ottosson, LCP Delta

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EU Policy Context on DHC and its Impact on Industry

London
LoT-NET Engagement Day
16/04/2024

Gabriele Pesce
Director of Innovation & Sustainable Finance

The Heating & Cooling Network

Who we are:

- International association for sustainable district heating and cooling
- Voice and forum of the sector
- Research & Innovation platform (DHC+) involved in 17 active European projects
- 150+ members from more than 30 countries
  National DHC associations, utilities, manufacturers, equipment suppliers, start-ups, universities, research institutes and consultancies

Euroheat & Power | DHC+

The Research & Innovation Platform

The DHC+ Platform is Euroheat & Power's European hub for research & innovation in district heating and cooling. It gathers 60+ stakeholders from academia, research, business and industry committed to move to a sustainable energy system.

- Access to EU finance and network
- Accelerating research & business scale-up
- Knowledge transfer in the sector
- R&I advocacy and communication

Heating and cooling decarbonisation is needed to be on track for 2040

Reduce GHG emissions by 90% in 2040, compared to 1990 levels

What are the sectors with highest untapped CO_2 abatement potential?

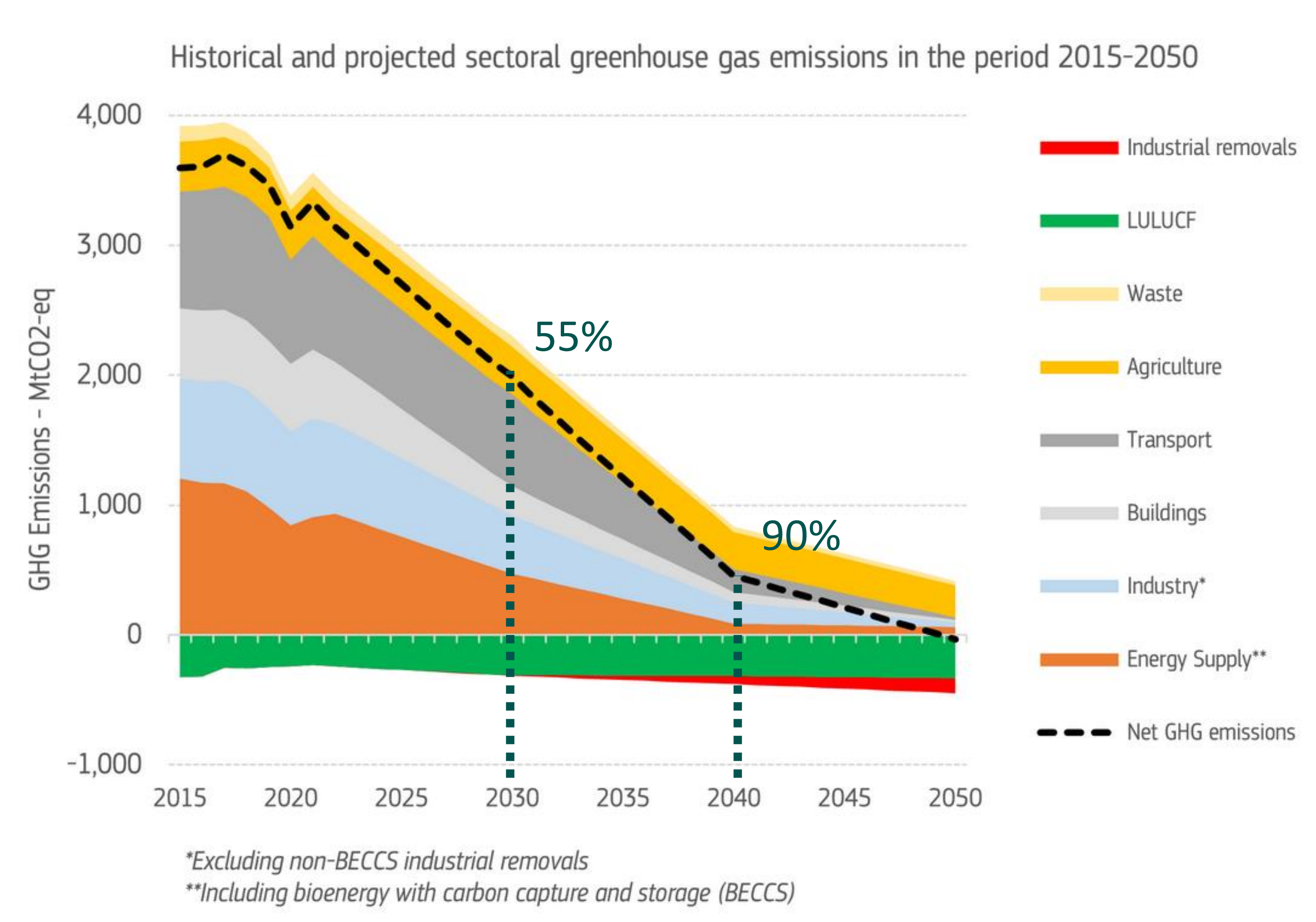
Buildings

- 42% EU energy demand
- 35% energy-related GHG emissions
- 80% energy demand for heating & cooling
- 75% coming from fossil fuels

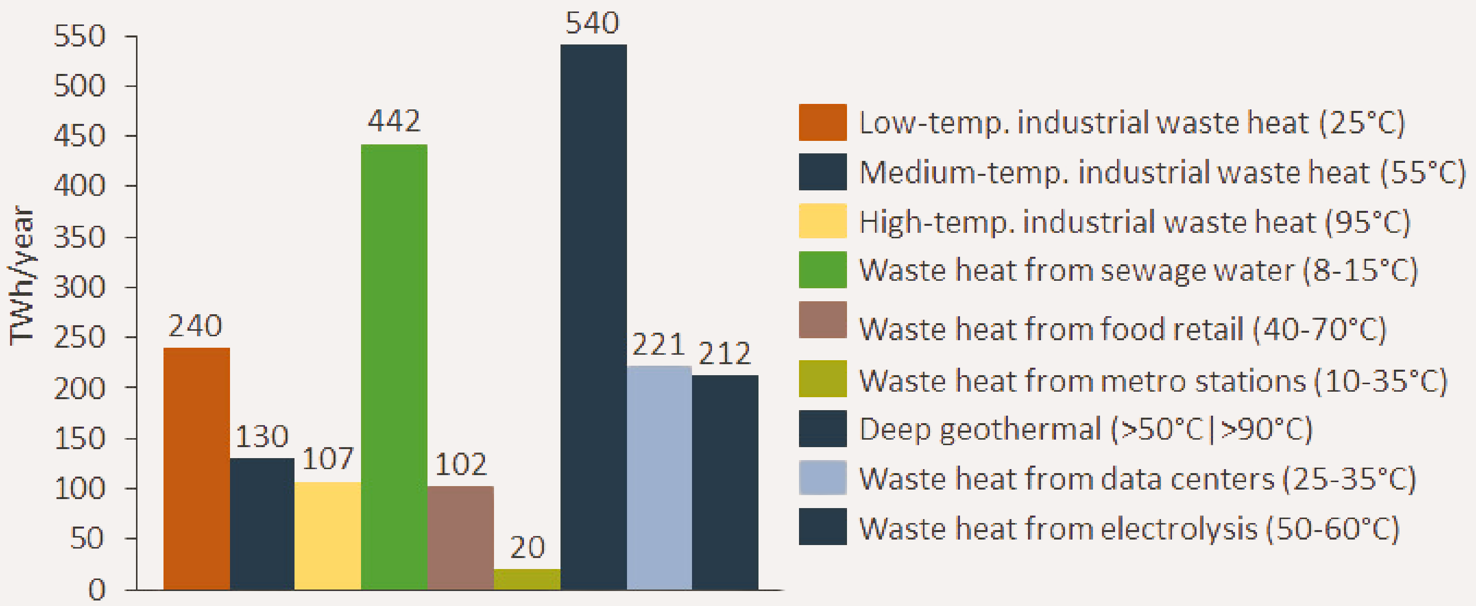
Industry

- 25,6% EU energy demand
- 60% energy demand for heating & cooling

And the decarbonisation curve in the next years in pretty steep



Let’s not waste abundant RES and climate-neutral heat sources !



Potentials for new heat sources 2050 - source: Aalborg university

More than 2000Twh/ year of renewable and climate-neutral heat sources are available in Europe.

This is more than the EU’s total forecasted heat demand by 2050 (1850 TWh/y) !

Diversification

Circularity

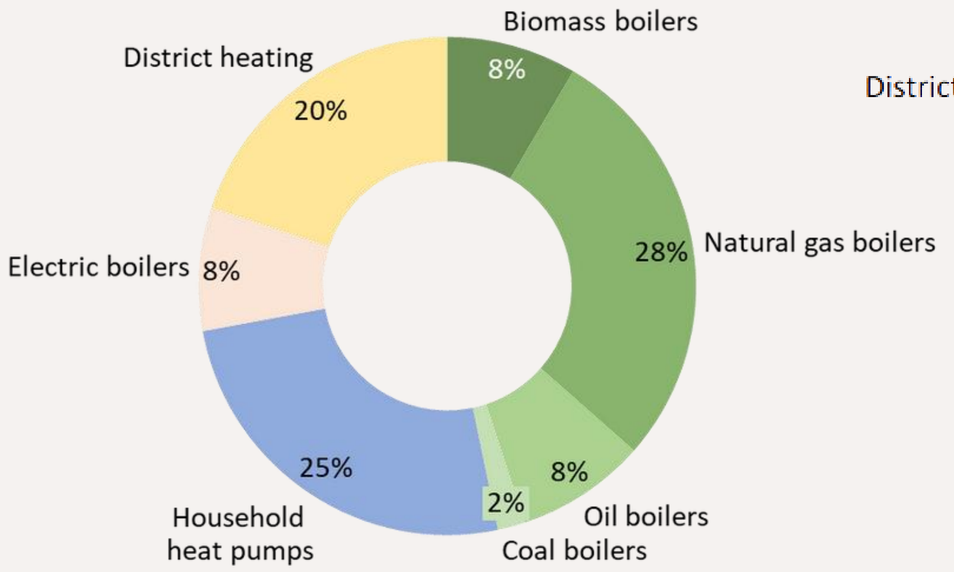
Peak shaving

Just transition

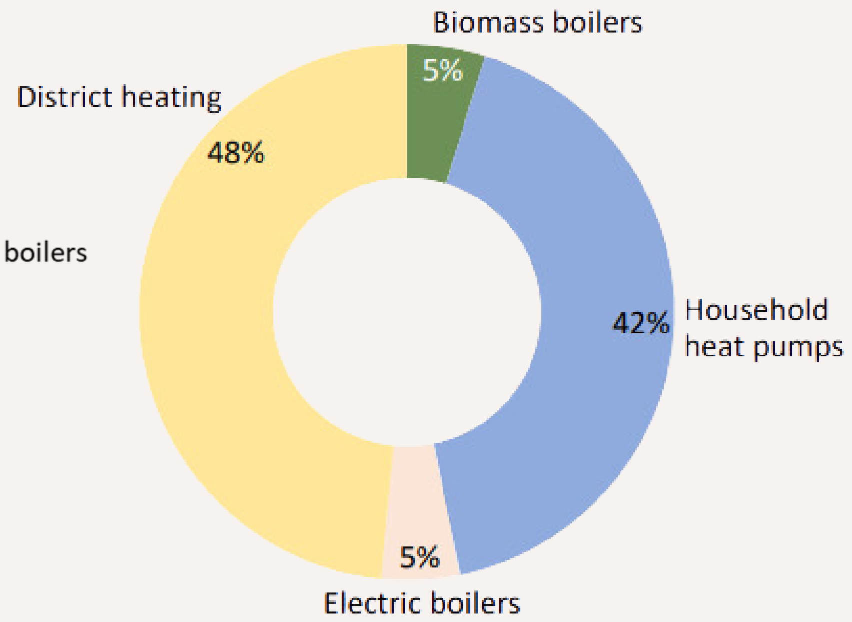
We need a paradigm shift to support clean heating and cooling

The European Heat Market

2030



2050



Source: Heat matters: the missing link in REPowerEU, Aalborg University 2023

What is means for the DHC sector

- To be on track, we should aim at a market share of 20% in 2030 (v. 13% today) and heat-demand reductions of 10%
- 3500 new DHC networks by 2030: investments estimated to 144bn€
- Renovation and expansion of 190.000 km of DHC pipes (upgrade + new connections)

What now?

The Fit for 55 is a solid foundation to tap into the potential of clean heat in Europe

Increased general renewable and sectorial targets

By 2030, all new buildings should be Zero Emission Buildings and by 2050 all buildings

New definition of efficient DHC with clear pathway to net zero, no new fossil fuel capacity from 2030

"Carbon tax" on all fossil fuels used in buildings (ETS2)

Improved permitting procedures for RES and HP

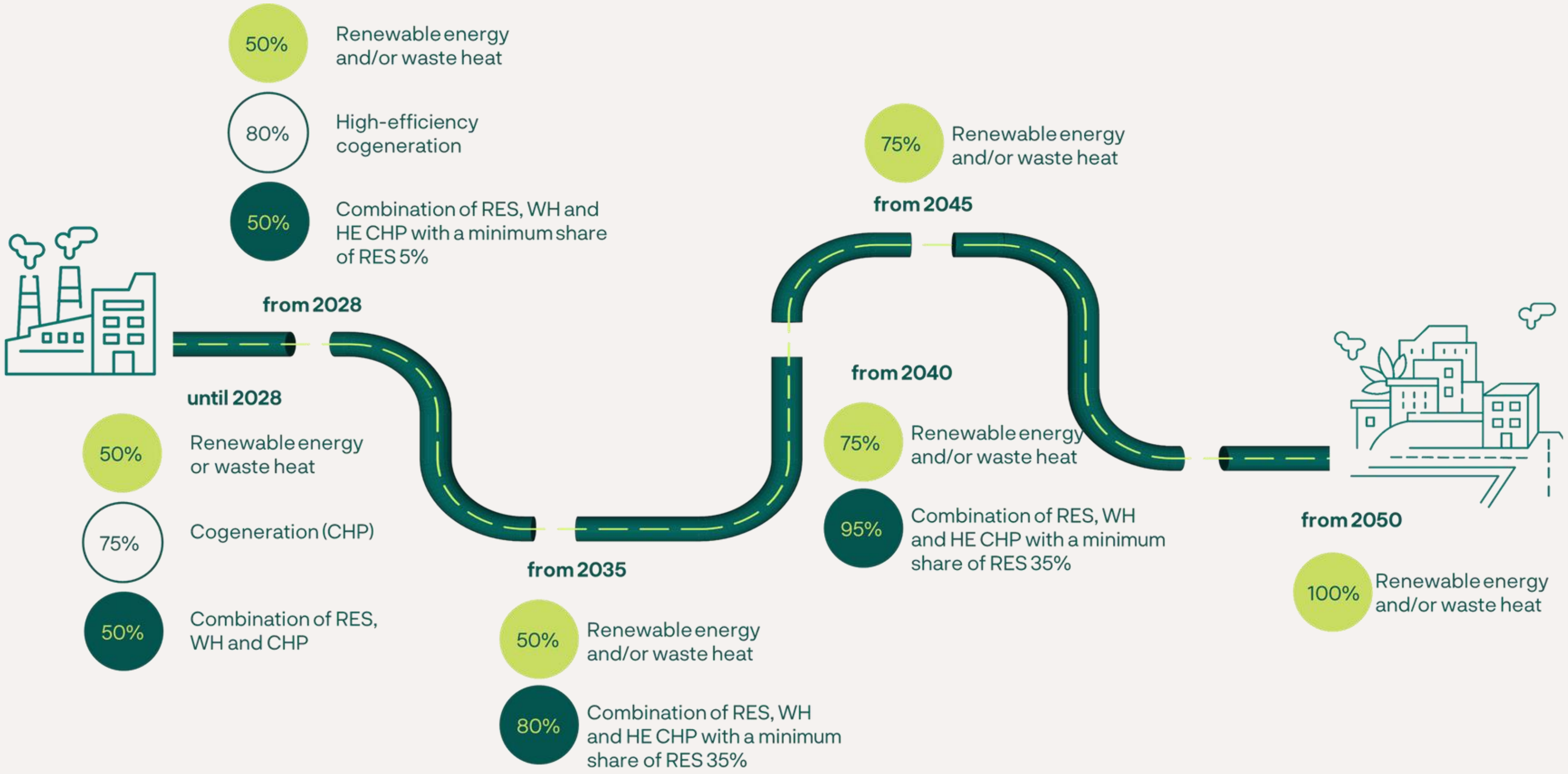
Mandatory local heating & cooling planning for municipalities > 45.000 citizens

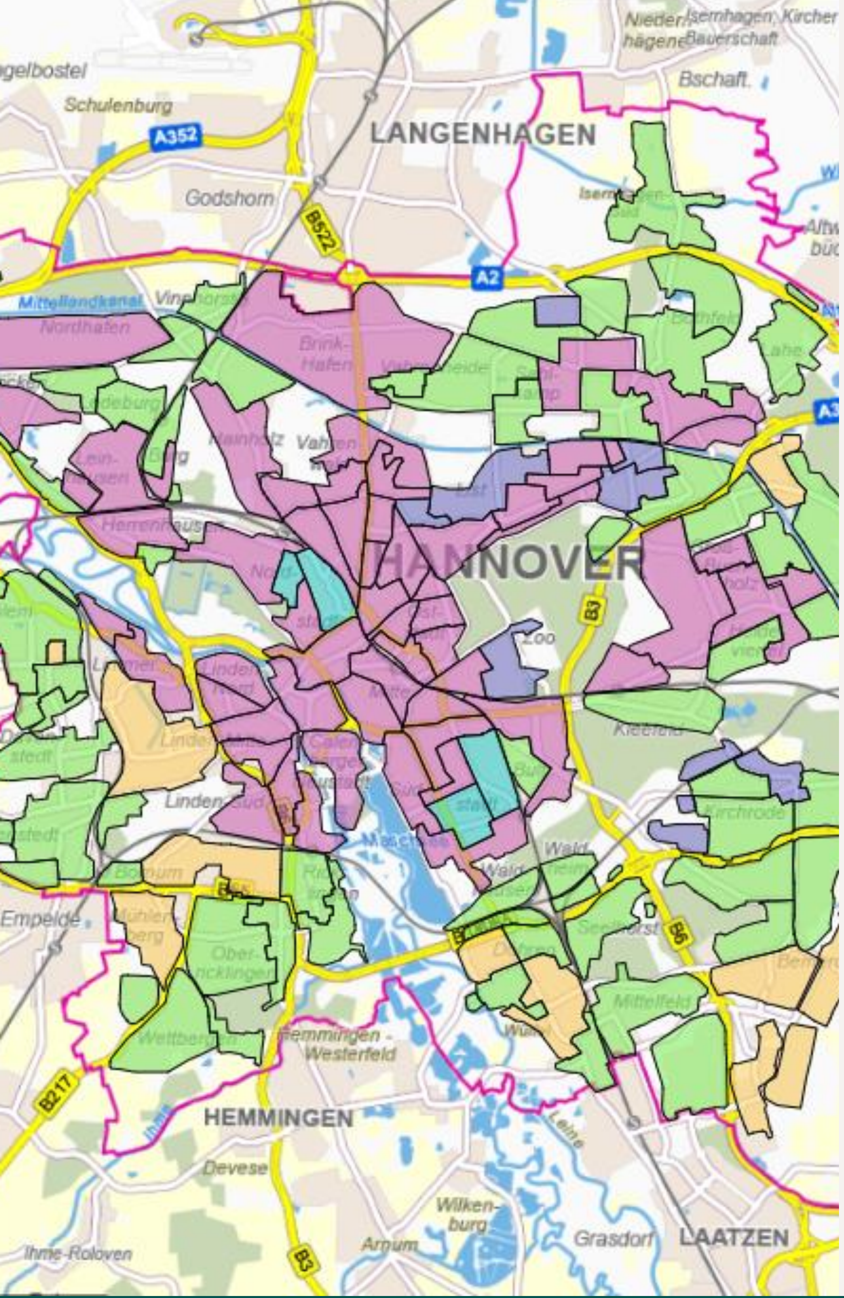
Phase-out subsidies for standalone fossil-fuel boilers in buildings by 2025
Phase-out of fossil fuels in heating and cooling with a view to a complete phase-out of fossil fuel boilers by 2040

Clean Heat toolbox for Member States (risk mitigation, capacity building for local authorites...)

DHC networks: Getting to Net Zero

The Energy Efficiency Directive introduce a new definition of Efficient DHC networks.
It includes milestones to get to net zero by 2050, excluding the addition of new fossil fuel capacity from 2030 onwards.





