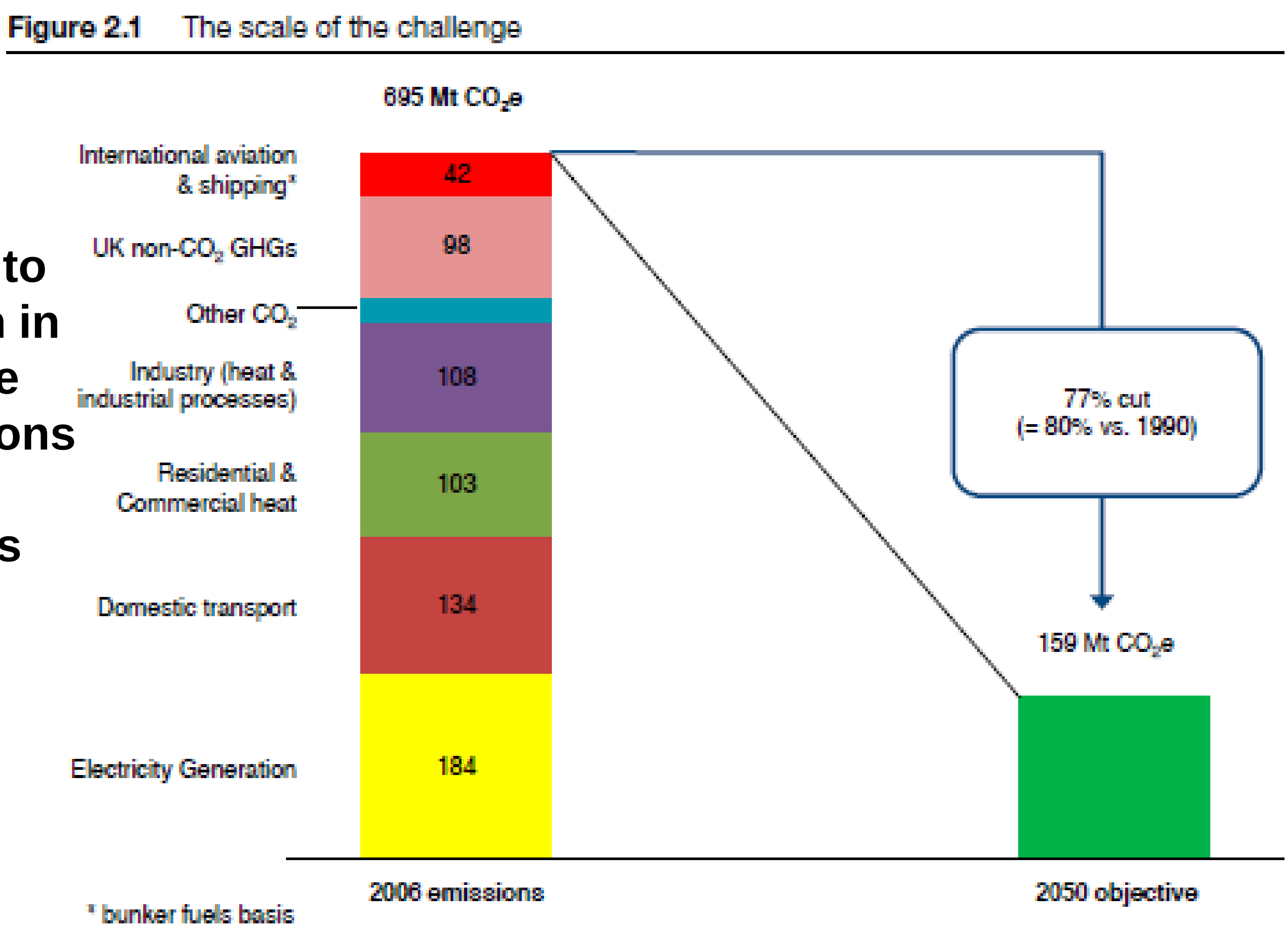
i-STUTE

interdisciplinary centre for
Storage,
Transformation and
Upgrading of
Thermal
Energy

Prof Bob Critoph
University of Warwick

Sustainable Thermal Energy Technologies for the Future
University of Warwick, 13th April 2016

Context



- **The UK is committed to a reduction in greenhouse gas emissions of 80% by 2050 across all sectors**