Local heating and cooling plans

Mandatory development of local heating and cooling plans for municipalities with at least 45.000 citizens:

- mapping of the potential for increasing energy efficiency, also via low-temperature DHC, high efficiency CHP, waste heat recovery, and RES
- energy efficiency first principle
- taking into account relevant existing infrastructure
- include a trajectory to achieve the goals of the plans in line with climate neutrality

Hannover’s draft plan

Currently:
62% with natural gas,
27% with DHC
the rest with oil, petroleum , local heating and biomass

By 2045:
DHC is expected to supply 56%
HPs 34%
local heating systems 9%

Map: [Hannover’s heat planning]

EED - assessment of utilising waste heat

MSs to aim to remove barriers for the utilisation of waste heat and provide support for the uptake of waste heat where the installations are newly planned or refurbished. In particular, it concerns:

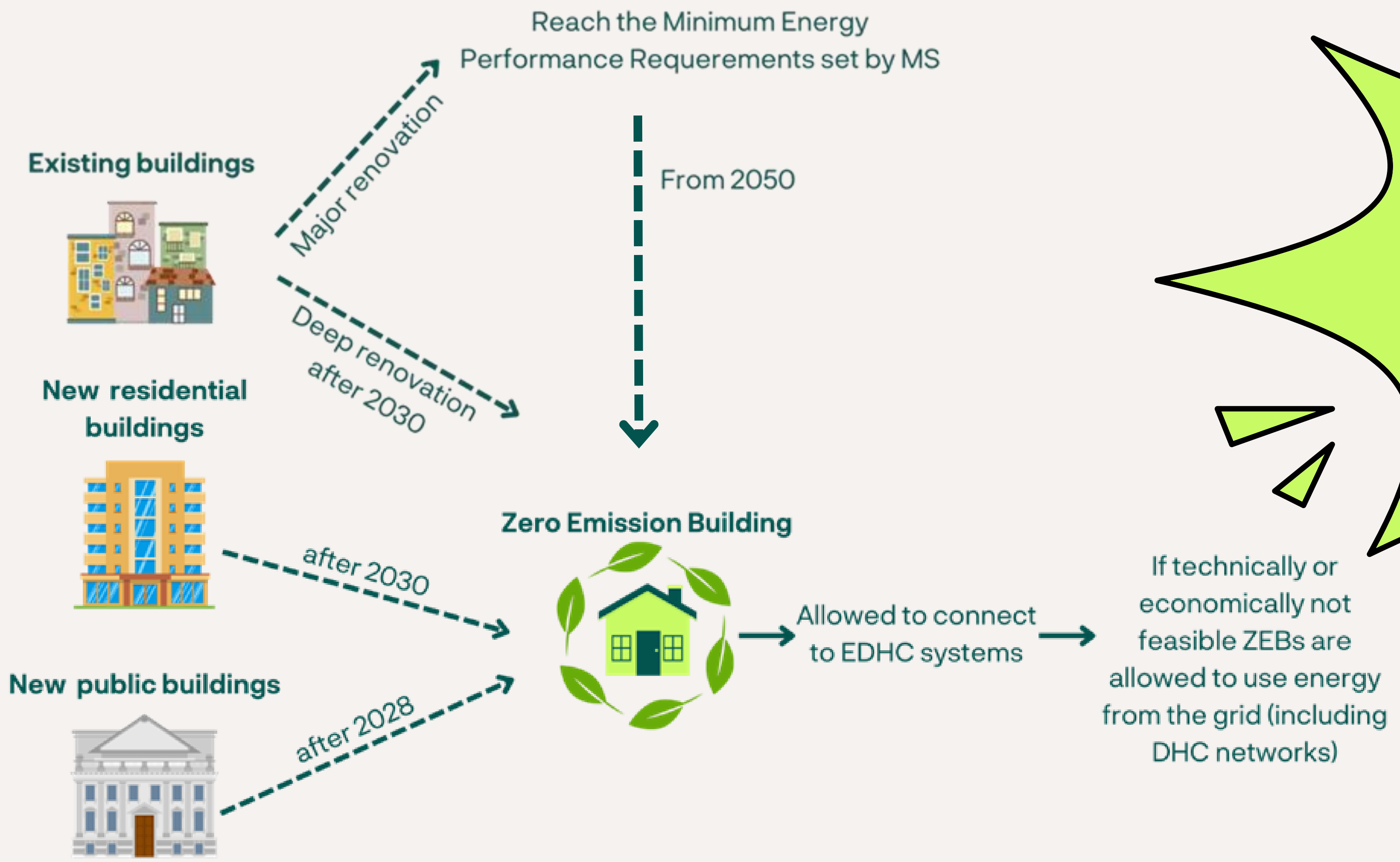
- thermal electricity generation installation with an average annual total energy input exceeding 10 MW on upgrading to high efficiency CHP,

- industrial installations with an average annual total energy input exceeding 8MW,

- service facilities (such as wastewater treatment facilities and LNG facilities) with an input exceeding 7MW to assess utilisation of waste heat on and off-site,

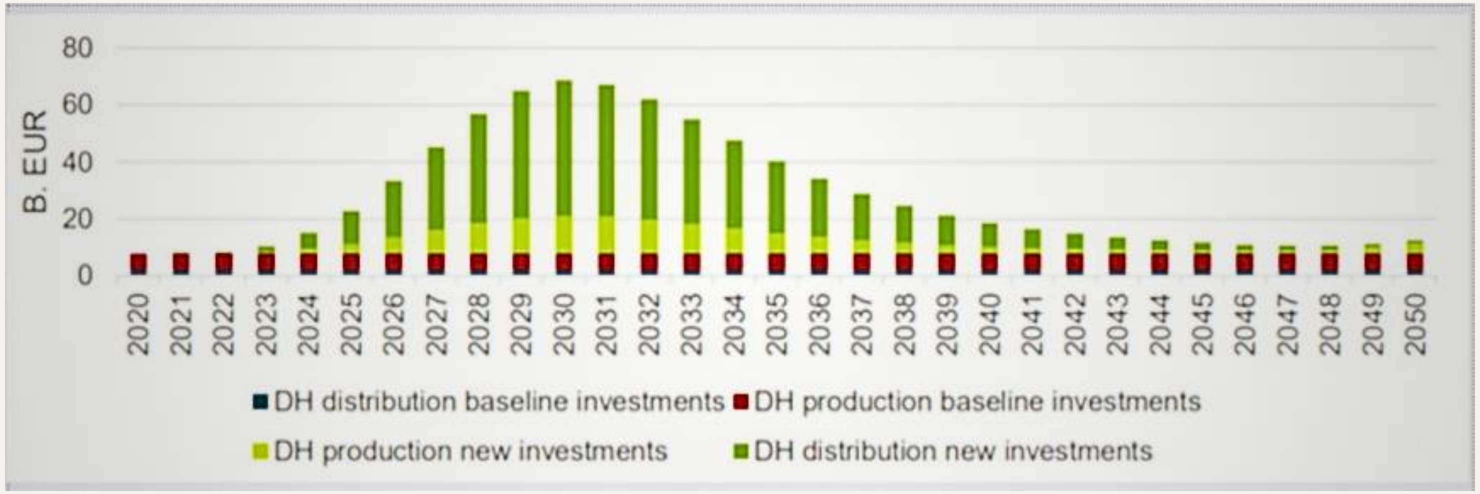
- data centres with energy input exceeding 1MW to assess the cost and benefit analysis of utilising waste heat and to connect to a DHC network.

EPBD - Zero Emission Buildings



Zero Emission Buildings are allowed to connect to efficient district heating and cooling systems in accordance with EED Art. 26

Private financing is fundamental to accelerate the decarbonisation of DHC



Source: Mathiesen et al. 2019

- 144 bln € needed and up to 65 bln € private investment required by 2030 to reach 2050 scenario
- High up-front costs and long term ROI make hard to get private investments
- Need for a supportive policy framework to attract more private investments in DHC
- Innovative business models and financial schemes

BUT

DHC can be now
what wind and solar were before

Main Innovation priorities for DHC sector

LTDH

WASTE HEAT

SYSTEM INTEGRATION

DIGITALISATION

RES INTEGRATION

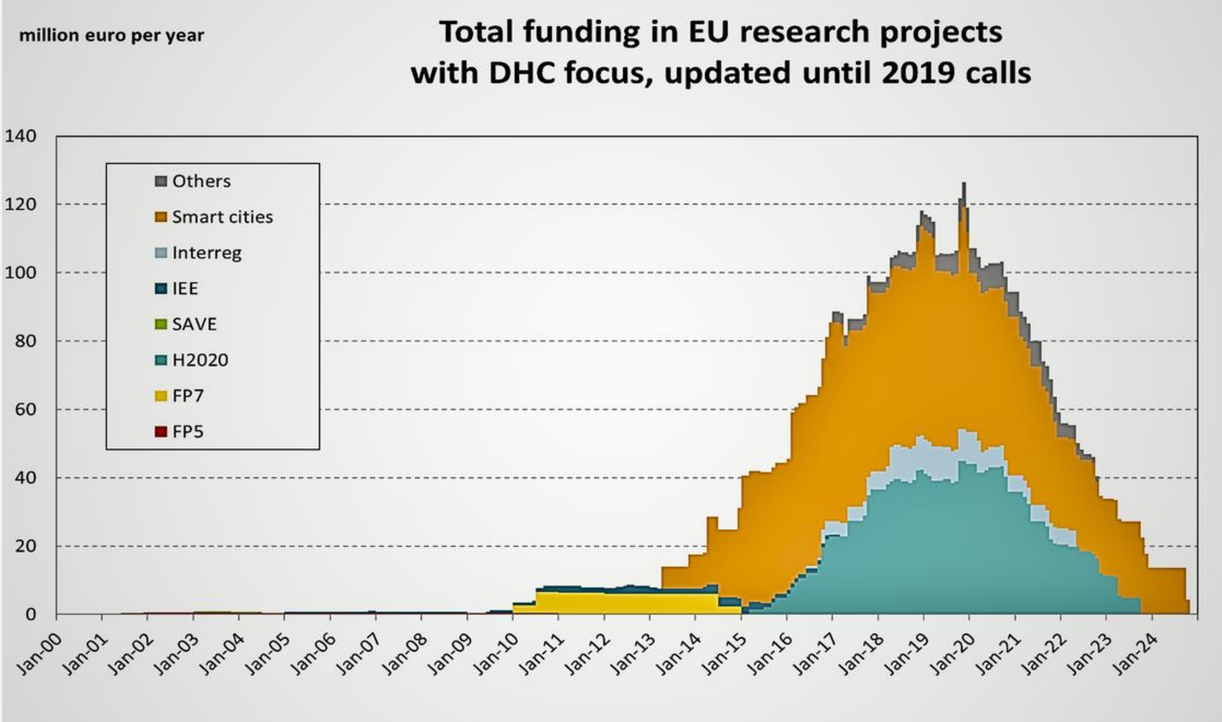
STORAGE

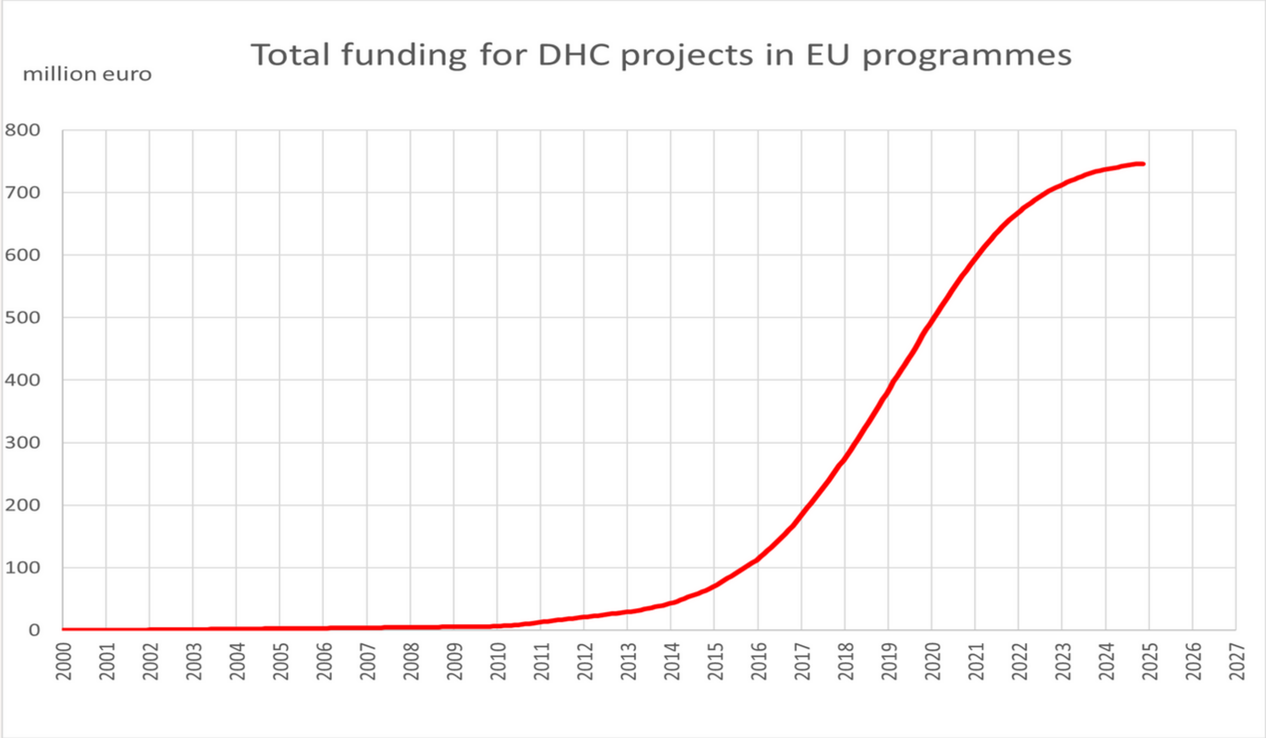
The provision of 100% renewable energy-based heating and cooling (100%RHC) in Europe is achievable even by 2040.

Budget needs 2021-2027

	Funding needed (million euro)		
	Public	Private	Combined
Waste heat	55	135	190
District cooling	200	150	350
LTDHC	250	200	450
Energy integration	175	150	325
Digitalisation	125	150	275
TES	250	250	500
Total	**1,055**	**1,035**	**2,090**

Public Funding for DHC research & innovation is steadily increasing in the last 10 years





Heating & cooling decarbonisation action plan

Umbrella Communication: Heating & Cooling Strategy review (VISION)

Recall the importance of H&C and all clean heat technologies to achieve the 2040 target

Identify challenges, opportunities and guidelines for action

Citizen deal: lift the financial & administrative burden off EU consumers (ACCEPTABILITY)

Heat planning & implementation VS emergency replacement

Zonal incentives based on Heat plans

Facilitate consumers' access to affordable clean heat solutions + consumer protection

Financing + de-risking of sustainable RES & recovered heat projects (COMPETITIVENESS / MARKET UPTAKE)

Dedicated support covering DEVEX/CAPEX/OPEX support (where project deemed relevant by H&C AP)

Dedicated instruments to de-risk, leverage private finance and facilitate access to funding

Streamlined permitting based on H&C plans (infrastructures, go to areas, etc)

Heat Pump Action Plan (INDUSTRIAL STRATEGY)

Thank you!

Gabriele Pesce

Director of Innovation &
Sustainable Finance
gp@euroheat.org

@EuroheatPower

Euroheat & Power

euroheat.org

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REFRIGERATION AIR CONDITIONING HEAT PUMPS

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Questions?

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Heat as a Service: Now or Never?

Klara Ottosson, LCP Delta

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LCPDelta

Heat as a Service: Now or Never?

16TH APRIL 2024

CONTACT: KLARA.OTTOSSON@LCP.COM

Introducing LCP Delta

Powering the energy transition across the whole value chain

LCP Delta is a specialised energy transition practice providing

Subscription research	Consulting	Technology and data	Training

…to organisations that are active in all parts of the value chain

Generation & storage	Networks	Demand & customer propositions

…delivering expertise and advice in

Power market forecasting	Energy storage & flexibility	Hydrogen	Power trading	PV
Distributed power	Policy impact analysis	System modelling	Business models	Energy management
EV charging infrastructure	Connected home	Low carbon heat	Customer engagement	Community energy

~ 100 people

Active since 2004

200+ clients

Agenda

Heat as a Service: Now or Never?

- **(Re)Defining HaaS**
- **Market today**
- **What is shaping the future of HaaS?**

(Re)Defining heat as a service

LCP Delta's previous definition of heat as a service

Using a risk-based definition

Financial risk:

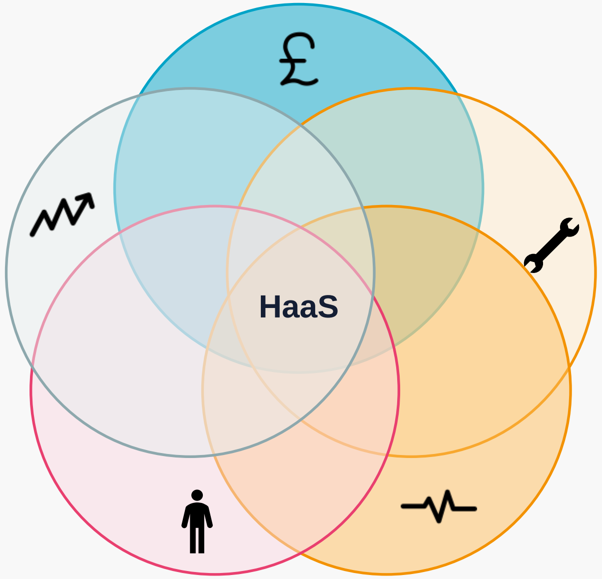
Service provider takes on credit risk by providing a heating appliance for a monthly fee and little or no upfront payment.

Technical risk:

The monthly fee charged by the service provider includes: routine maintenance, repairs, and appliance replacement if necessary within the contract period.

Energy price risk:

Service provider offers a fixed price per unit of heat or warmth generated for a period of time, typically a year.



Behaviour risk:

Service provider charges for the outcome (warmth) provided, thereby taking on the risk that customers use heating inefficiently by, for example, opening windows. This also includes the risks associated with timing of demand, which are related to energy price risks.

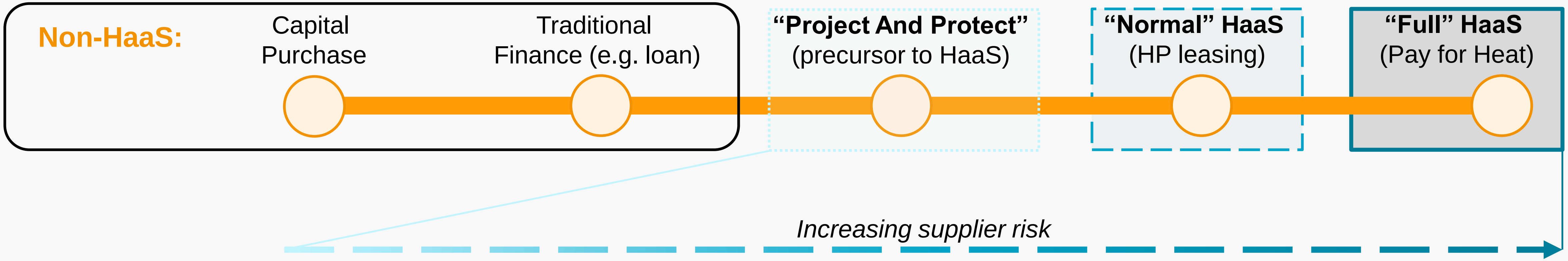
Performance risk:

Service provider charges per unit of output (heat) or for the outcome (warmth) provided by the heating appliance (or guarantees savings on heating costs). For service providers selling warmth, this includes the risks that 1) the heat distribution system is inefficient and 2) the thermal efficiency of the property is poor.

LCP Delta's new definition of heat as a service

There are three levels of heat as a service

Ways to fund a heating installation:



'Project and protect'

- Not strictly HaaS but often a precursor to it.
- A complete HP solution, from design & installation to finance & service. It is not strictly an "as a service" offer as the customer owns the HP in full after paying off the loan.

'Normal' HaaS

- Heat pump leasing with a service and maintenance wrapper.
- May come with longer guarantee where provider accepts some technology risk beyond manufacturer warranty.

Focus of this presentation

'Full' HaaS

- Provider owns appliance and only charges customer for the heat used.
- Typically would include a heat meter to measure appliance output. Payments may be smoothed across the year to avoid winter peaks.

HaaS today

Current penetration of residential HaaS in Europe

HaaS represents an insignificant of heat sales in most countries in Europe, but these 4 are the exception

GERMANY

Annual HaaS share		Market players
Heat pump	5%	thermondo, Viessmann, EWE, ökoloco
Boiler	<1%	

DENMARK

Annual HaaS share		Market players
Heat pump	<5%	OK, NÆRVARME DANMARK, EWII
Boiler	X	

NETHERLANDS

Annual HaaS share		Market players
Heat pump	X	Feenstra, essent
Boiler	<5%	

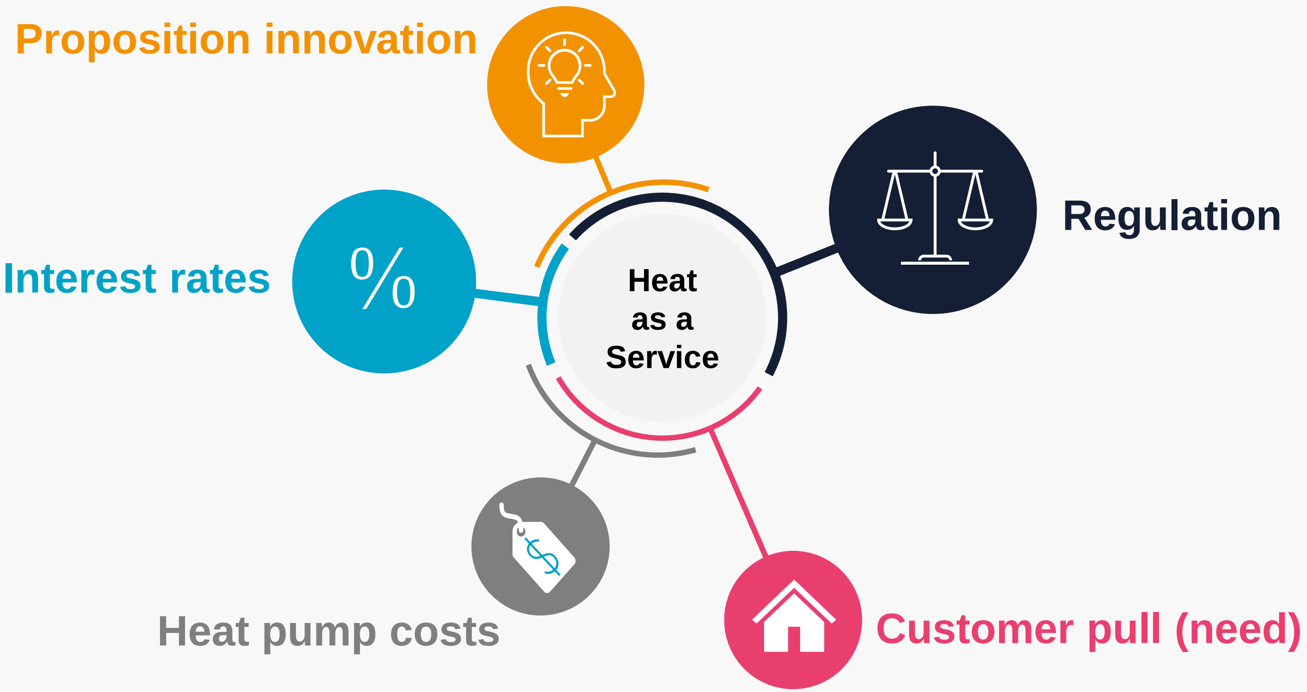
UK

Annual HaaS share		Market players
Heat pump	X	BOXT, BeWarm, Hometree, Warmly
Boiler	<1%	

Thermondo's proposition is currently paused.

What is shaping the future of HaaS?

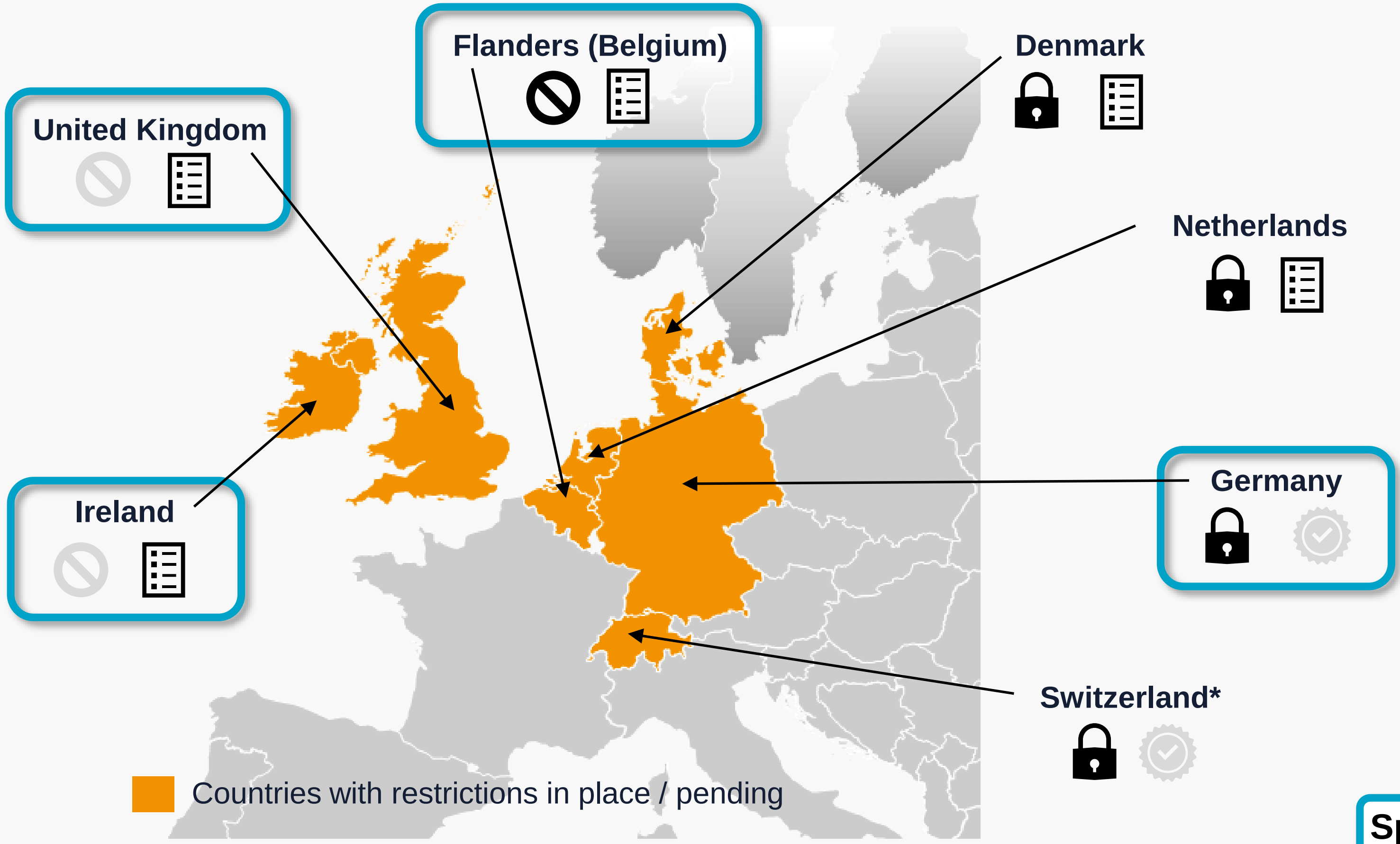
What will impact the growth of heat as a service?

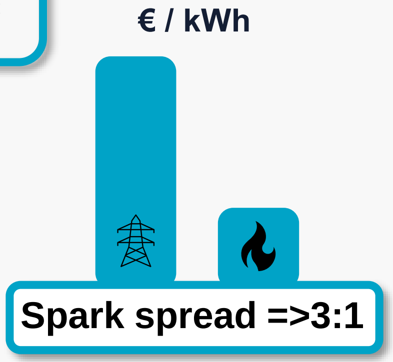


Market influencer: Regulation

Retrofit restrictions on standalone natural gas boiler replacements may create a bigger need for HaaS

Approach	
Restricted	
De facto ban	
Outright ban	
Status	
Proposed	
Confirmed, not implemented	
Confirmed & implemented	

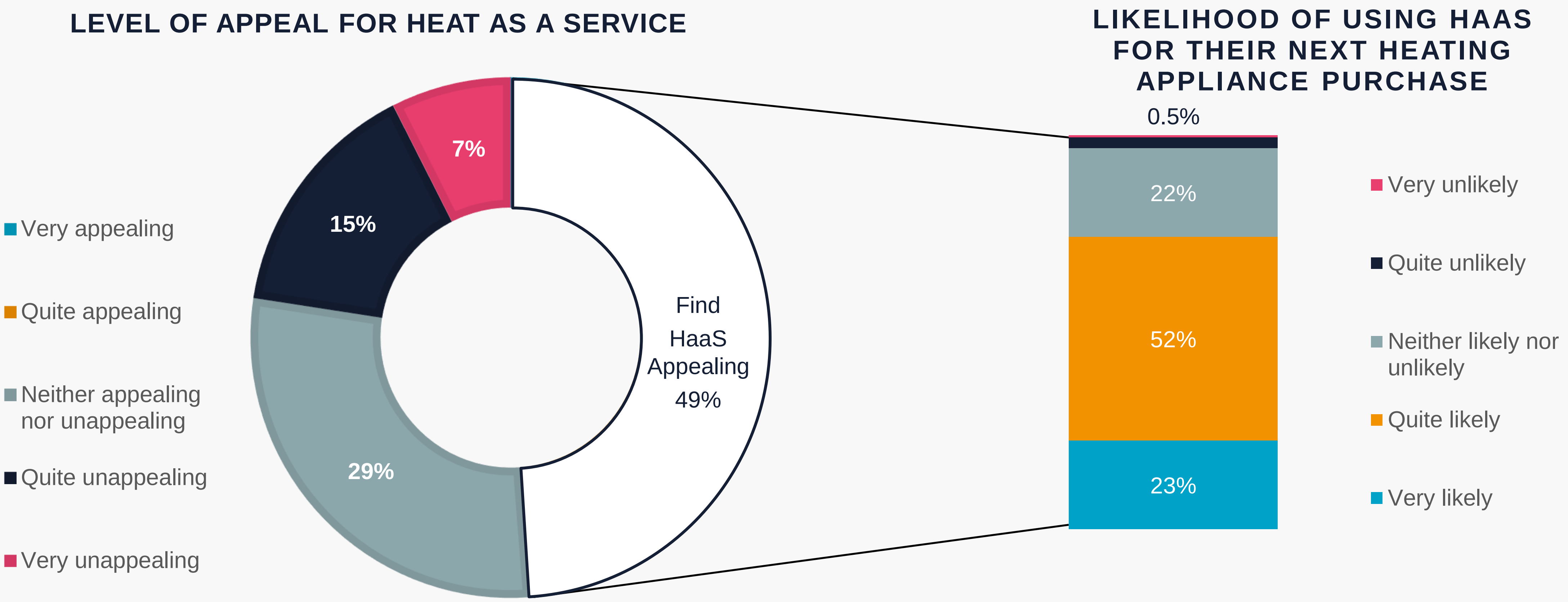




*some cantons in Switzerland have already implemented restrictions, but none at the national level.

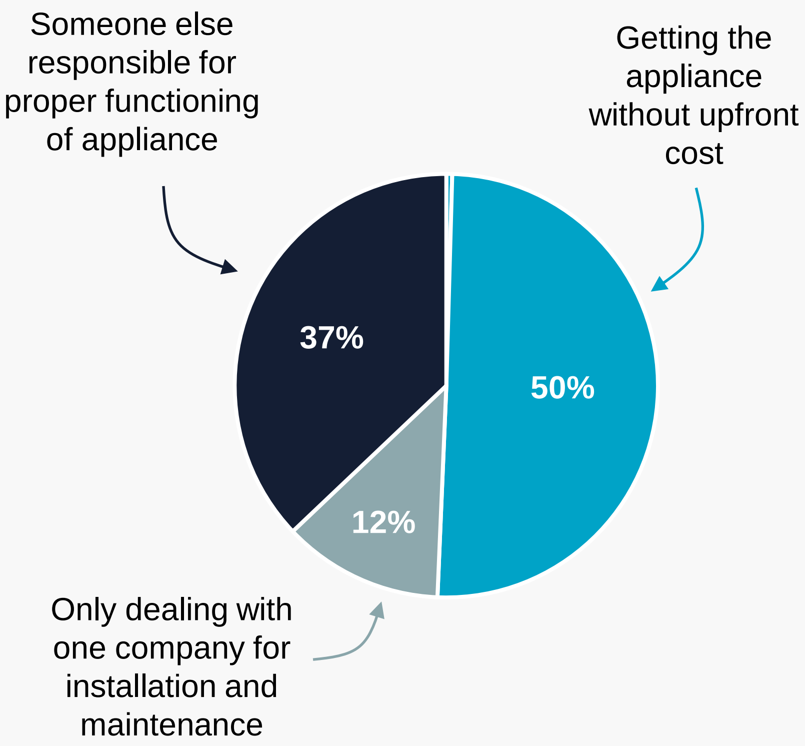
Market influencer: Customer pull

Based on customer research in 6 countries: DE, FR, IT, NL, UK & ES

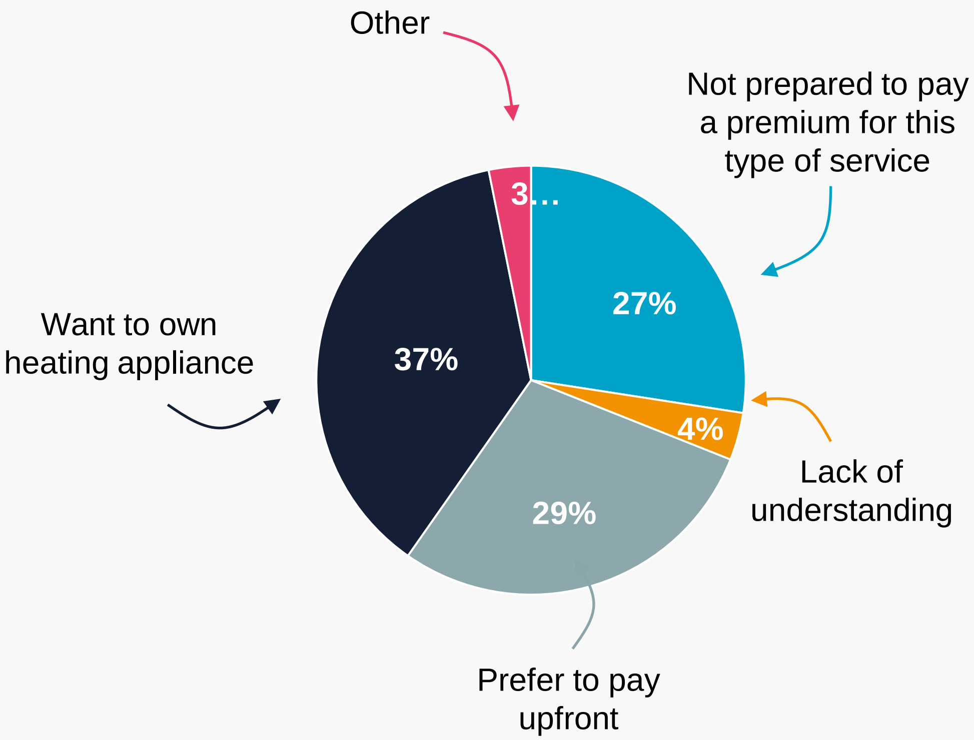


Market influencer: Customer pull

Most appealing feature of HaaS*:



Least appealing feature of HaaS:



*based on participants who find HaaS as appealing, n = 1,567

Heat as a service: now or never?

When will heat as a service take off ?

13% Now

57% Soon (In 5-10 years)

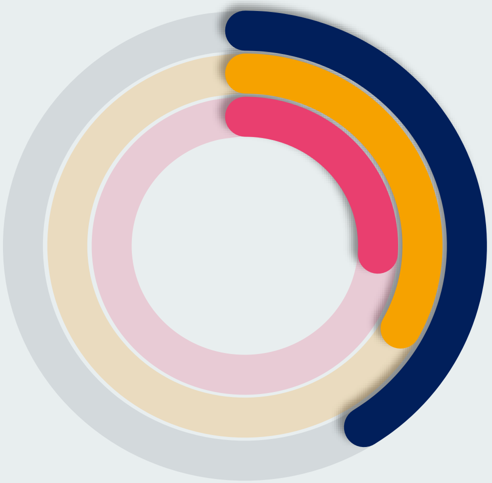
27% Eventually (In more than 10 years)

What could slow the uptake?

Unfavourable subsidy structure – typically favouring ownership
- E.g. recent changes in Germany
- Boiler Upgrade Scheme in UK not available with HaaS

Competition from other propositions

If choosing one, homeowners would go for this as preferred option:



41% Green loans
33% Heat as a Service
26% Salary sacrifice

Examples of players offering alternative payment methods

TSB, PTZ Éco-prêt 0%, British Gas, ENGIE, Santander, bullfinch, Cloover, hiber, HAASHEAT heating as a service

LCPDelta

Thank you!

CONTACT: KLARA.OTTOSSON@LCP.COM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Low Temperature Heat Recovery & Distribution Network Technologies

Session 3: Future Heat Network Technologies

Chair: Professor Bob Critoph, University of Warwick

Advanced Vapour Compression Heat Pumps

Professor Neil Hewitt, Ulster University

Thermal Energy Storage in the UK Energy System

Professor Phil Eames, Loughborough University

Heat Network Delivery: The Warwick Case Study

Dr Ángeles Rivero Pacho, University of Warwick

Professor David Elmes, Warwick Business School

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Low Temperature Heat Recovery & Distribution Network Technologies

Advanced Vapour Compression Heat Pumps

Professor Neil Hewitt, Ulster University

Heat Pumps and Premature Aging

- 1980's – PhD "The Development of an Alternative Refrigeration Cycle
- 1990's – Compact Plate Heat Exchangers, CFC Replacements, Scroll Compressors, Ground Source Heat Pumps

- 2000's – Air source heat pumps, integration, end-user engagement, cost reduction versus performance increases

- 2010's – Integration challenges and thermal storage, electrification of heat, smart systems, demand side response and distributed energy management, end-user engagement (And Research Director)

- 2020's – Industrial Heat Pumps (200 deg. C and beyond), waste heat recovery, heat networks, geothermal (And Head of School)

Our Work Packages

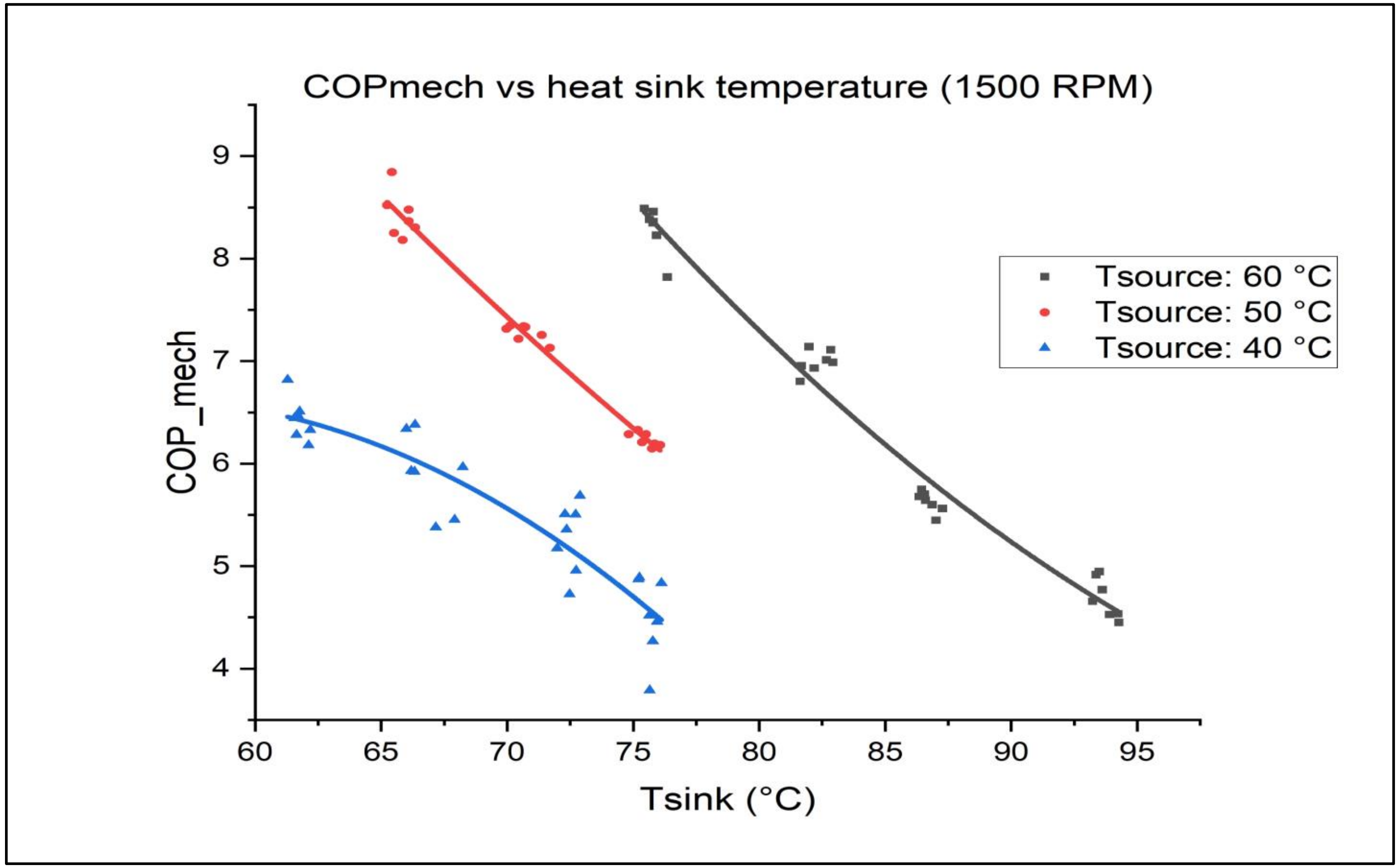
WP3.1: Low temperature lift, high COP VC heat pump to deliver heat from LT network to load (e.g. lift of 20^{o}C with COP>9, enabling network to supply conventional radiator system)

WP3.2: VC Heat Pump for Demand Side Management; variable renewable electricity supply will be matched to demands using building/process heating controls in association with variable compressor speed and storage

WP3.3: High temperature VC heat pumps from network to process heat in commercial or industrial applications.

WP3.4: Combined heat pump/ORC for heat to electricity or reverse, allowing maximum flexibility between combined (thermal/electricity) energy systems.