Building a low-carbon economy – The UK's contribution to tackling climate change. The First Report of the Committee on Climate Change December 2008 London: TSO . ISBN 9780117039292

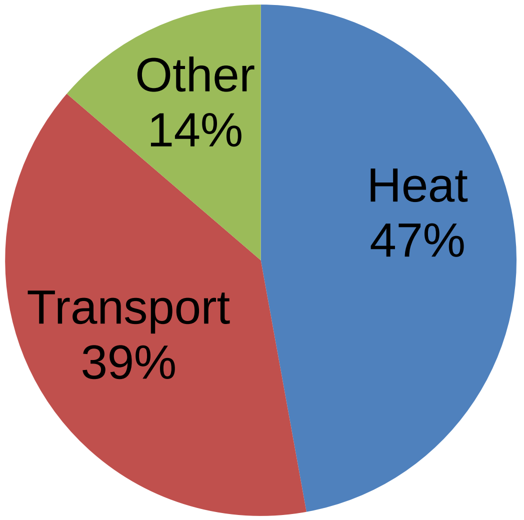
Context

- In 2011, RCUK initiated a call to fund up to six interdisciplinary Centres in '<u>End Use Energy Demand'</u>. Each Centre would be funded for five years initially with a nominal budget of £5M.
- i-STUTE was awarded one of the centres and funding commenced from April 2013 – its distinctive feature is concentration on <u>heating and cooling.</u>

Why heating and cooling?

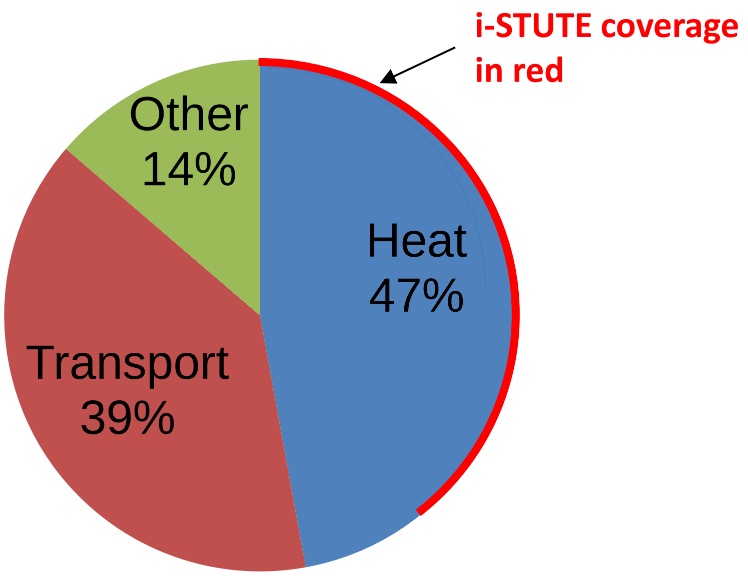
- 47% of fossil fuels in the UK are burnt for low temperature heating purposes (25% of CO_2 emissions)
- 16% of electricity in the UK used to provide cooling - Worldwide it represents 10% of greenhouse gas emissions

Energy Consumption by end use 2012

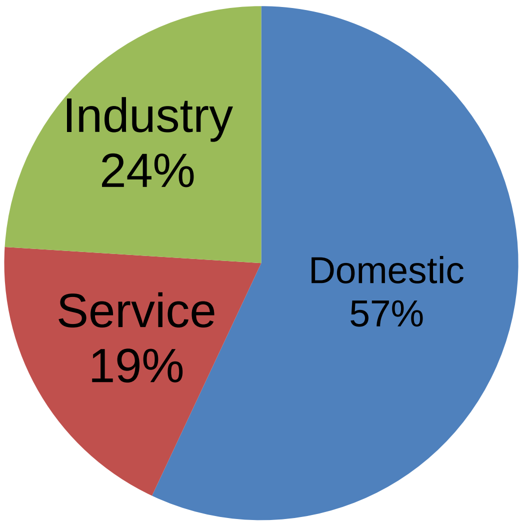


Provisional data for 2012 (DECC)