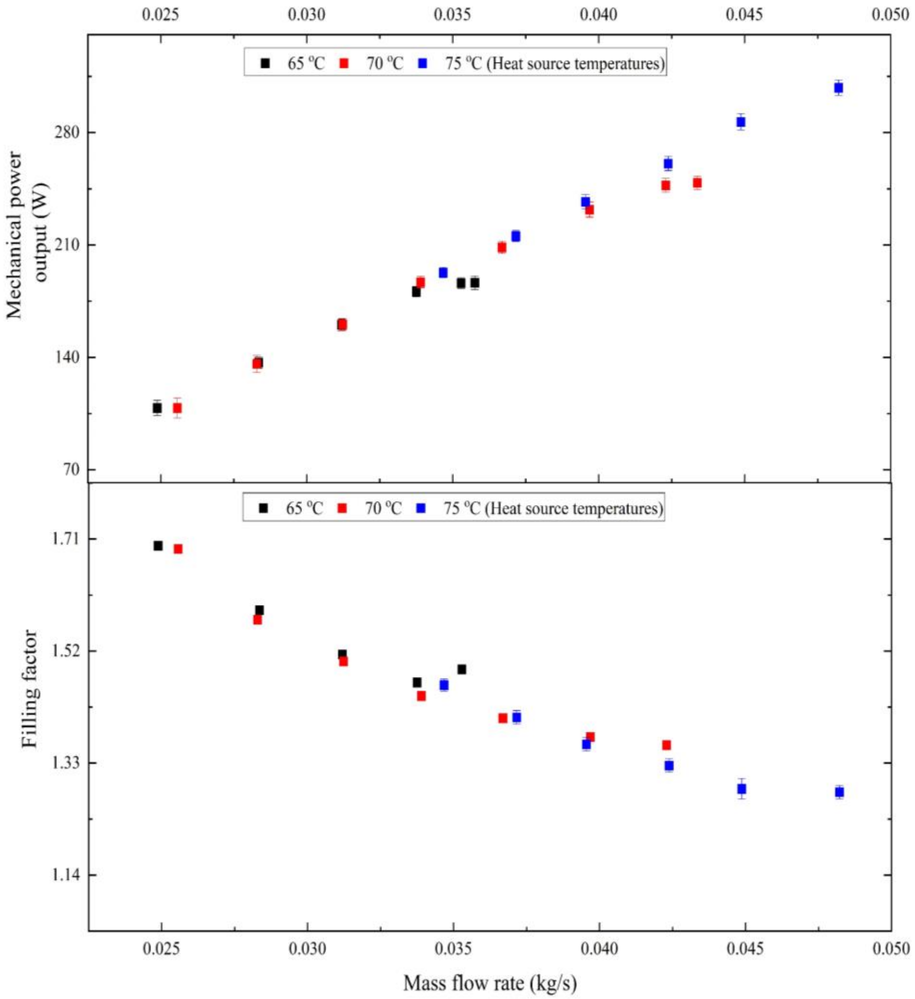
WP 3.1: Low temperature lift, high COP VC heat pump
WP 3.3: High temperature VC heat pump



WP3.4: Combined heat pump/ORC for heat to electricity

Reversible HP-ORC

Alternator



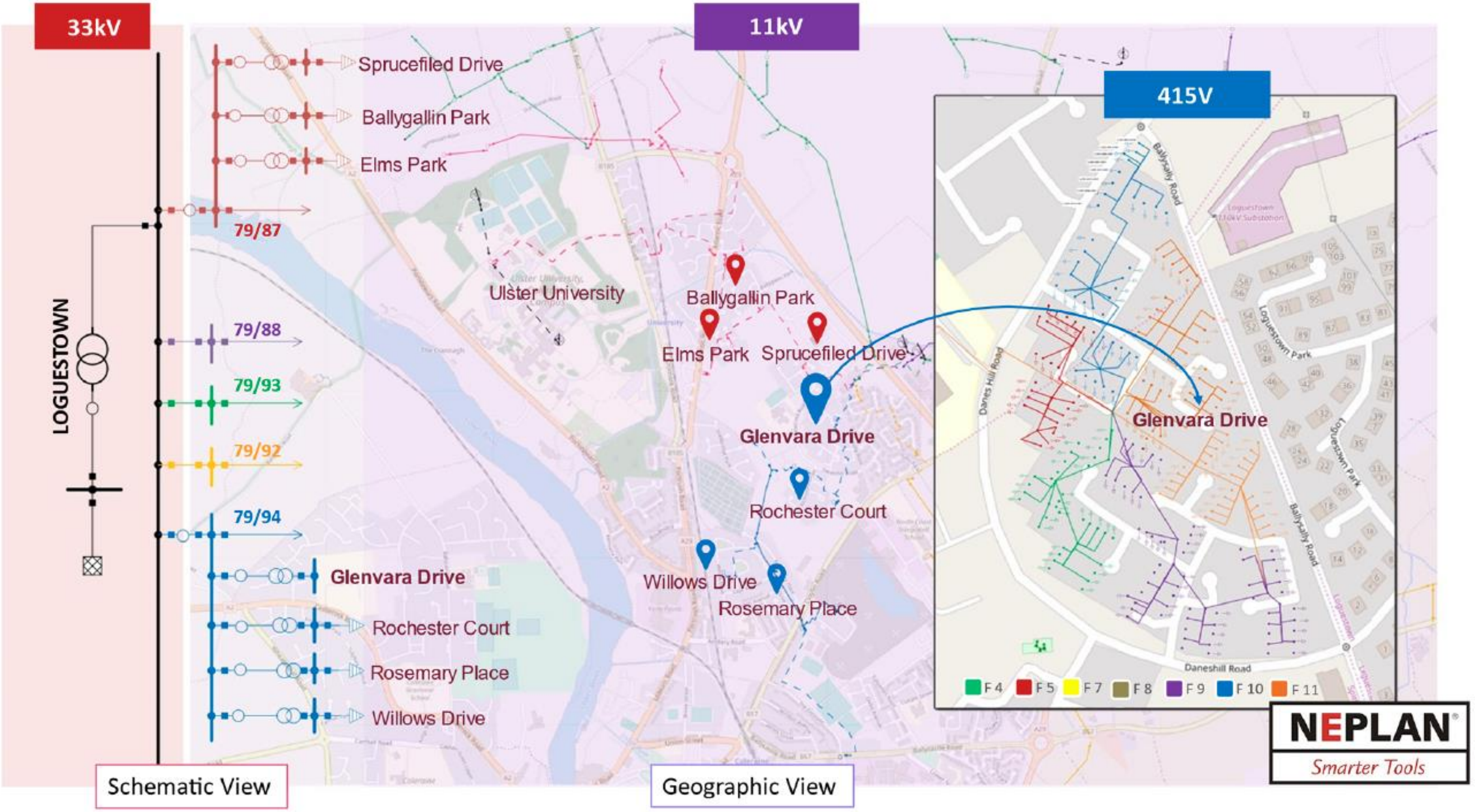
Discharge side with the check valve removed

DC electronic load

WP 3.1: Low temperature lift, high COP VC heat pump
WP 3.3: High temperature VC heat pump
WP 3.5: The ORC

- **The Takeaways….**
- Fluid Choice R1233zd(E) will be challenged by PFAS phase outs
  - Water or Gas Cycles for high temperature heat pumps
  - High COPs are very possible
- Organic Rankine Cycle
  - 5% Power return at low temperatures
  - Best use will be as an expansion turbine where 20% power to the compressor will increase the COP

WP 3.2: Demand Side Management



Osaru Agbonaye, Patrick Keatley, Ye Huang, Oluwasola O. Ademulegun, Neil Hewitt (2021) Mapping demand flexibility: A spatio-temporal assessment of flexibility needs, opportunities and response potential, Applied Energy, Volume 295

WP 3.2: Demand Side Management

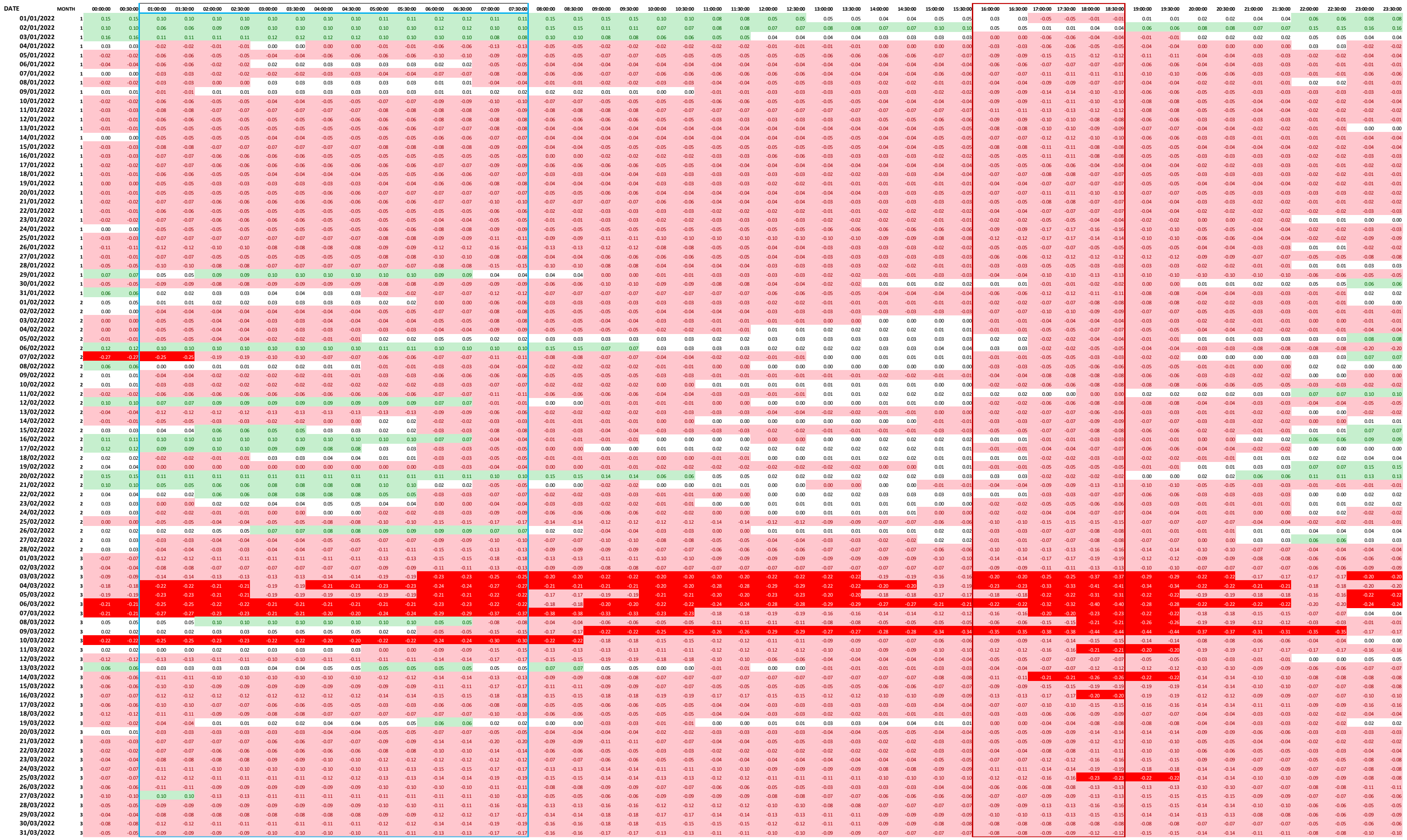
WP 3.2: Demand Side Management

With Project Rulet and Dr Patrick Keatley

sirach LoT-NET IOR.org.uk

REFRIGERATION AIR CONDITIONING HEAT PUMPS

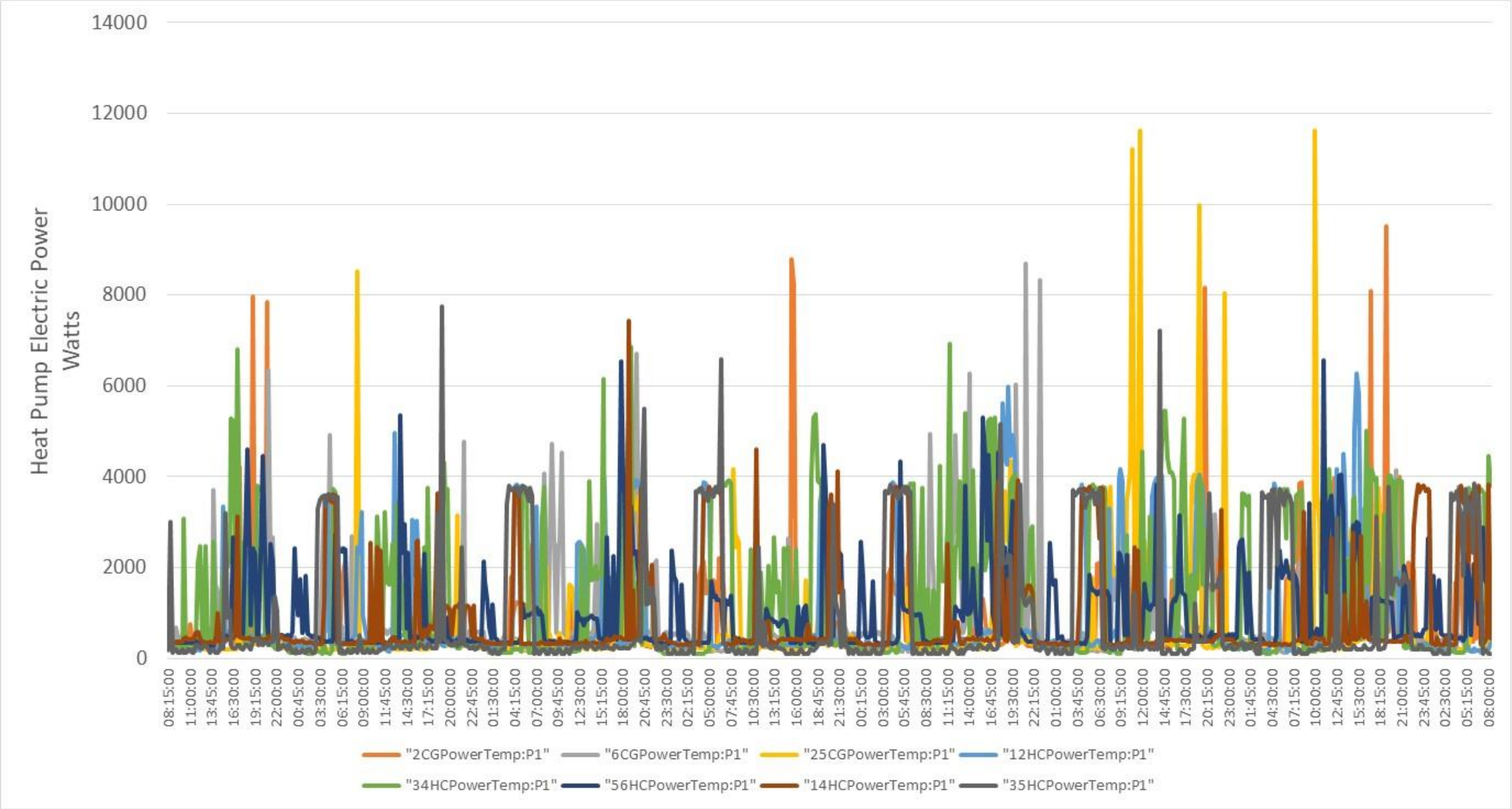
WP 3.2: Demand Side Management



DATE	MONTH	00:00:00	00:30:00	01:00:00	01:30:00	02:00:00	02:30:00	03:00
01/01/2022	1	0.15	0.15	0.10	0.10	0.10	0.10	0.
02/01/2022	1	0.10	0.10	0.06	0.06	0.09	0.09	0.
03/01/2022	1	0.16	0.16	0.11	0.11	0.11	0.11	0.
04/01/2022	1	0.03	0.03	-0.02	-0.02	-0.01	-0.01	0.
05/01/2022	1	-0.02	-0.02	-0.06	-0.06	-0.05	-0.05	-0.
06/01/2022	1	-0.04	-0.04	-0.06	-0.06	-0.02	-0.02	0.
07/01/2022	1	0.00	0.00	-0.03	-0.03	-0.02	-0.02	-0.
08/01/2022	1	-0.02	-0.02	-0.03	-0.03	0.00	0.00	0.
09/01/2022	1	0.01	0.01	-0.01	-0.01	0.01	0.01	0.
10/01/2022	1	-0.02	-0.02	-0.06	-0.06	-0.05	-0.05	-0.
11/01/2022	1	-0.03	-0.03	-0.08	-0.08	-0.07	-0.07	-0.
12/01/2022	1	-0.01	-0.01	-0.06	-0.06	-0.05	-0.05	-0.
13/01/2022	1	-0.01	-0.01	-0.05	-0.05	-0.05	-0.05	-0.
14/01/2022	1	0.00	0.00	-0.05	-0.05	-0.05	-0.05	-0.
15/01/2022	1	-0.03	-0.03	-0.08	-0.08	-0.07	-0.07	-0.
16/01/2022	1	-0.03	-0.03	-0.07	-0.07	-0.06	-0.06	-0.
17/01/2022	1	-0.02	-0.02	-0.07	-0.07	-0.06	-0.06	-0.

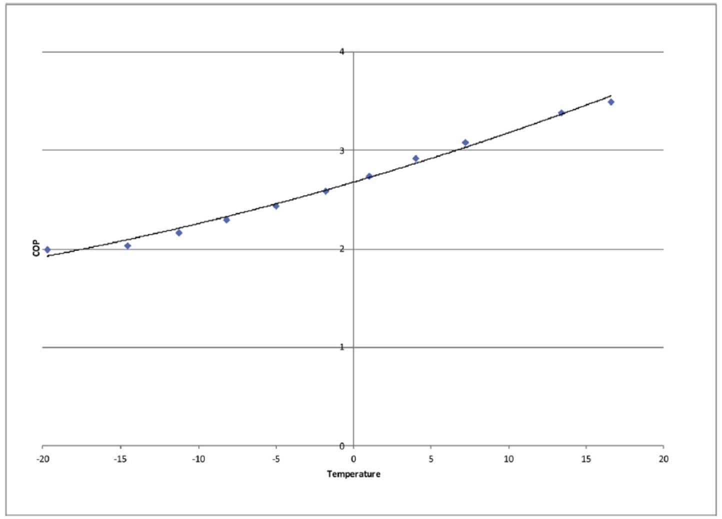
Green = Trial (plus network costs, etc) cheaper than E7; white is when E7 = Trial; pink is when Trial > E7; red is when Trial >20p more expensive than E7.

WP 3.2: Demand Side Management

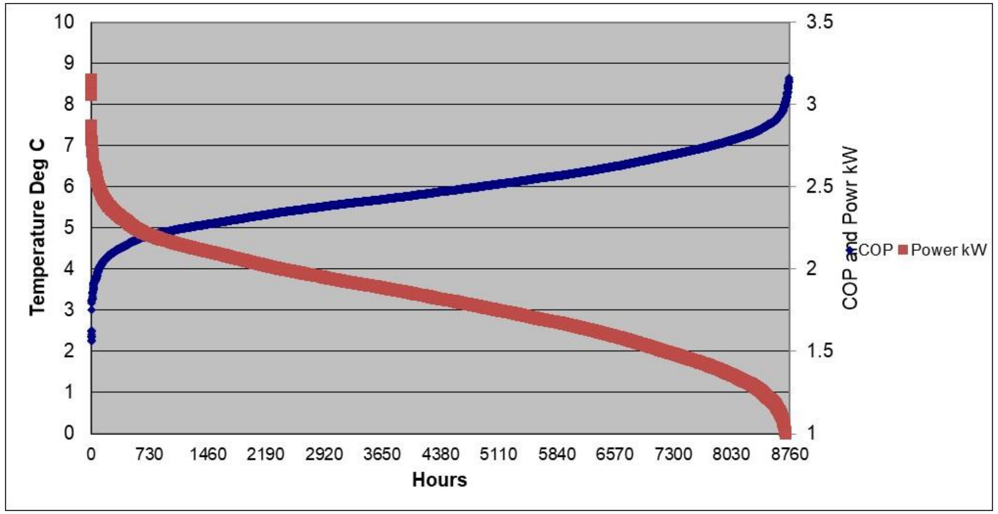


WP 3.2: Demand Side Management

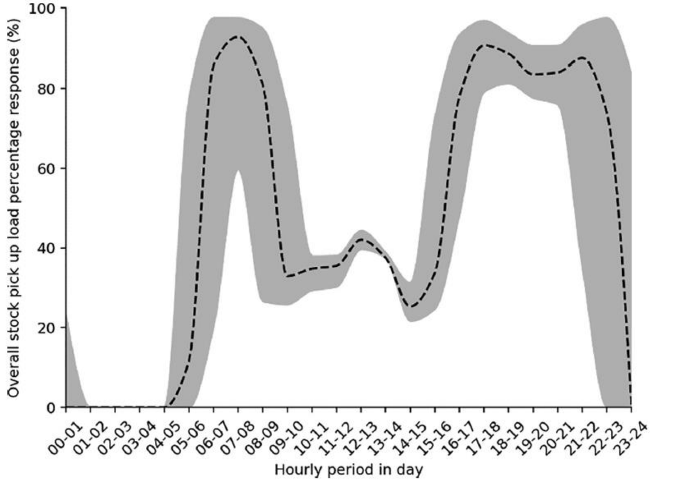
Numerous authors consider After Diversity Maximum Demand (community types, social etc.)
A range of UK values is typically from 1.3 kW to 1.93 kW per household per heat pump.