Energy Consumption by end use 2012



Heat Use by Sector



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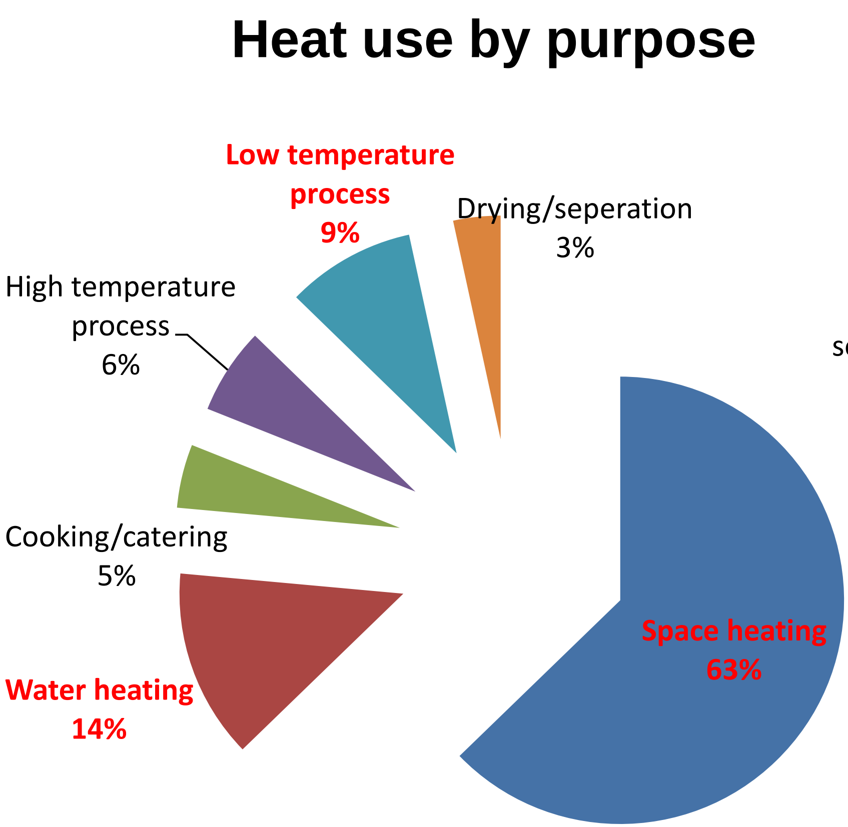

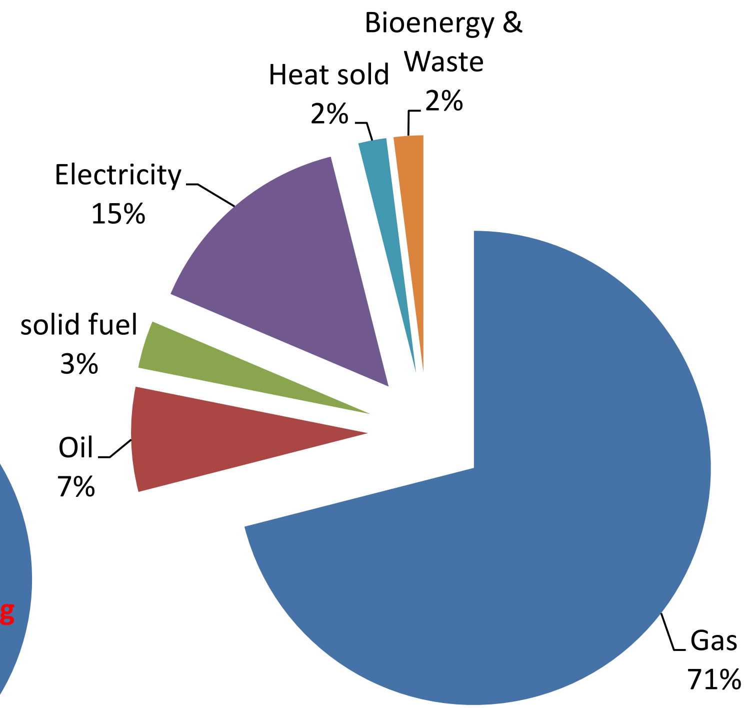

Breakdown by fuel of total heat use

i-STUTE coverage in red

Who are we, what do we do?

Energy
For a Low Carbon Future

Loughborough University

- Thermal energy storage
- Consumer behaviour

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- Thermal heat pumps
- Business models

Ulster University

- Electric heat pumps
- Integration with storage

London South Bank University

- Commercial and industrial refrigeration
- Engagement with SMEs

Work packages in:

- Cooling / refrigeration
- Low temperature heating
- Industrial heat
- Business models
- Consumer behaviour / acceptability

+

- Dissemination

i-STUTE – www.i-STUTE.org

SIRACH - (Sustainable Innovation in Refrigeration, Air Conditioning and Heat Pumps) www.sirach.org.uk

SIRACH Deliverables

- Disseminate i-STUTE results via Network meetings.
- Hosting Network meetings in the UK and overseas.
- Provide regular features in a key monthly journal.

Event name	Date	Subject	Attendees
Emerson Technologies, Ulster	25 February 2014	Heat pump and compressors	29
Spirax Sarco, Cheltenham	21 May 2014	Heat powered cycles	36
ICCC International Conference - London	25 June 2014	Challenges to implementing sustainability	35
Mitsubishi Electric – Edinburgh	2 September 2014	Innovation in Air Con and Heat Pumps	32
Sainsbury's Supermarket– Leicestershire	22 October 2014	Commercial refrigeration, cooling, heating	50
Climate Center – Leamington Spa	5 February 2015	Components for Air Con , Heat Pumps	42
Arctic Circle, Hereford	23 April 2015	Development in Heating and Cooling Technologies	35
IRC Congress, Yokohama, Japan	16 - 22 Aug 2015	Sustainable heating and cooling	48
Newcastle University	01 October 2015	District Heating and Cooling	50
Daikin Training Centre Woking	20 January 2016	Domestic and Commercial Heating and Cooling - next generation technologies .	30
Brunel University	20 April 2016	Energy reduction and sustainability in the food chain.	
Heriot Watt	August 2016	Gustav Lorentzen Confernece	
Ireland Energy Research Centre in Cork	23rd November 2016	Title programme to be confirmed.	

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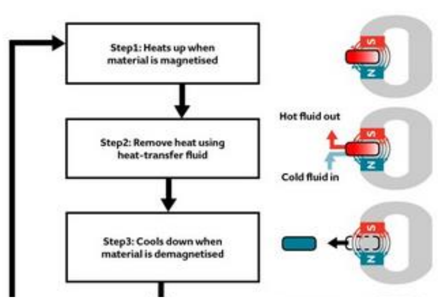
INNOVATION MAGNETIC REFRIGERATION



Magnetic refrigeration has the potential to reduce energy use by 30% and requires no refrigerant. **Metkel Yebiyo** and **Graeme Maidment**, of Sirach, describe the technology, its main applications, and the challenges facing firms trying to get the concept to market

MAGNETIC ATTRACTION

At the 2015 United Nations Climate Change Conference, COP 21, in Paris, world leaders negotiated to limit global warming to below 2°C by 2100. The talks were aimed at avoiding serious climate catastrophes around the world, and participants sought to reduce greenhouse gas emissions by increasing the use of zero carbon technologies.

Magnetic refrigeration is one such emerging, innovative and potential low carbon technology. The interest in it as a new heating or cooling technology – and as an alternative to conventional vapour compression – has grown considerably over the past 15 years.

The principle of magnetic refrigeration is based on a phenomenon known as the magnetocaloric effect (MCE). Discovered by Emil Warburg in 1881, this was related to the property of exotic materials – such as gadolinium and dysprosium – that heat depends on the variation of temperature (ΔT), the mass of material (m) and its specific heat capacity (Cp). This effect is maximal at a specific temperature – called the Curie temperature – of the material.

The main limitation of the magnetocaloric system shown in Figure 1 is the relatively small temperature difference that can be achieved between the cold and hot source.

Temperature exchange

A number of techniques have been used to increase this exchange, including active magnetic regenerative refrigeration (AMRR). The principle of this cycle uses a heat-transfer fluid – in contact with the magnetocaloric materials (MMC) – flowing from the cold side to the hot side when the MMC is heated (magnetised), and from the hot side to the cold side when the MMC is cooled down (demagnetised). This progressively increases the temperature difference between the cold and hot so[...] to about 20K, making the system poten[...] suitable for commercial applications.

There are various potential applicati[...] Initial developments have been orienta[...] towards the commercial and domestic refrigeration markets, and include disp[...] cases, beverage coolers, and commerci[...] domestic fridges.

However, magnetic cooling can also [be] adapted to other refrigeration applicati[...] such as air conditioning (including automotive), cryogenics or in heating systems – for example, heat pumps.