1. COP can be a lot lower



2. ASHP COP is affected by Air Temperature



3. Time of Day is important

WP 3.2: Demand Side Management

- **The Takeaways**

- Air Source Heat Pumps will decarbonise space heating (with decarbonised electricity)
- Thermal storage is a must for diversity on a daily basis
- Diversity decreases with time of day (thus thermal storage)
- Diversity decreases with temperature (smart load controls)
- Don’t charge the EV when the heat pump is running….

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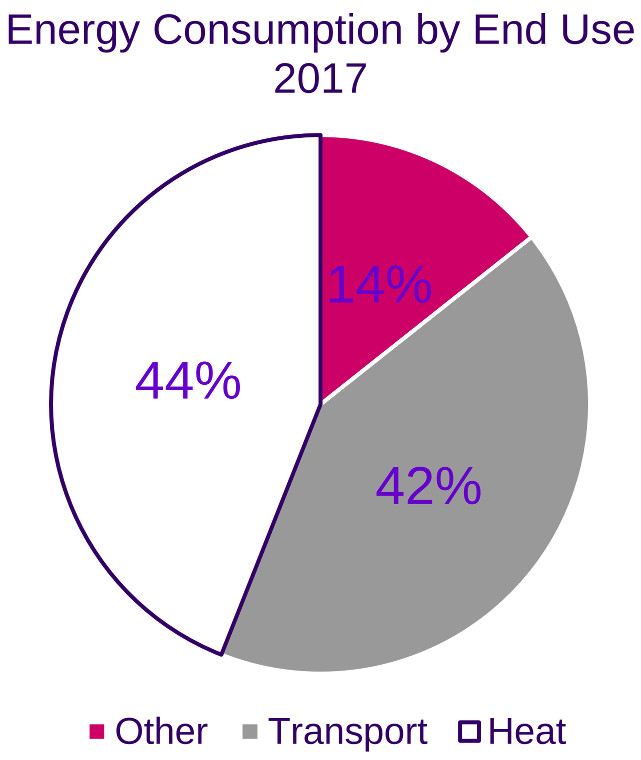
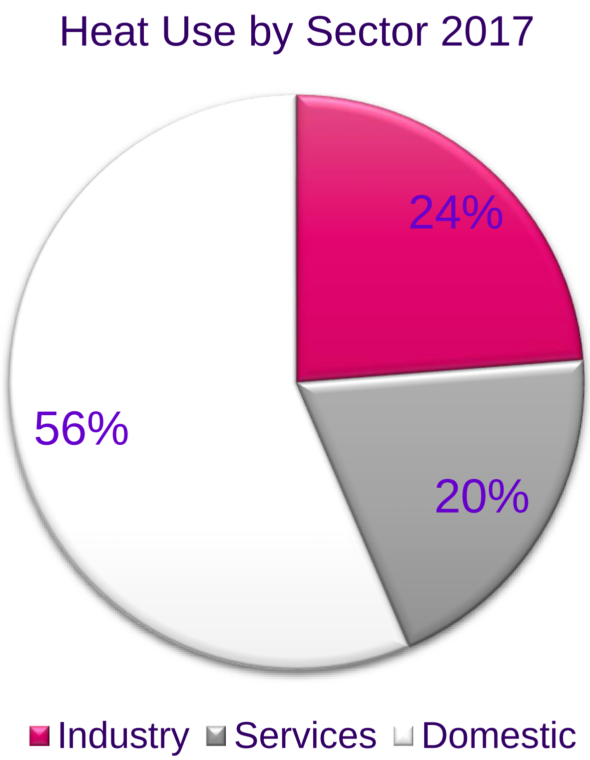
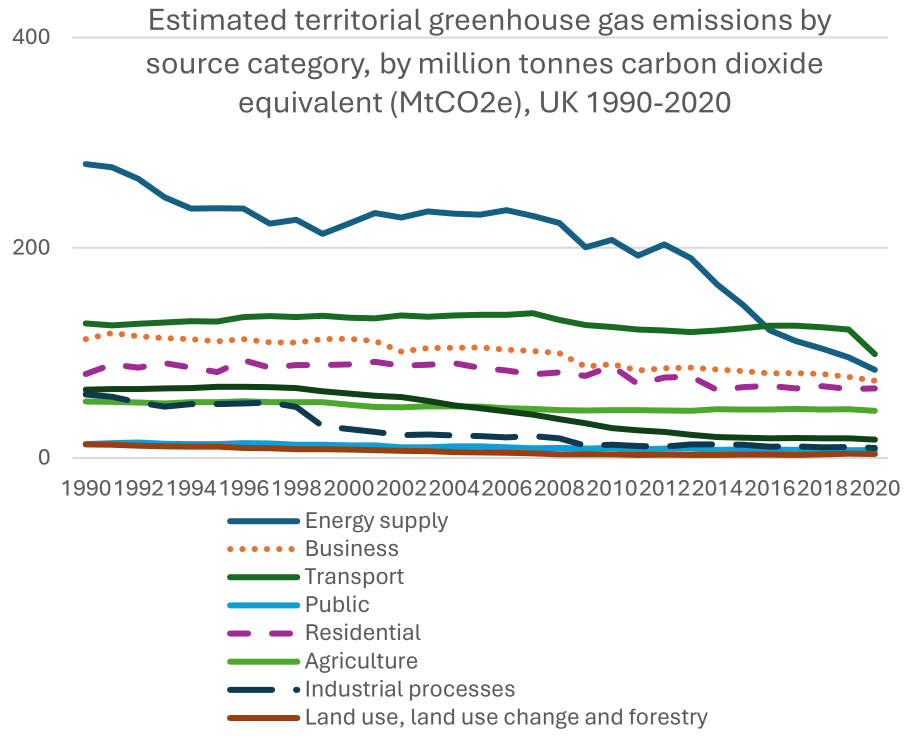
Thermal Energy Storage in the UK Energy System

Professor Phil Eames, Loughborough University

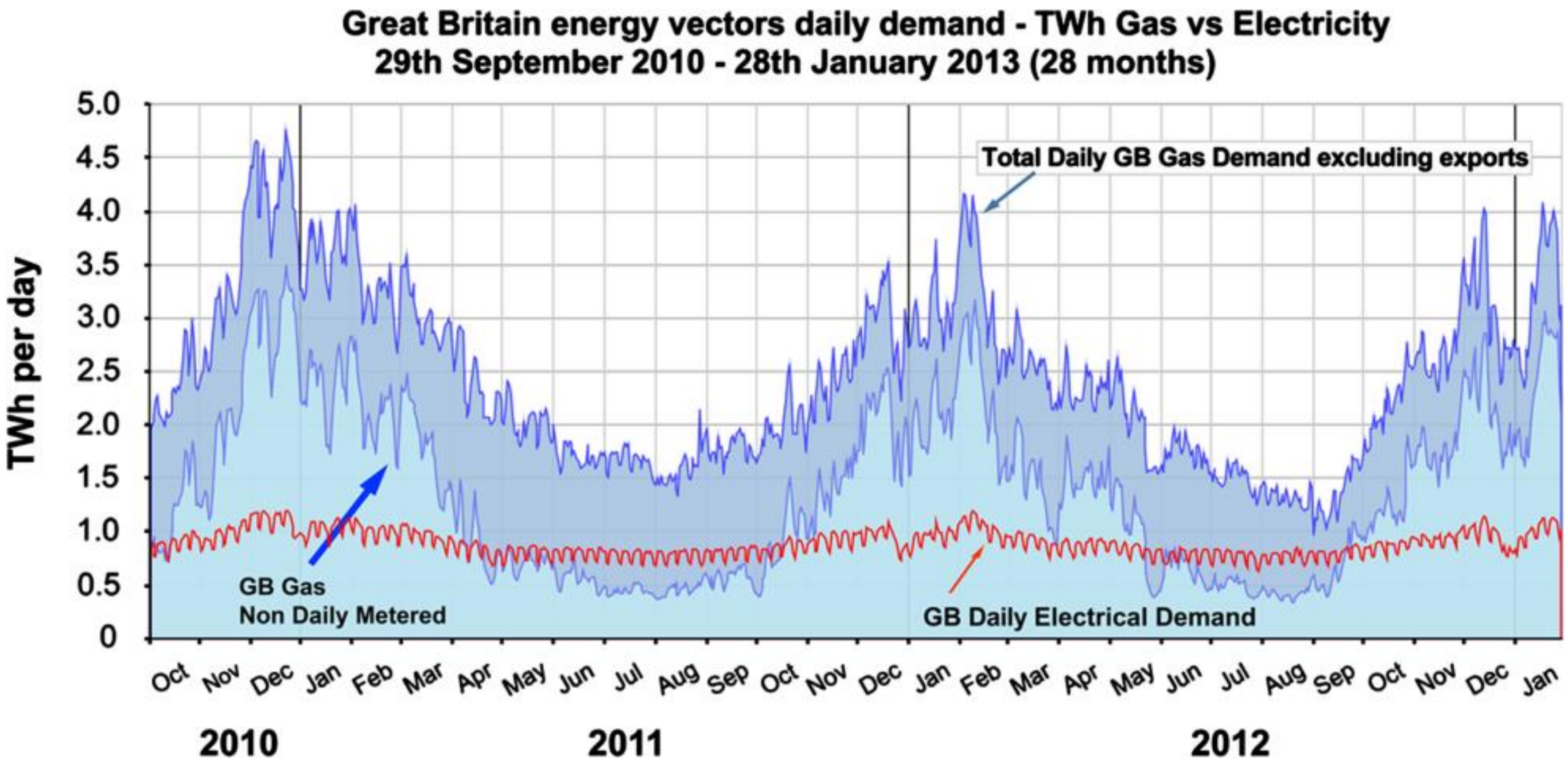
Heat demands







Heat Demands



When analysed on a 30 minute basis winter peak demand for low grade heat can peak at values of approximately 300GW compared to electricity demand which peaks at about 60 GW.

Wilson, I. G., Rennie, A. J., Ding, Y., Eames, P. C., Hall, P. J., & Kelly, N. J. (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.

Roles for thermal storage

Main routes being considered for decarbonisation of heat delivery include:-

- electrification of heat / district heating
- use of low carbon alternative fuels

Space heating and cooling loads strongly influenced by weather, leads to limited diversity in a specific geographical area. (Peak loads occur concurrently.)

Applications of thermal energy storage with electrification of heat / district heating

- Thermal storage can be used to take advantage of i) electricity cost variations ii) maximise use of low/zero emissions generation, iii) reduce/manage peak electricity demand & iv) times to operate ASHP to improve COP

- Time between charge and discharge ranges from hours for small distributed stores to months/seasons for large centralised stores.

Thermal storage

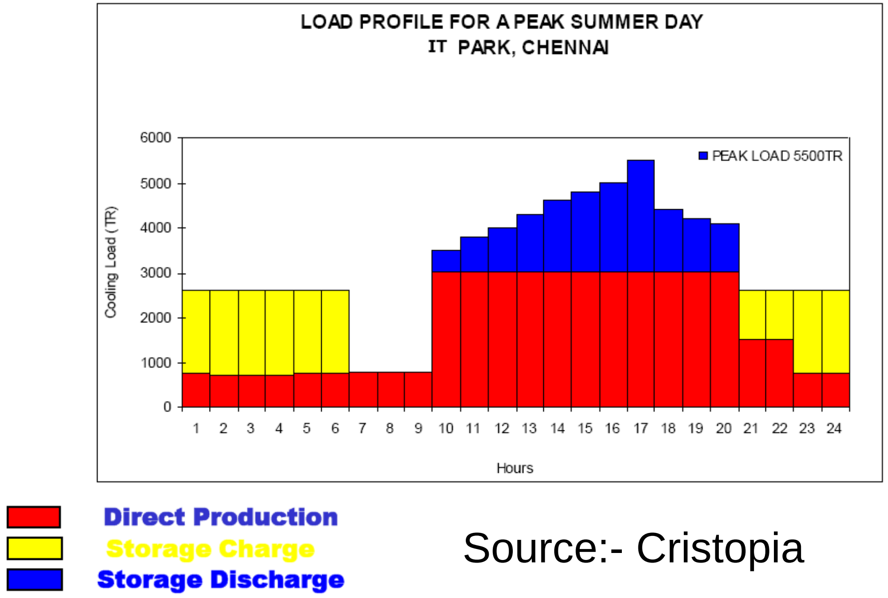
Sensible

Latent

Thermochemical

Specific application requirements determine the approach

- Temperature,
- Load characteristics,
- Storage capacity required,
- Cycle characteristics, charge/discharge rate, time,
- Energy storage density,
- Round trip efficiency/parasitic heat loss,
- Materials requirements,
- Controls,
- Durability,
- Cost.

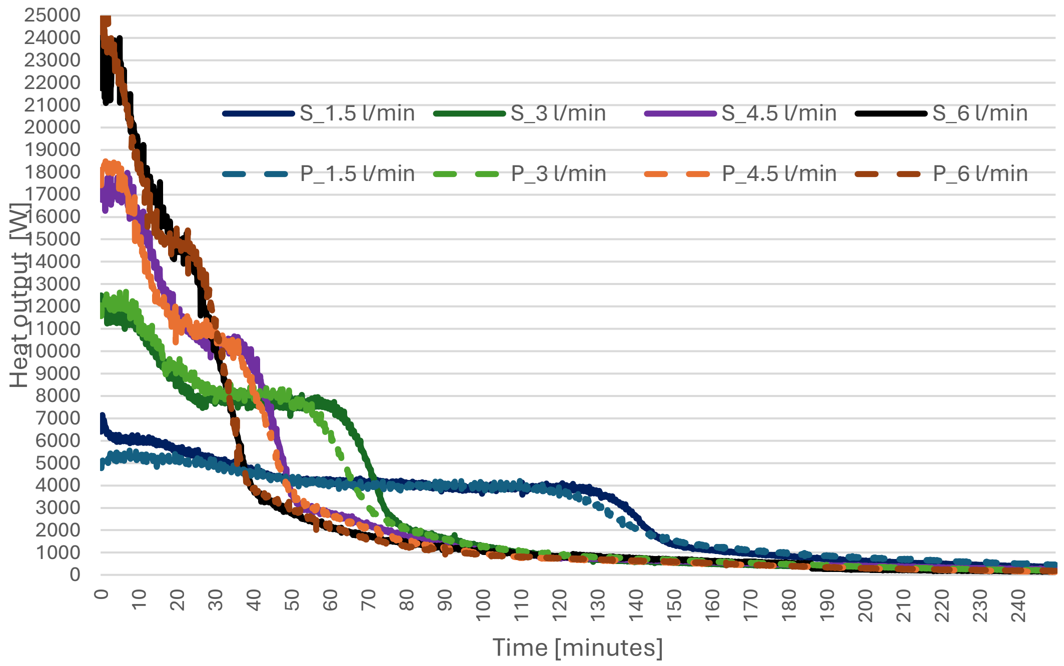


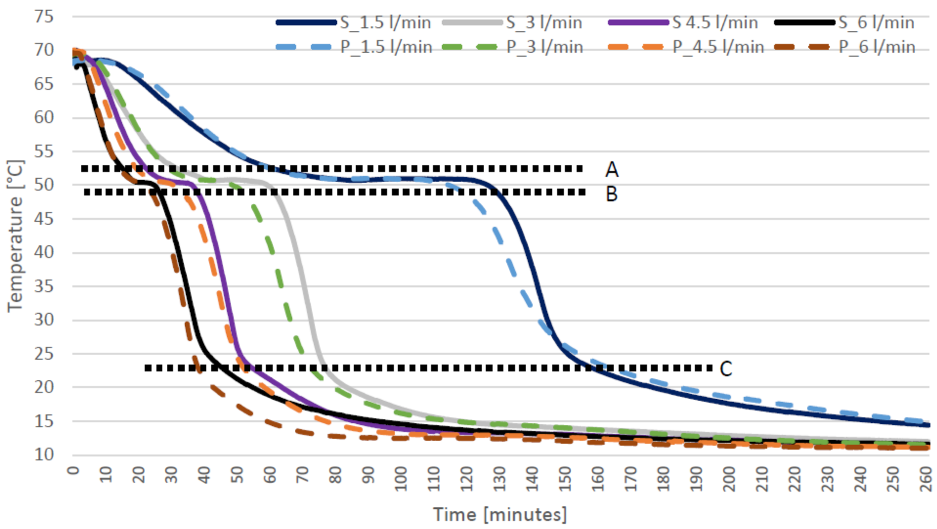
Source:- Cristopia

Thermal storage approaches (In day load shifting)

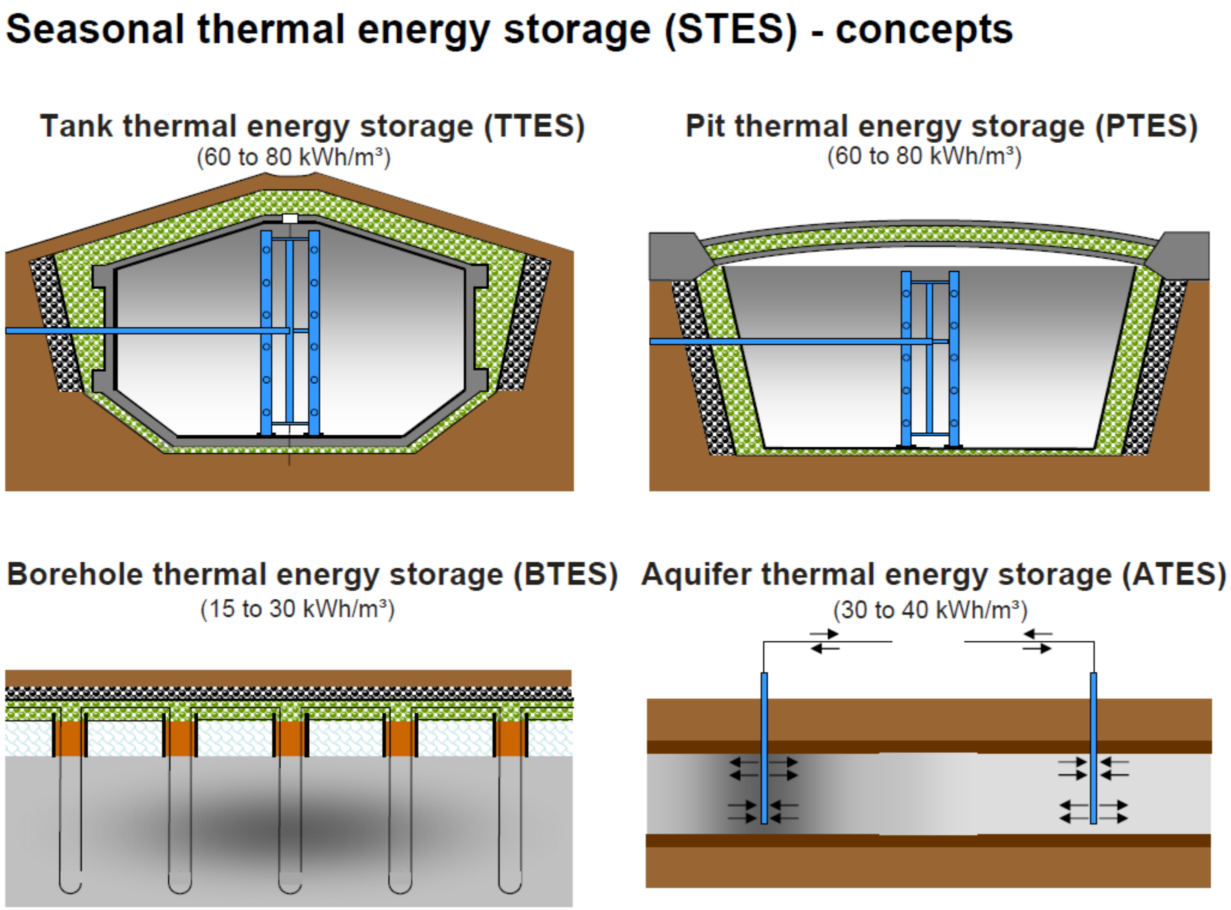
Modular PCM thermal stores

Dwelling based heat storage ≈12.5 kWh capacity
Time shift heat pump/DHN operation
PCM phase transition temperature 54°C
Now being trialled in DESNZ funded Long Duration Energy Storage project ADSorB





Thermal storage approaches (long duration)



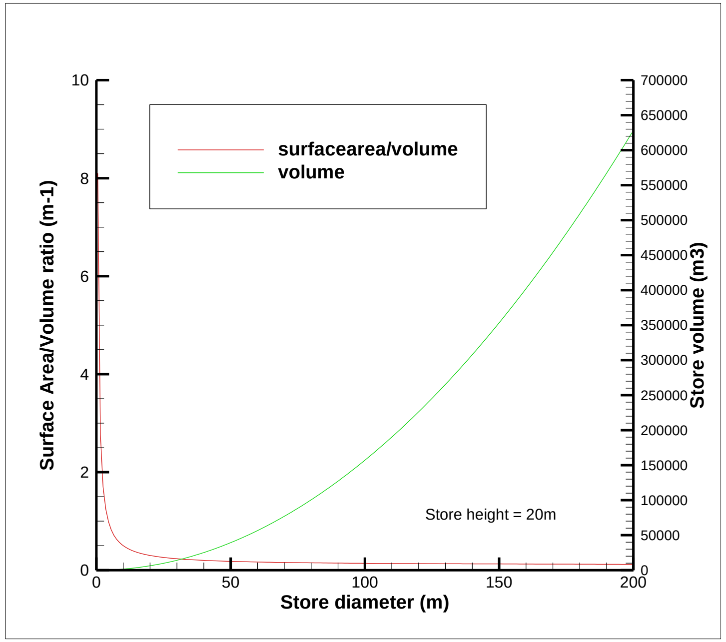
Mangold, D. Seasonal Heat Storage – Pilot Projects and Experiences in Germany. *Solites.* [Online] http://www.solites.de.