The demand is likely to be driven by environmental regulations, because magnetic heating or cooling does not use a refrigerant but, instead, a heating or cooling fluid, which could be water-based. As a result, there is no possibilit[y] of refrigerant leakage and no direct CO[...] emissions, so it fully complies with all regulations, including F-Gas in Europe

REFRIGERATION AND AIR CONDITIONING MAGAZINE

rac

“ – The Cooling Awards have played a major role in improving the industry [click here for editor's view](#) ”

Andrew Gaved, Editor

SEAR[...]

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AIR CONDITIONING | REFRIGERATION | LEGISLATION | F-GAS | REFRIGERANTS | DATA CENTRE COOLING | LOW CARBON | ANDREW'S BLOG

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SIRACH cooling technology network to visit Mitsubishi Electric in Livingston

31 July 2014 | By Andrew Gaved

Event on September 2nd for IOR group to focus on both air conditioning and heat pump technologies

Tweet 0

Air conditioning and heat pump innovation will be on the agenda on September 2nd whien SIRACH, the Sustainable Innovation in Refrigeration Air Conditioning and Heat recovery network holds its

sirach

COOL[...]

High Eff[...] Glyc[...]

Secondary Ref[...] protection of P[...] Refrigeration a[...]

THE NETWORK FOR SUSTAINABLE INNOVATION IN REFRIGERATION AIR CONDITIONING AND HEAT RECOVERY

SIRACH MEETING - ENERGY SOLUTIONS FOR GREEN BUILDINGS

The SIRACH networking meeting was held on 5th February 2015 at the Climate Center at their Sustainable Building [...] Leamington Spa. Metkel Yebi[...]

The main focus of the SIRACH event was to explore the latest developments and innovations that are creating energy solutions for Greener Buildings. The event included a series of presentations, an interactive group networking session and a tour of the UK's first commercial showcase for

HEATING AND COOLING MAGNIFIED

The Sirach network encourages research and debate to promote sustainable innovation in refrigeration, air conditioning and heat pumps. Members **Metkel Yebiyo** and **Graeme Maidment** introduce the group

London South Bank University

Ulst[er] Uni[versity]

Loughborough University

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Current Projects

Energy — For a Low Carbon Future

Next generati… …formers

pc…

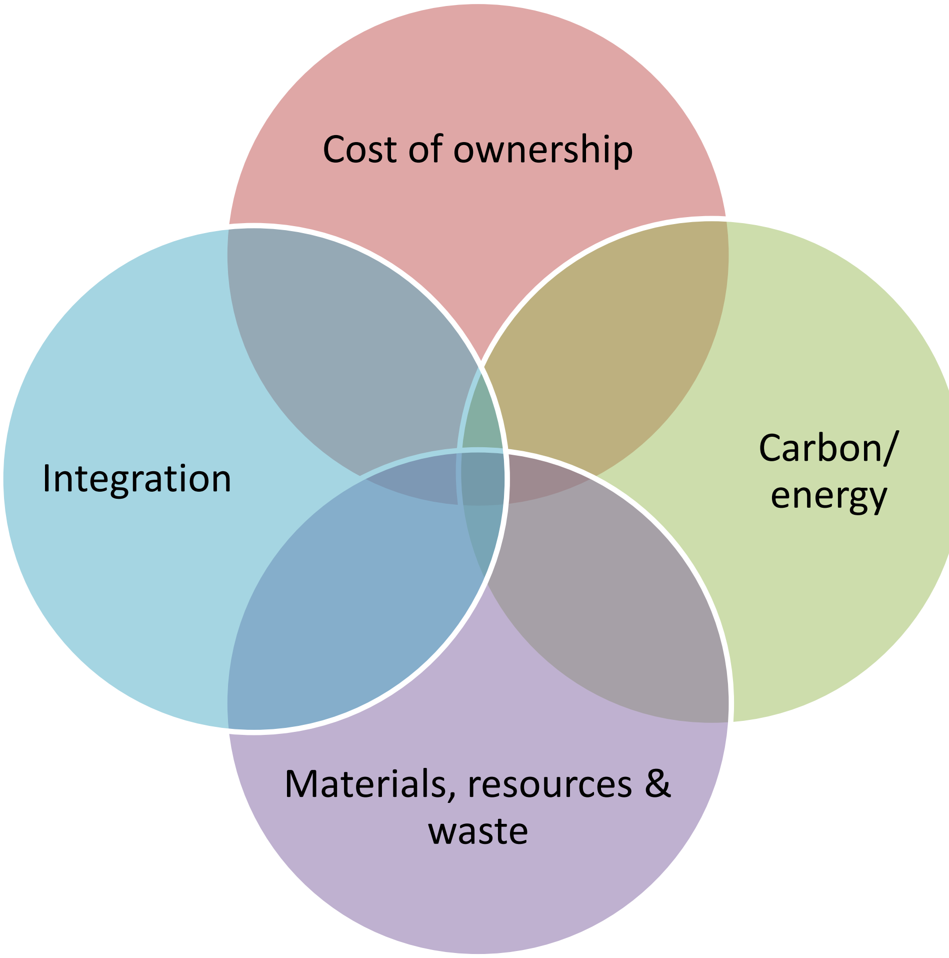
- Not a full list
- Not everything that is important
- A combination of what is within our expertise and what promises major CO_2 emission reductions