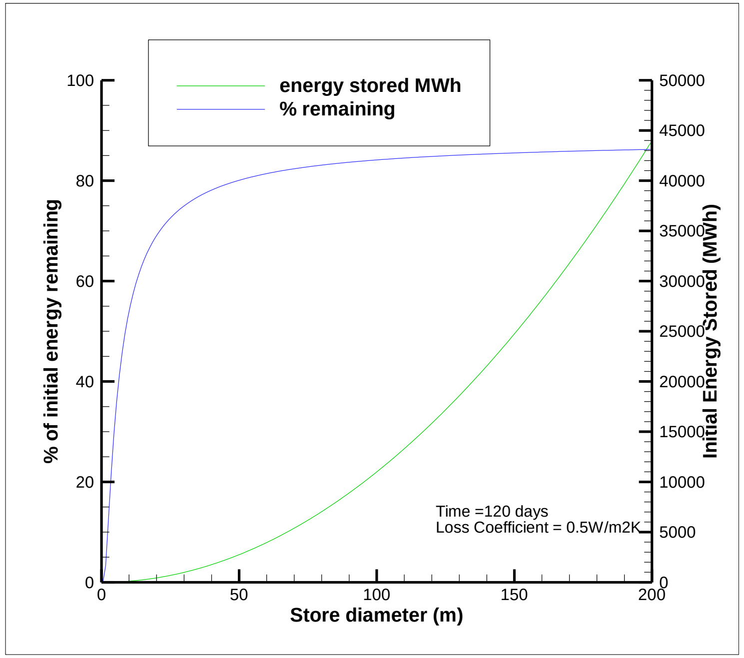
The importance of surface area/volume ratios and store size for long duration energy storage

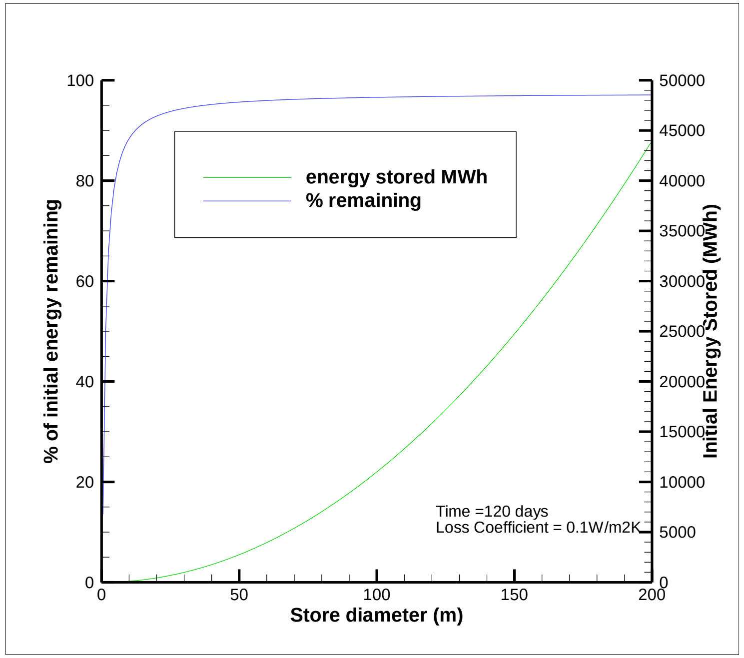
Heat stored is proportional to volume
Heat loss is proportional to surface area

For a sphere SA/Vol= 3/r,
For a cylinder SA/Vol = 2/r+2/h

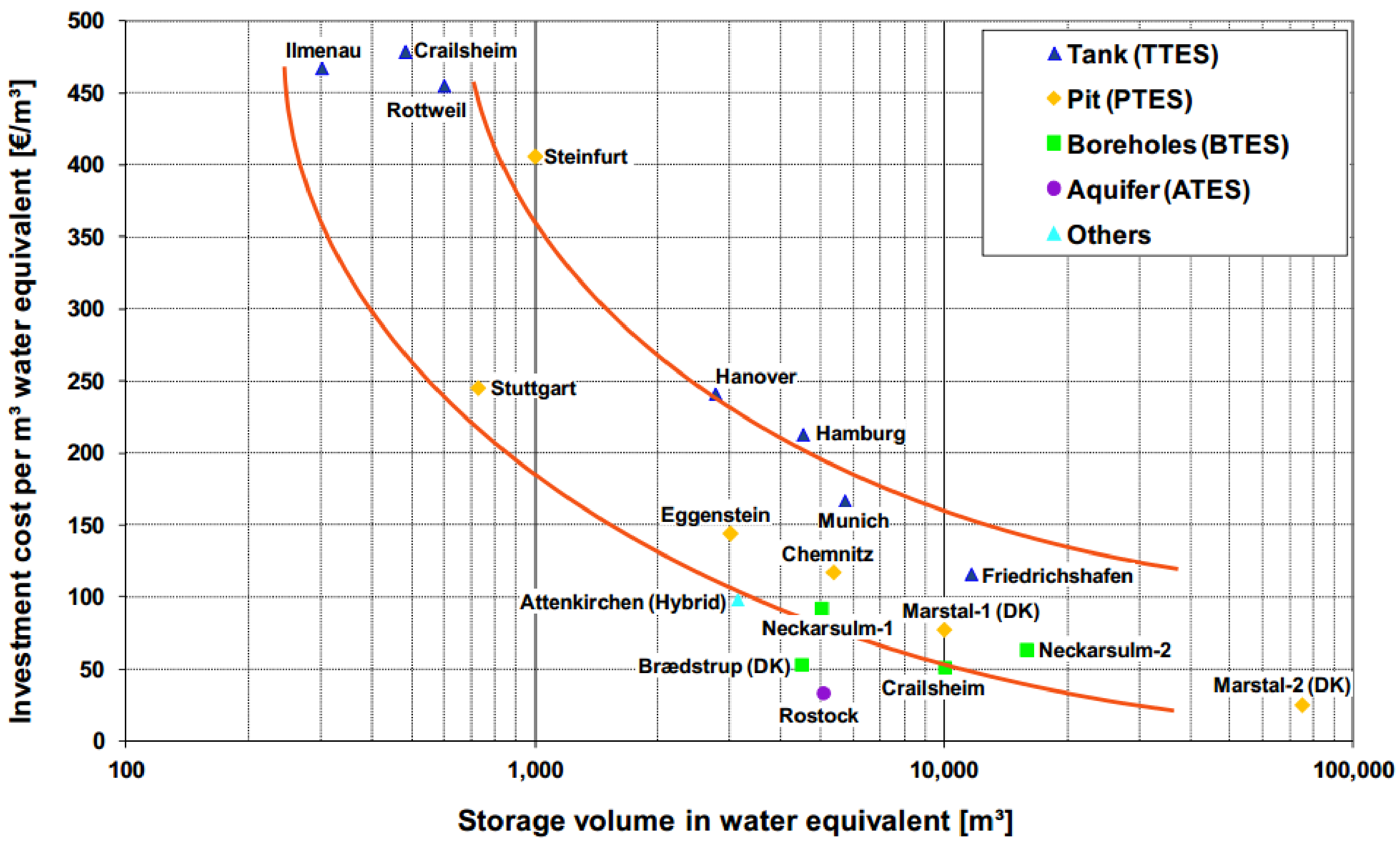
For thermal stratification store height is important







DH system modelling



Specific storage costs of demonstration plants (cost figures without VAT) Schmidt T, Miedaner O, *Solar District Heating Guidelines, Storage*. Solar District Heating, 2012.

Pit storage 60-80kWh/m^3

Investment cost Marstel-2 30€ /m^3

Investment cost/kWh ≈ 0.5€

Thermal storage for an average town

Stores of volumes up to 2,000,000 m^3 have been proposed in Austria. With an effective 60°C operating temperature and perfect thermal stratification storage capacity is 140 GWh. (2,000,000 m^3 = 20x316x316m or 30x258x258m) (316x316 = area of 14 football pitches)

Annual heat loads (Space and domestic hot water) for average existing UK dwelling is approximately 12 MWh, (new build should be half this), 140GWh store is thus equivalent to total annual heat load for 11,666 current dwellings.

Population of Loughborough (2021) 64,884, average UK household size 2.4 people implies approximately 27,000 dwellings.

Total annual domestic heat demand for Loughborough 324 GWh could be stored in 2.3 stores of this capacity.

Thermal storage for an average town

Assuming 8MWh space heat load per dwelling is spread over the 6 month winter heating season, with the peak load week being 3 times the average load in this period, the peak week heat load will be approximately 0.9MWh

The combined peak winter weekly heat load for the 27,000 dwellings is 24,300MWh

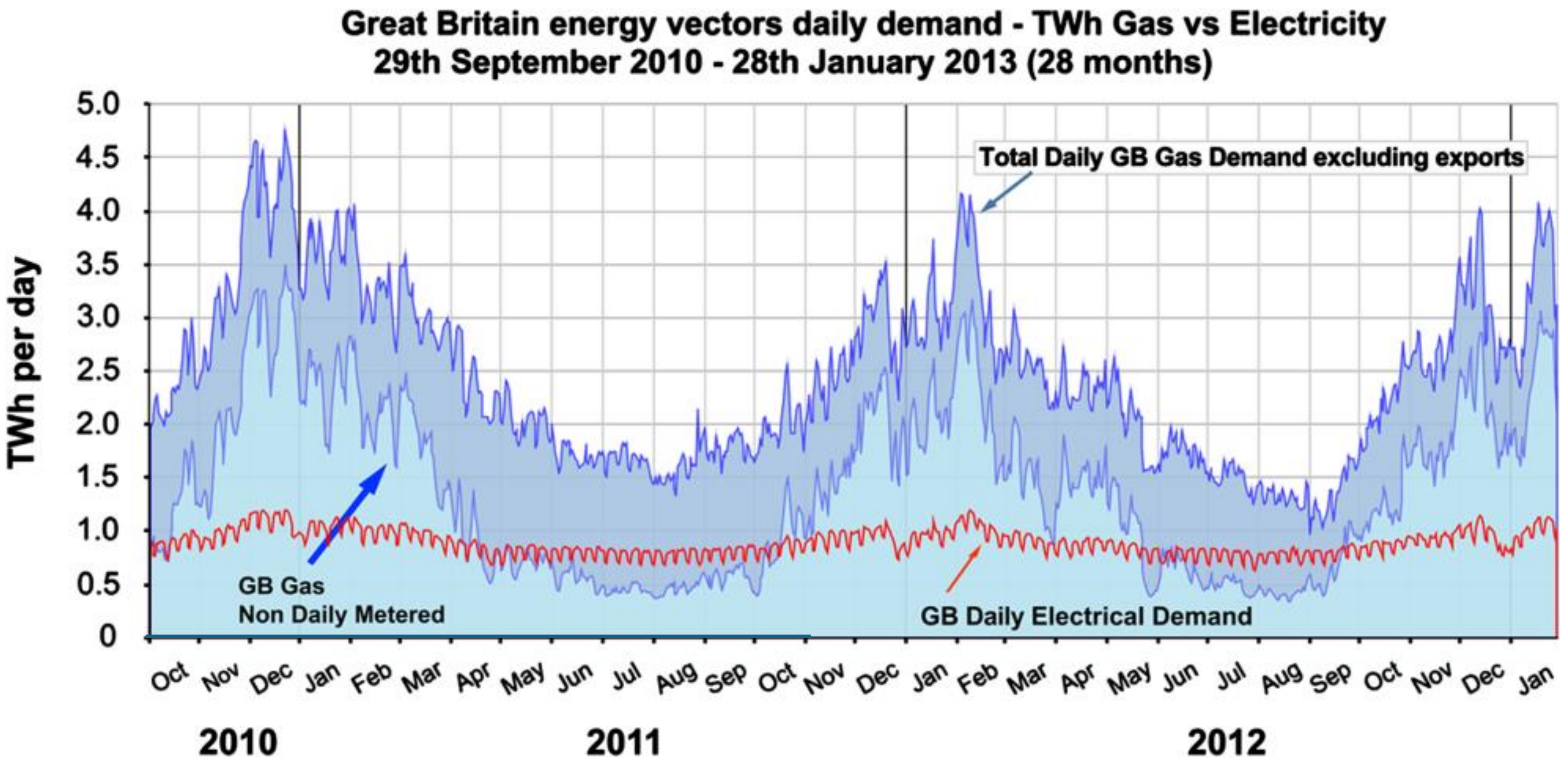
The store size to meet this load assuming no heat generated in this period (blocking anticyclone over UK for 7 days reduces wind generation, solar generation minimal) would require a store of 347,142m^3 (20x132x132m or 20m deep with an area of 2.44 football pitches (7120m^2) (approx. 0.9 football pitches per 10,000 dwellings)

Approximately 28,000,000 dwellings in the UK so approximately an area of 2,520 football pitches required to store the peak domestic heating seasons weeks heat load.

Area of 2520 football pitches 17,942,400$m^{2.}$ (20 m deep stores)

Heat storage capacity of 25.12 TWh

Checking back to Heat Demands



Non daily metered gas peak is around 3.5 TWh.
If sustained for 7 days 24.5 TWh of demand.

Calculated value with assumptions 25.12 TWh

Wilson, I. G., Rennie, A. J., Ding, Y., Eames, P. C., Hall, P. J., & Kelly, N. J. (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.

Flexibility afforded by small distributed stores

Modular PCM thermal store presented previously provides 12.5 kWh of heat storage.

Assuming 90% of dwellings either supplied by DH or heat pumps and each includes a store there would be 25,200,000 stores with a combined storage capacity of 315 GWh of heat storage sufficient to meet 9% of the peak winter demand (3.5TWh) or approximately 70% of a summer days demand (450GWh).

What are the indicative minimum amounts of renewable generation required?

Area	Loughborough		UK	
Renewable Source	Wind	Solar	Wind	Solar
Capacity Factor	0.3	0.15	0.3	0.15
Heat Pump COP	3	3	3	3
Annual heat demand (AHD) GWh	324	324	336,000	336,000
Annual Renewable Generation GWh/MW installed capacity	2.628	1.314	2.628	1.314
AHD/COP GWh	108	108	112,000	112,000
Indicative installed capacity required MW	41.09	82.18	42,618	85,236

Hydrogen pathway using gas boilers

Electrolyser efficiency 50-80%, lower if not operating at ideal conditions.

Assume hydrogen boiler is 90% efficient.

Hydrogen Effective COP= 0.45 to 0.72.

Indicative installed generating capacity required for a green hydrogen pathway using gas boilers can be found by multiplying values by Heat Pump COP/Hydrogen effective COP, 6.66 to 4.16.

If the heat pump COP is reduced to 2.5 then the multiplication values are 5.55 and 3.47.

Conclusions

Energy demand associated with space and water heating for domestic and none domestic buildings is a major component of the UKs greenhouse gas emissions.

Due to the variability of renewable electricity generation, energy storage is essential, heat storage when the demand is for heat is more efficient than alternatives, particularly so if heat pumps with good COP are used.

Large thermal energy stores can store heat effectively for long periods of time, summer to winter.

Small distributed stores can provide significant in day flexibility in meeting loads.

The volumes of storage required appear high however TWh storage capacities that will be needed if we are to transition to net zero are achievable.

High temperature heat storage although not covered here can play a role in large scale electricity storage.

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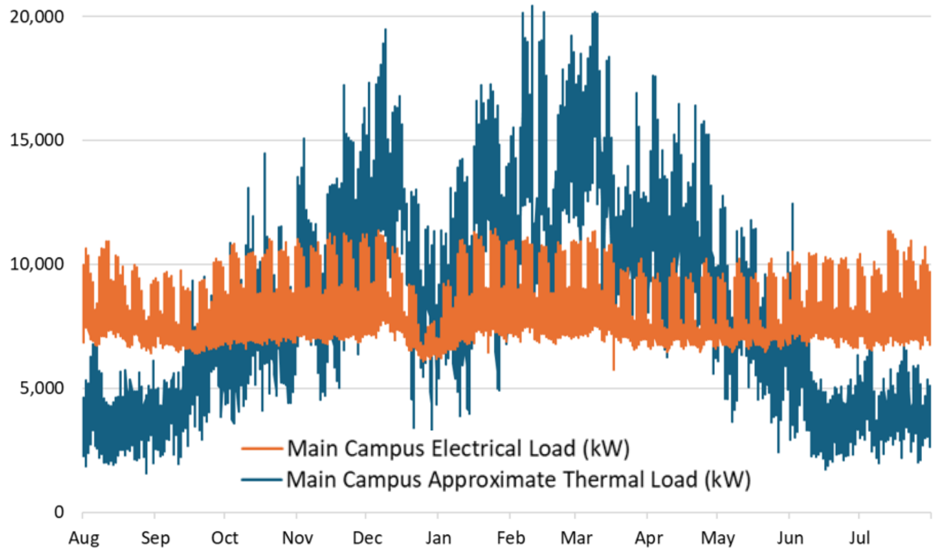
Low Temperature Heat Recovery & Distribution Network Technologies

Heat Network Delivery: The Warwick Case Study

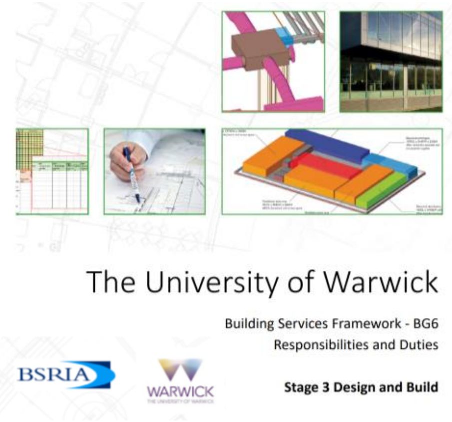
Dr Ángeles Rivero Pacho, University of Warwick
Professor David Elmes, Warwick Business School

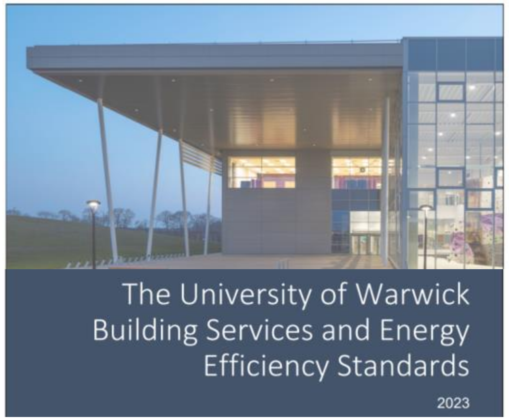
University of Warwick: Reduce, Decarbonise, Smart

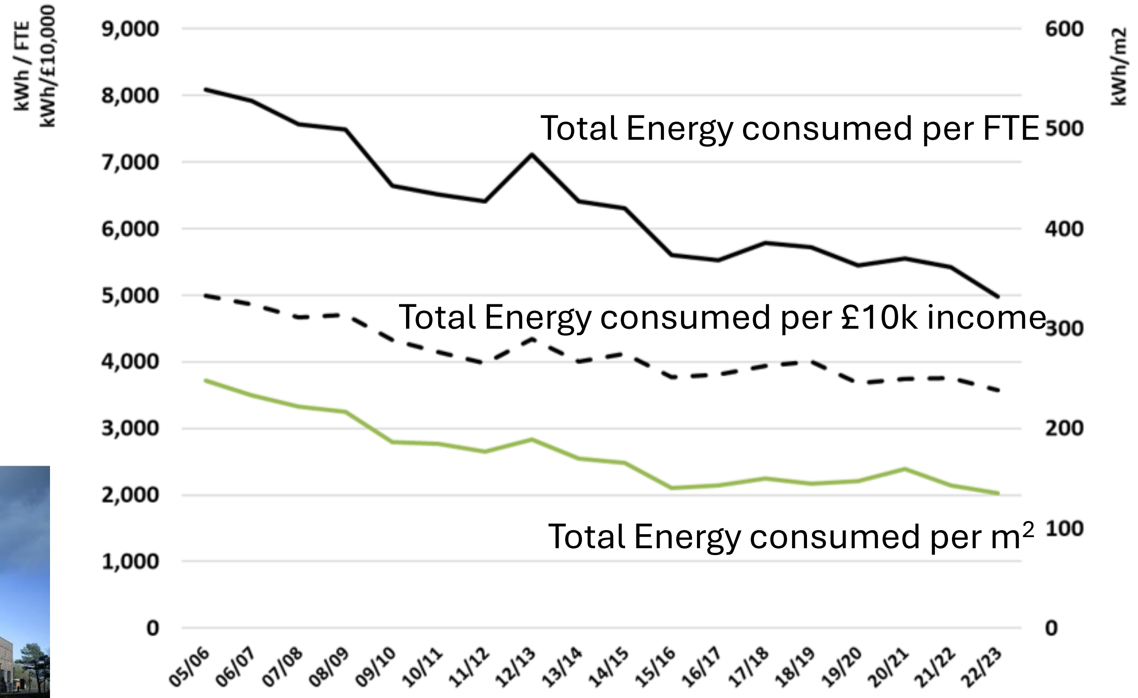
- Warwick's campus – a 'town' of 30,000
  - We operate both the electricity network and a heating/cooling network
  - One of the first Universities to publish a Carbon Management Implementation Plan in 2011
  - Reduced Scope 1&2 emissions by 40-60% per unit space, income & FTE between 2006-2021 but only by 18% overall due to 40% growth
- Declared a Climate Emergency in 2019
  - Net zero for Scope 1&2 by 2030, also Scope 3 by 2050
  - Rethink needed: bold not incremental
- Reduce – 20% further reductions through standards & continuous improvement
- Decarbonise – 40% through sustainable heat centres & local PV
- Smart – aiming for the remaining 40% through being a smart, local energy system



Warwick: Setting standards to embed reductions







- Reducing the energy use has been matched by committing to purchase renewable electricity.
- Total market-based CO2 emissions reduced by 31% between 05/06 and 22/23.