Behavi… …entres

adoption and comm…

i-STUTE cooling based projects

- Supermarket refrigeration
- Data centres
- Transport refrigeration
- Integrated heating and cooling



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Retail refrigeration

- Roadmap
- Joint publications
- Prototype cabinet

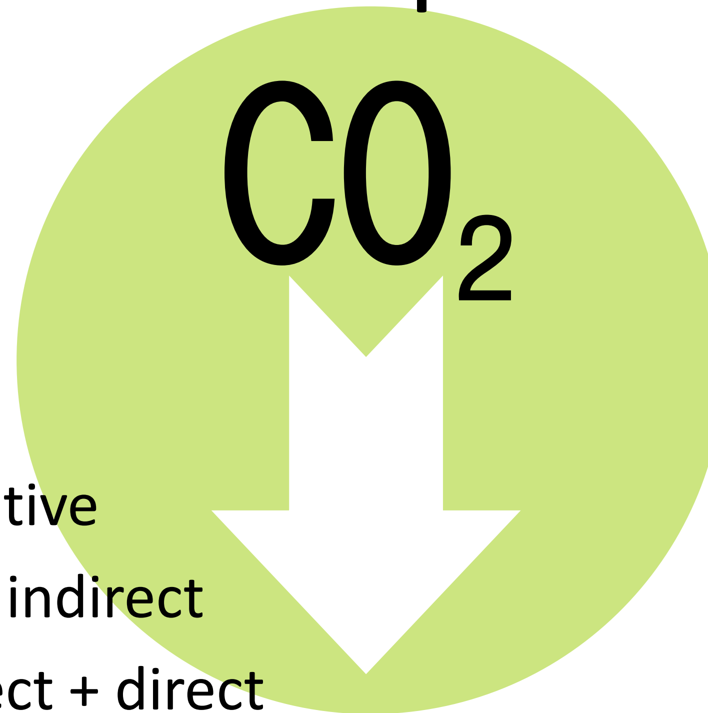
Retail refrigeration

Road map updated after industry consultation

Input from:

1. **IOR**
2. **CIBSE**
3. **ASDA**
4. **CEBES**

Conclusions from Road map



Large potential savings

Many have:

Short application time

Short payback time

Savings not necessarily cumulative

Cabinets (retrofit or new) – mainly indirect

Retrofit refrigeration systems – indirect + direct

New refrigeration systems – mainly direct

Great potential to reduce emissions being explored with ASDA

Prototype cabinet

George Barker open fronted multi-deck

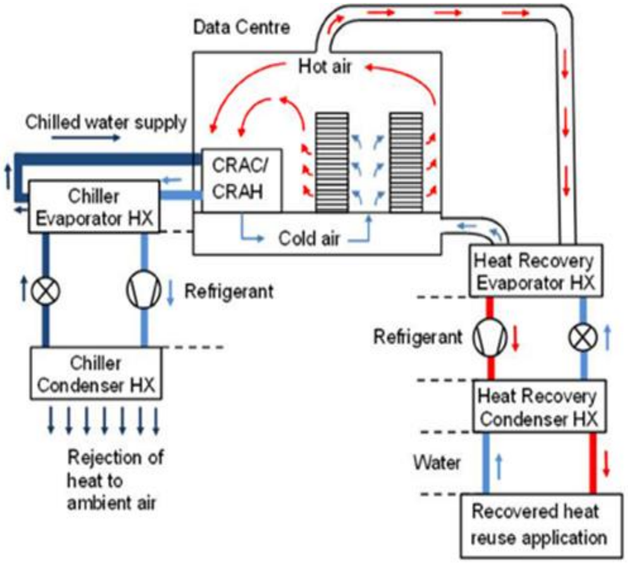
Typically used in ASDA stores

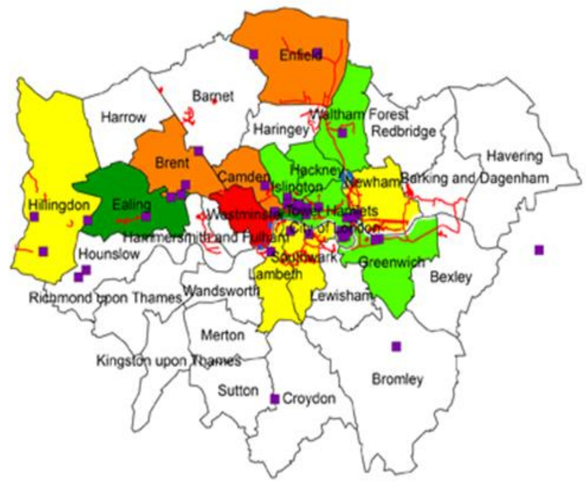
Adapt using selected technologies

Select from road map (link technologies), not always additive effect

Test and validate

Recovery and reuse of waste heat from data centres

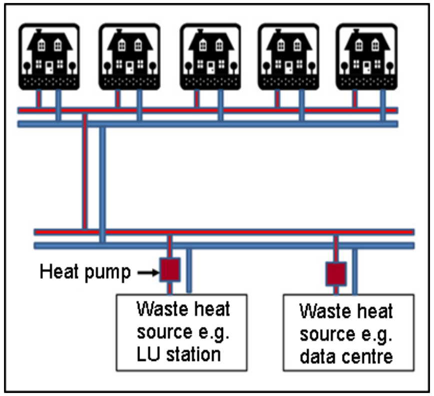




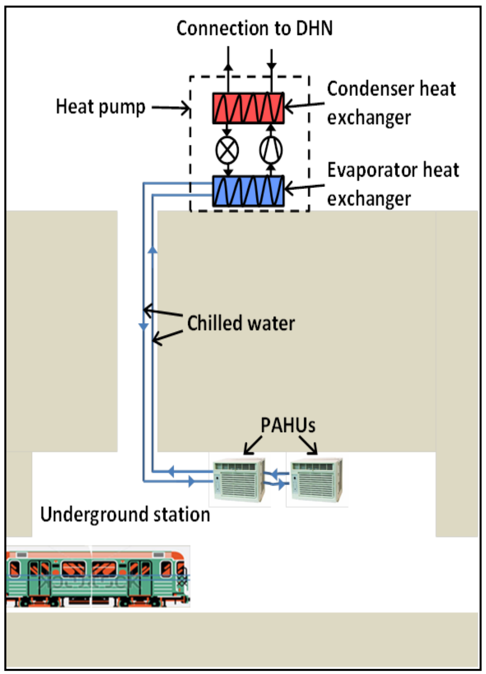
- Can recover heat from air return
- Need to increase temperature using heat pump for most reuse applications

- Data centres in central London represent a large heat resource
- Could use waste heat recovered from data centres in district heating networks
- A significant proportion of heat demand could be met for many London districts

MICAH – metropolitan integrated cooling and heating



District heating network



Waste heat recovery

- Investigate recovery of waste heat from LU tunnels and its use as a heat source for Islington Council (IC) district heating network (DHN)
- Innovate UK project involving LU, IC and LSBU
- Temperature of recovered heat will be raised to required level for input to DHN using heat pumps
- Potential energy carbon and cost savings available will be evaluated
- General approach could be extended to other waste heat sources e.g. data centres