Warwick: Decarbonising both electricity & heat

Shut down the gas burning Combined Heat & Power plants over time….

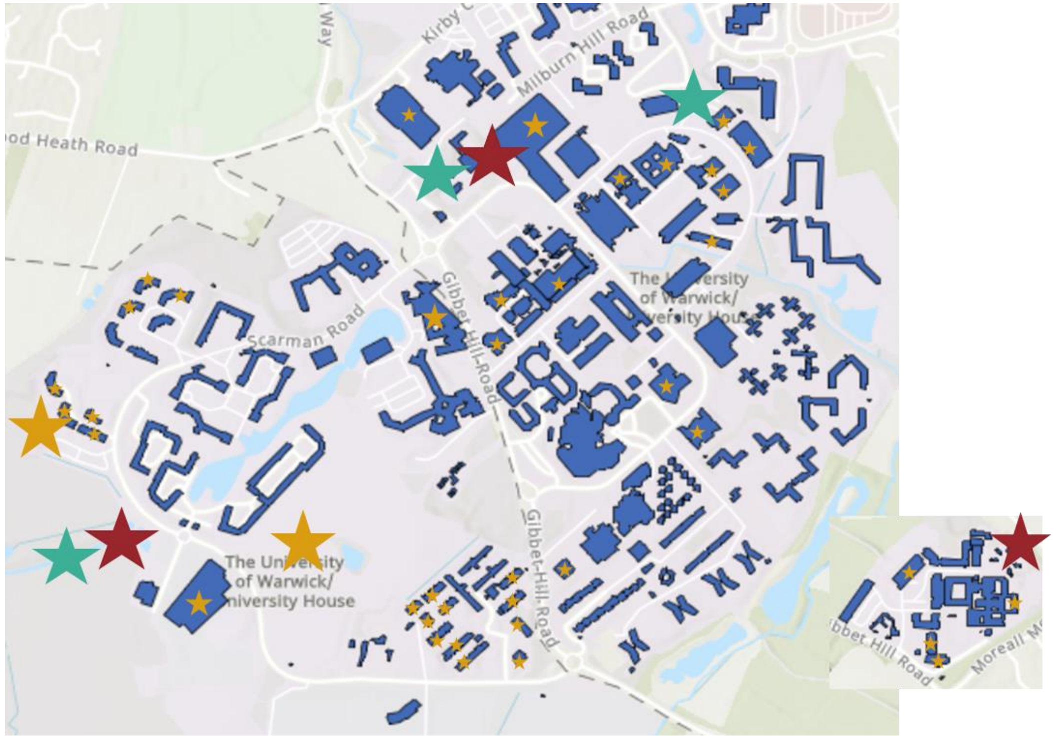
- Central energy centre already on standby, saving 2500t CO_2/yr

Sustainable Heat Centres

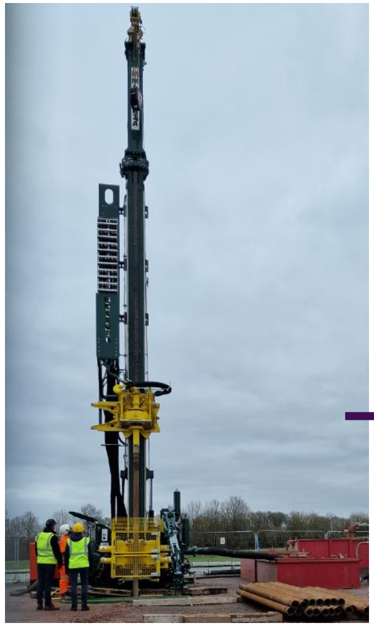
- We've evaluated deep geothermal heat, medium depth ground source heat pumps (~300m), shallow ground source heap pumps (8m) and air source heat pumps as top ups for old buildings.
- Test drilling for medium depth GSHPs started Dec 23
- Draft Heat Purchase Agreement by mid 2024

Solar (PV) – roof-top & ground

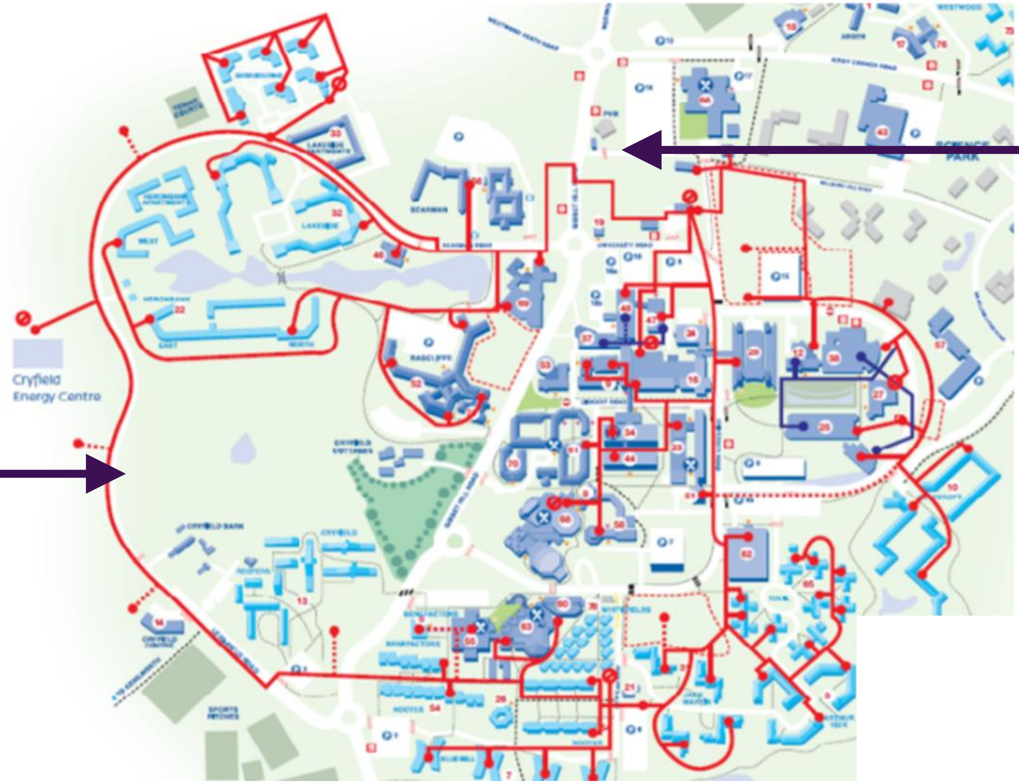
- Pre-2024 roof-top solar: 1MW
- 0.7MW more roof-top completing early 2024
- 1.5MW more roof-top out to tender
- 3+3MW ground arrays in 2024/5 to provide 90% of summer demand and reduce purchased power by 70-80% over the year



Warwick: Large Ground-source Heat Pumps to provide Sustainable Heat Centres



Cryfield Rig



Kirby Corner Rig

Warwick: A Smarter Local Energy System

SMART

- “Smart Square” making energy use more flexible
- Better, smarter buildings…
  - Monitoring & control standards
  - Making base loads flexible
- … as part of a smarter local energy system
  - Fewer peaks, less CAPEX
  - Lower temperature heat network
  - Flexibility to the network

710 acres (2.88 km^2)

Warwick: A Smarter Local Energy System

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Residential Non-residential Car Park

Warwick: A Smarter Local Energy System

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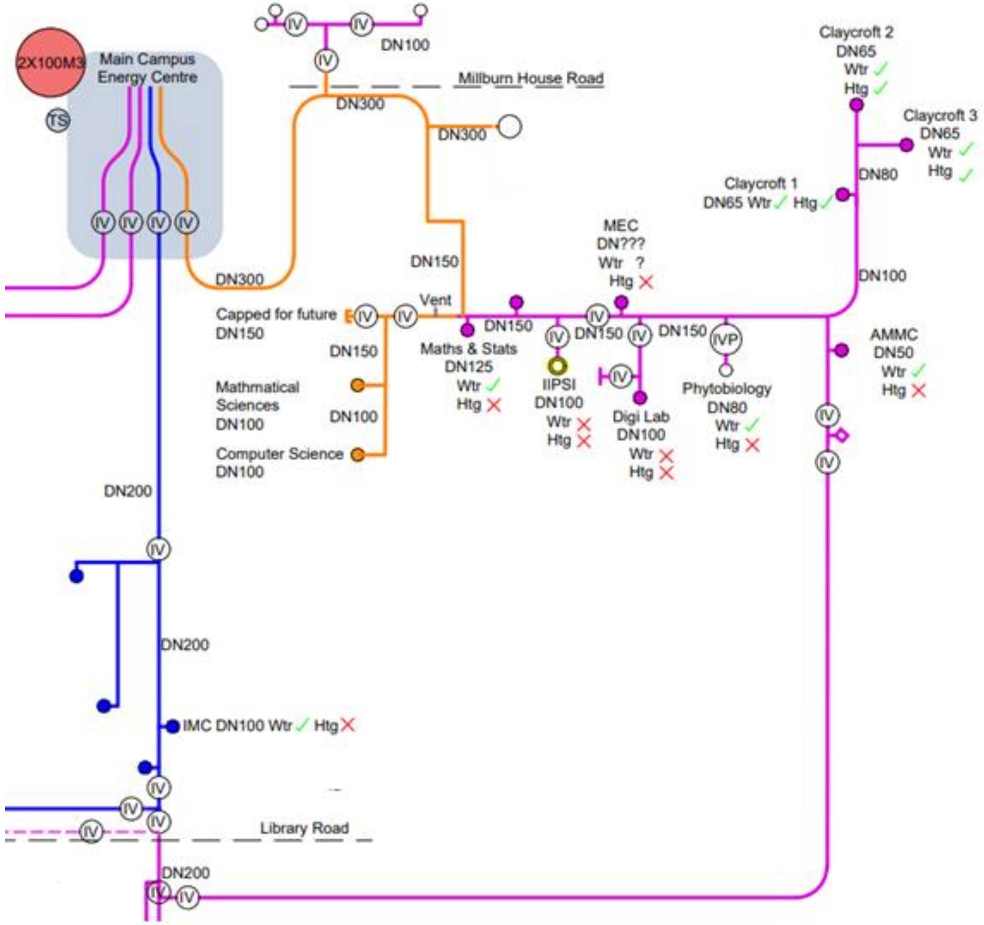
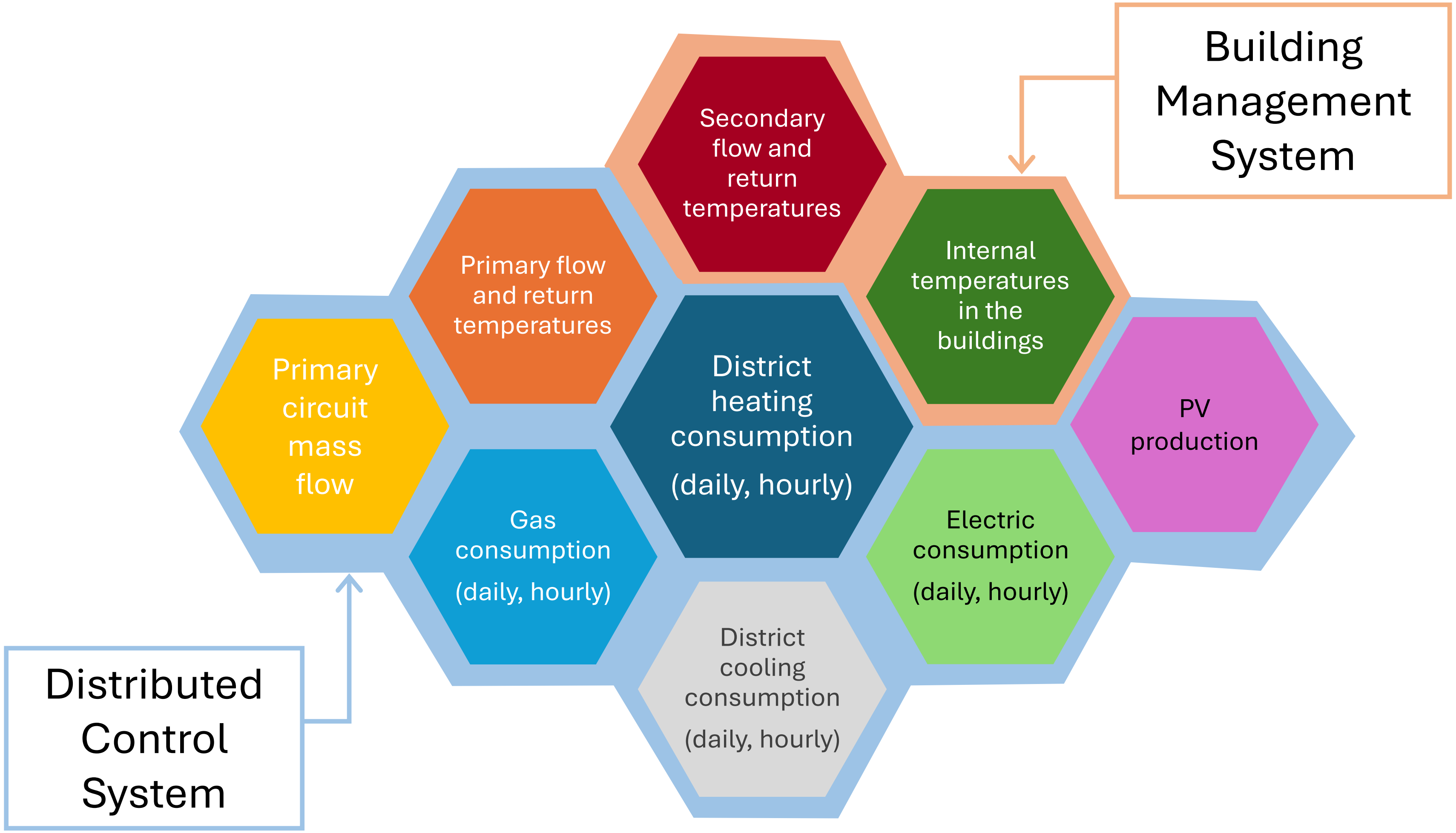
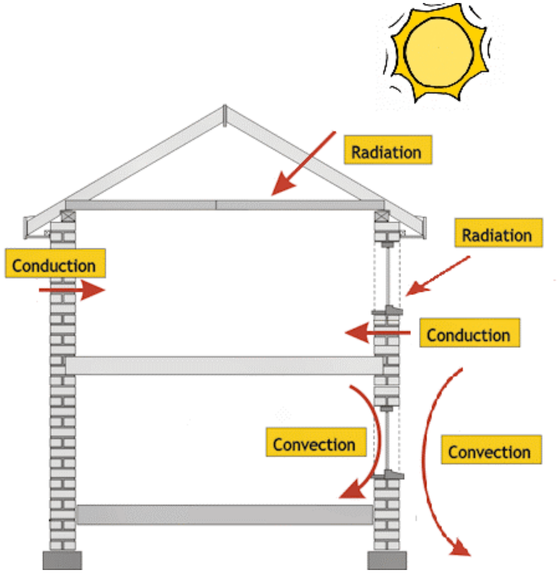


Smart Square: the need for comprehensive data



- Accurate and reliable internal temperatures are needed
- Also accurate and reliable secondary circuit temperature is needed
- BMS data was difficult to access as contractors managed it
- Rebooting needed for some building control systems
- Ultimately the need for DCS and BMS integration

Smart Square: adding thermal mass to building analysis



Thermal transmittance

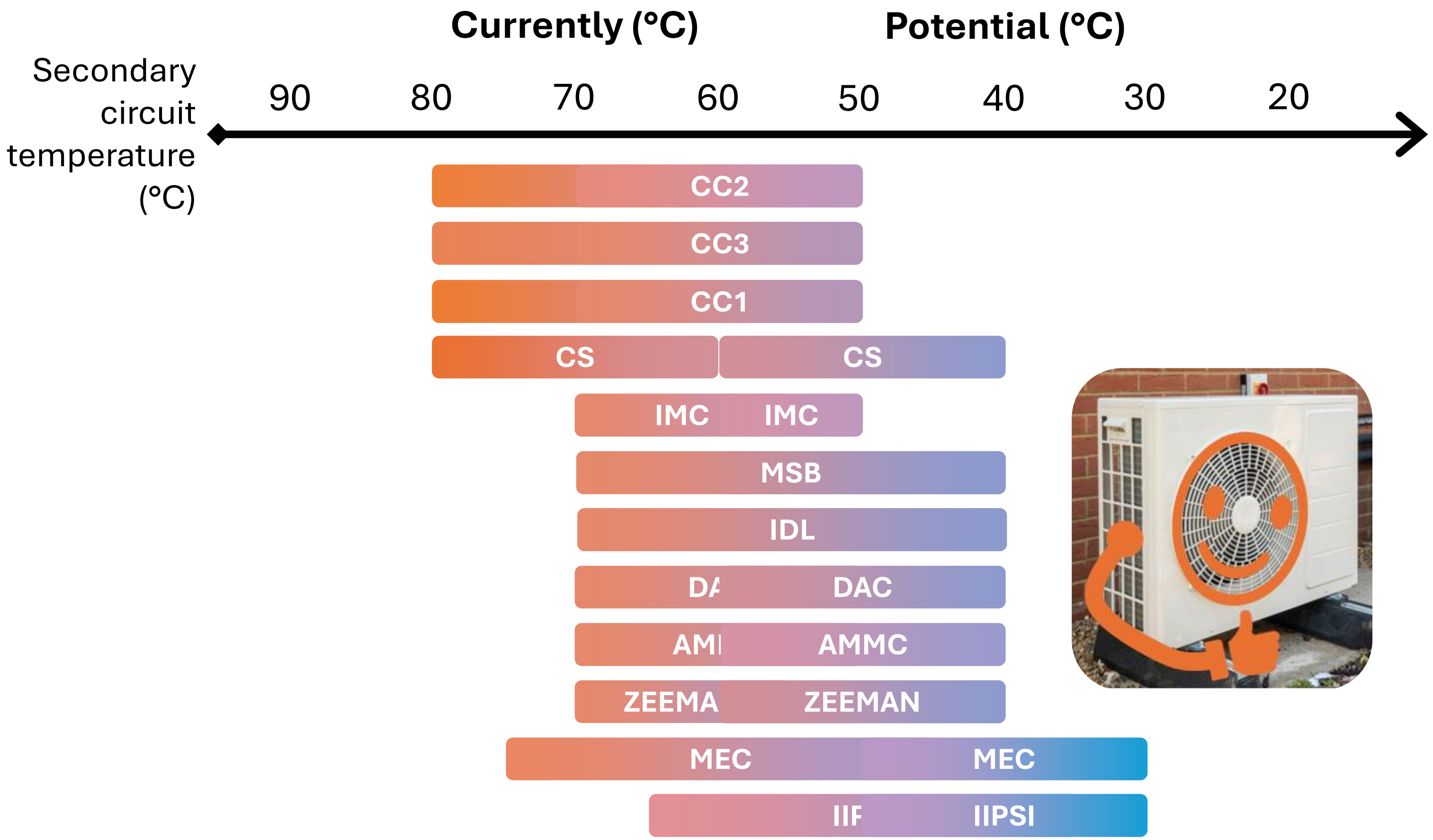
Thermal mass

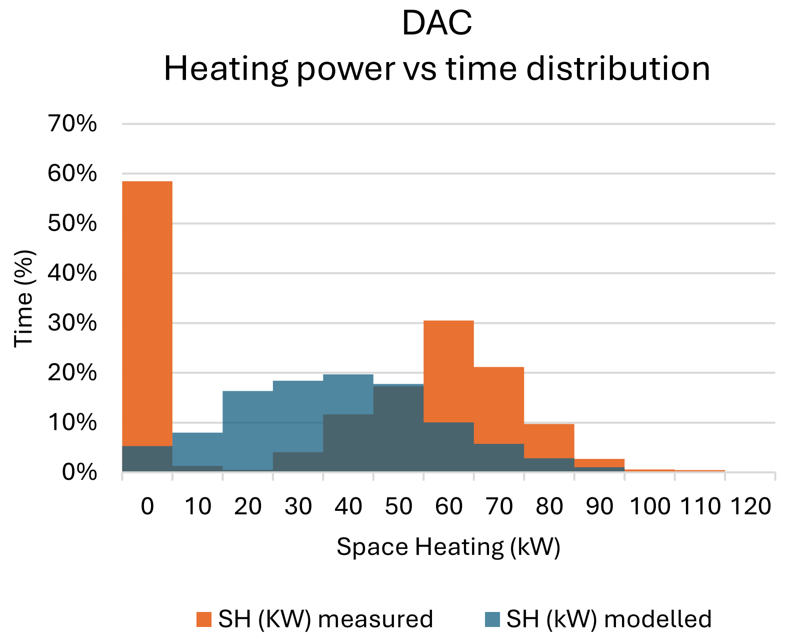
Solar gain

But...

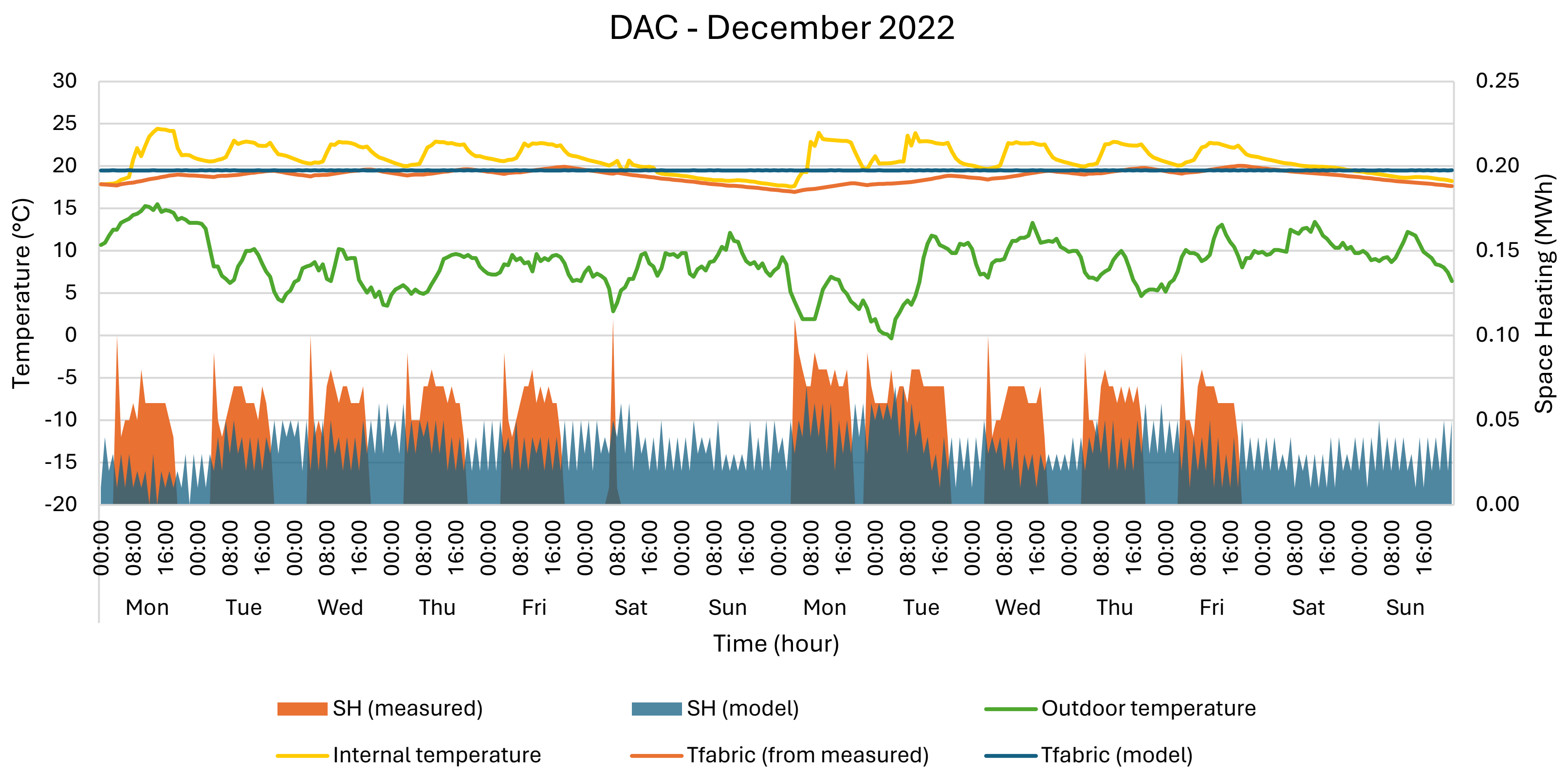
"Human factor"

Smart Square: reducing temperature in the district heating network





Smart Square: using building thermal mass to reduce peaks



Measured maximum Space Heating power: 0.11 MW

Low temperature network maximum Space Heating power: 0.07 MW

↓36%

Measured total Space Heating energy: 10.18 MWh

Low temperature network total Space Heating energy: 11.03 MWh

↑8%

When heat is electrified with Heat Pumps:

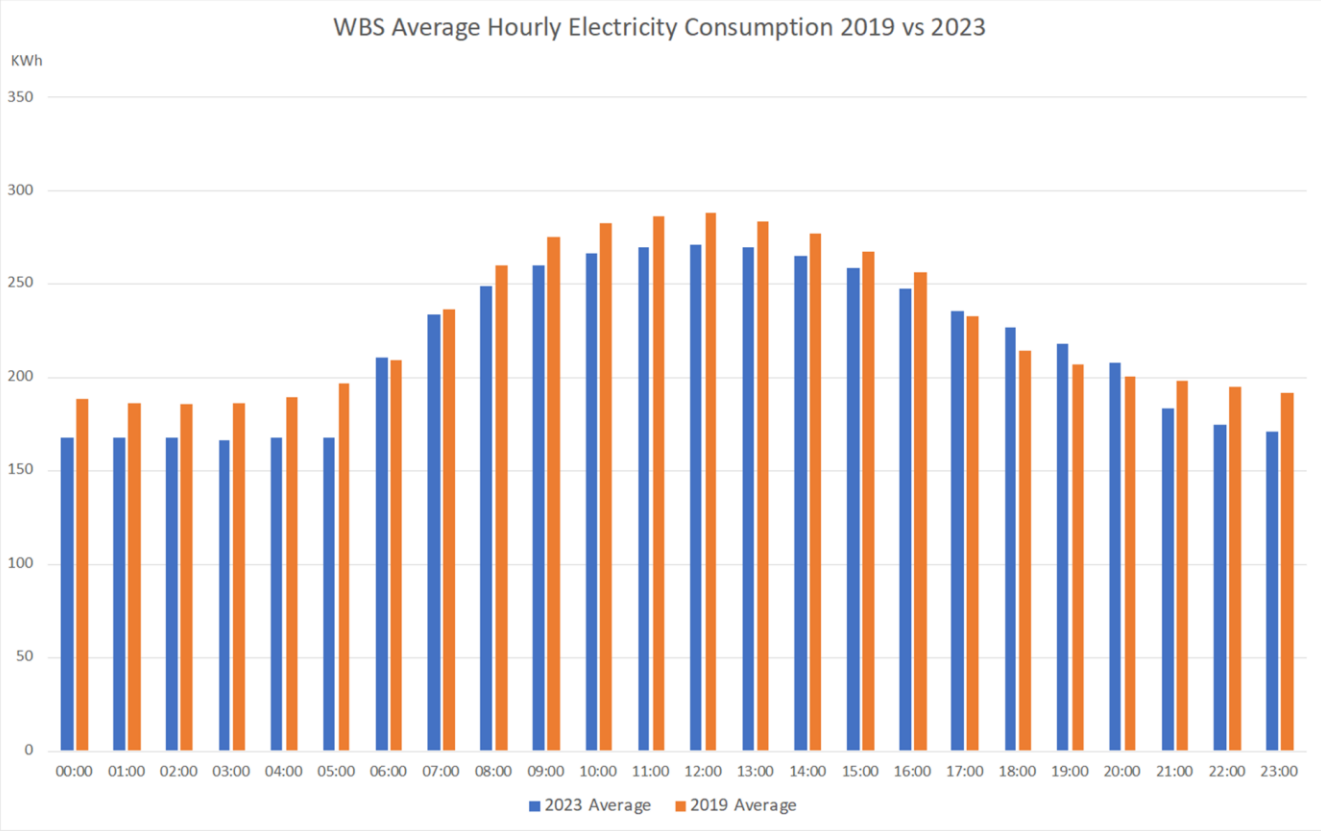
Current Space Heating profile COP: 1.72	**Lower temperature network Space Heating profile COP:** 3.15

Current temperature network Electrical energy consumption: 6.08 MWh

Lower temperature network Electrical energy consumption: 3.82 MWh

↓37%

Warwick Business School: Changing Electrical Demand 2019 - 2023



- Baseload makes up the vast majority of our consumption – it was around 80% in 2019
- By the end of 2023 we had reduced baseload by approximately 15% - it still makes up over 70% of demand because we had also slightly reduced peak demand
- Around the shoulder hours (6-8am & 5-8pm) demand increased compared to 2019 - this was due to the HVAC system and enhanced post-COVID ventilation

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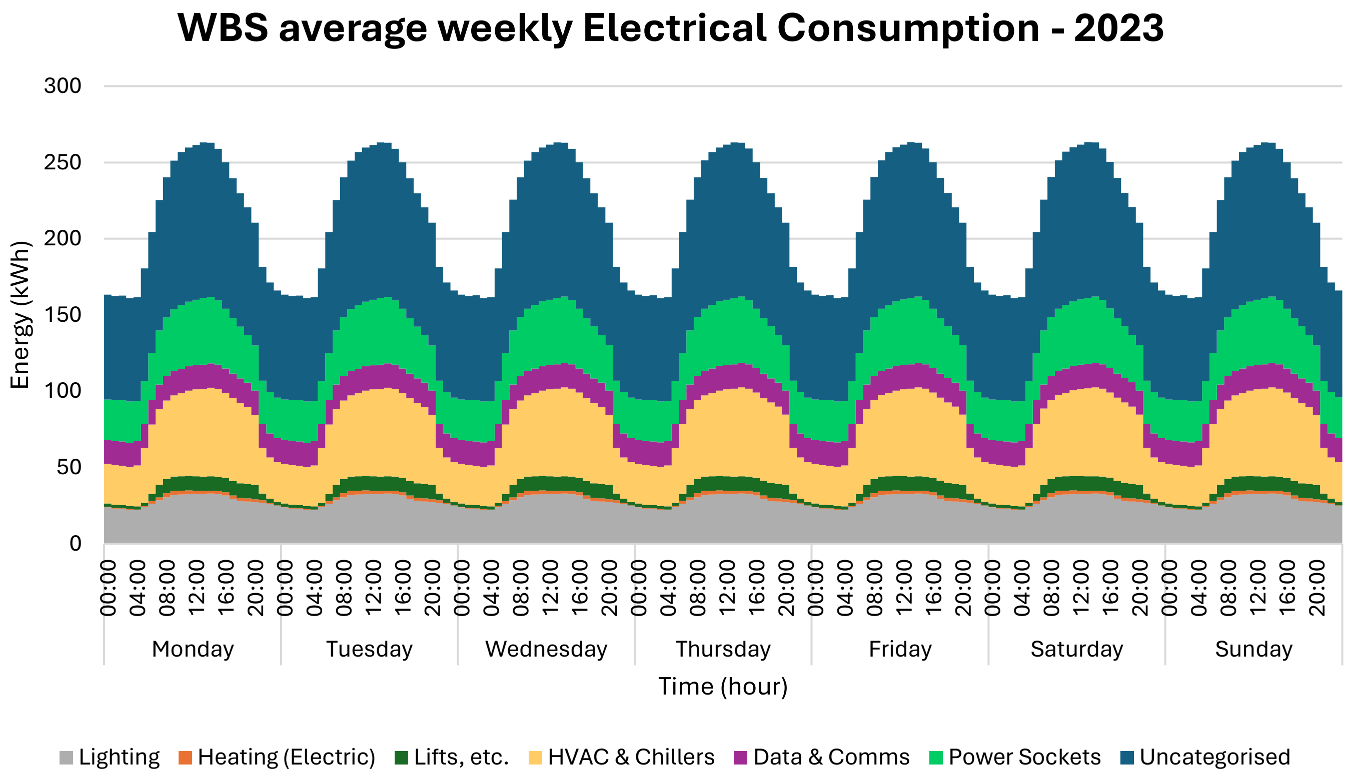
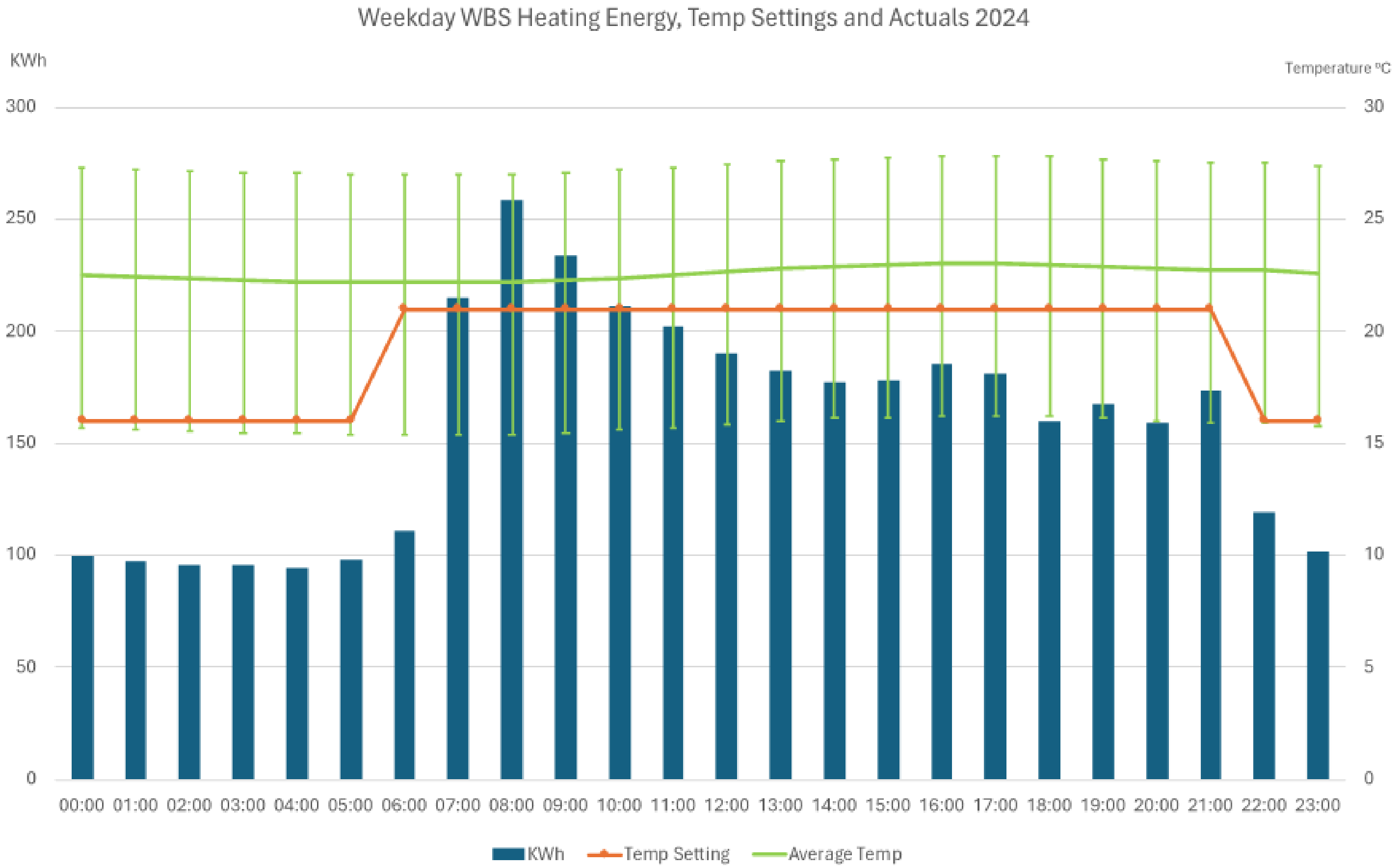
Smart Square: Improving controls to reduce "unknown" demand and make baseload more flexible

Consumption Type	2022	2024
Lighting	9%	14%
Heating (Electric)	4%	1%
Lifts, etc.	2%	3%
HVAC & Chillers	18%	26%
Data & Comms	5%	7%
Power Sockets	0%	14%
Uncategorised	62%	35%

Total Electricity	41.7 MWh	39.0 MWh



Smart Square: Proposing standards for net zero monitoring, control, and operations



- Heat Profile for WBS matches other buildings with a morning peak, trailing off
- System is set to deliver min. of 16°C at night and 21°C in the day
- Our sensors show an avg. temp of 22-23°C over the whole day
- Our sensors show max. temp ranges between 16 and 27 °C for 90% of time
- Older buildings need standards for retrofit monitoring and control

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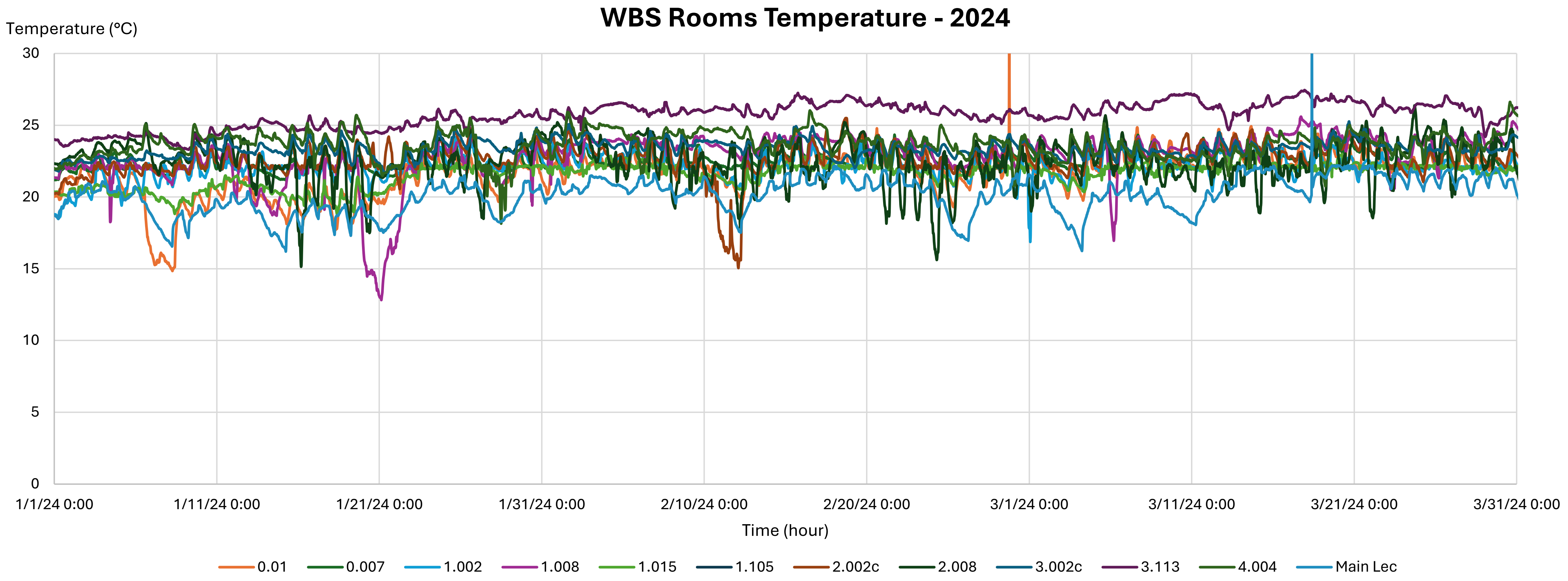
Smart Square: For older buildings, standards for retrofit monitoring and control



REFRIGERATION AIR CONDITIONING HEAT PUMPS

Smart Buildings projects summary

Inputs

Weather

- National Grid composite weather variable (CWV)
- Solar irradiance

Energy

- Building heat, gas and electricity consumption

People

- Building occupancy

Building

- Control settings (set points and schedules)
- Heating system performance data
- New heat sensors spread to reflect range of key variables (façade, floor, room type)

Outputs

- Optimise DH network for low temperature delivery - minimum running cost / CO_2 emissions
- Simulation programme for any network / building
- Recommendations re thermostatic sensors:
  - optimum placement in a building
  - minimum number required
- Lessons learned concerning:
  - variability within building types and uses
  - impact of changing building standards on need for monitoring and control systems

In Summary: Reduce, Decarbonise, Smart

- Reduce
  - Reduced Scope 1&2 emissions by 40-60% per unit space, income & FTE between 2006-2021 BUT only by 18% overall due to 40% growth
  - The need to set bold standards not rely on incremental improvements
  - Now at 31% overall reduction with a further ~10% from rolling out construction & operational standards
- Decarbonise
  - Evaluated multiple alternatives for decarbonising heat and stop burning gas
  - Proceeding with large, ground source heat pumps accessing the aquifer
  - Decarbonising heat to reduce a further 30-40% of Scope 1&2 emissions
  - +200% roof top PV underway and potentially +600% ground based PV to lower electricity costs
- Smart
  - Across the buildings in Smart Square: Fewer peaks, less CAPEX, lower temperature heat network, flexibility for the surrounding electricity network.
  - Within the buildings in Smart Square: Monitoring & control standards and making base loads flexible
  - Rolling "Smart" across campus to reduce Scope 1&2 emissions 30-40%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Close

Professor Bob Critoph