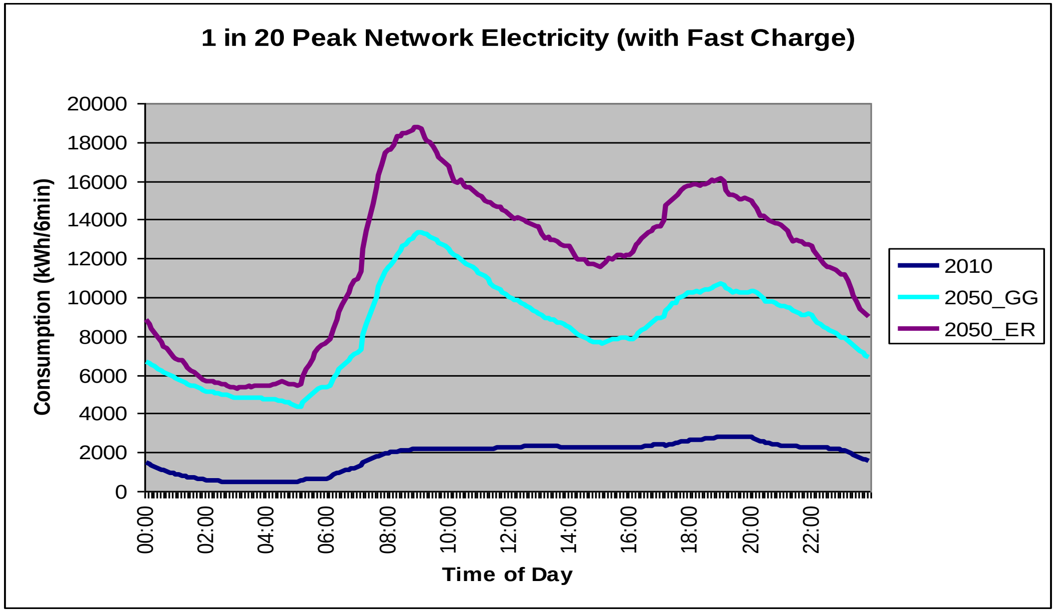
Projects in Space Heating

Task
Compact chemical heat store
Compact latent heat energy storage
Advanced electric heat pump
Next generation gas powered heat pump

Compact chemical/latent heat store

Domestic Heat pumps cannot economically provide the high powers (25kW) required for instantaneous hot water production

Grid limitations prevent instantaneous demand heat pumps. 4 – 7 x Electricity distribution network capacity needed? Rewire +250,000 km in 15-30 years?



Source: S. Marland, National grid, Why hybrids and gas heat pumps?, GasTech seminar 19th March 2012

Compact chemical/latent heat store

***Possible solutions*:**

- Hybrid electric heat pump/gas boilers have been suggested as one solution but as the housing stock thermal performance improves, DHW provision will become a larger fraction of the total load.

- Another option is the gas fired heat pump – three products on or near market

Compact chemical/latent heat store

Another approach to the problem is heat storage

Advanced compact heat stores can smooth out the diurnal peaks on the grid. They are part of a complex solution that involves hybrids, gas fired heat pumps and perhaps other technologies

Latent heat energy storage (short term)

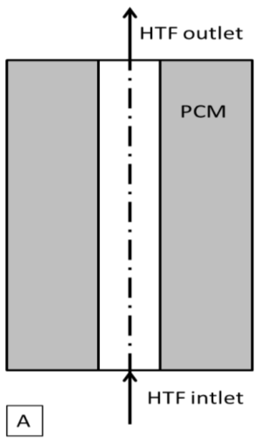
This project will develop and test a prototype system scalable to meet 2-4 hours of maximum winter space and water heating load

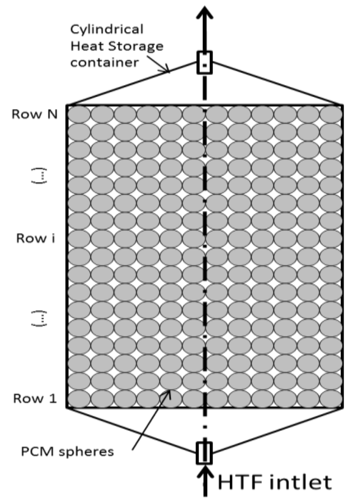
Chemical heat store (long term)

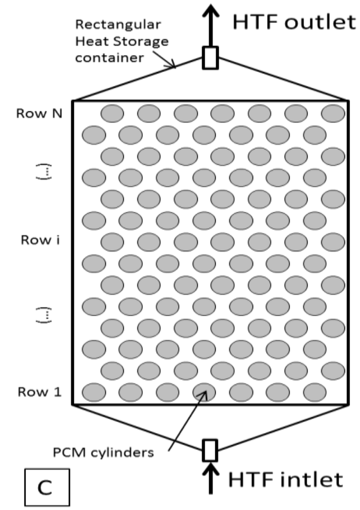
Objective is to develop a chemical thermal energy store with an energy density of at least **five times** that of a comparable water store at 65˚C

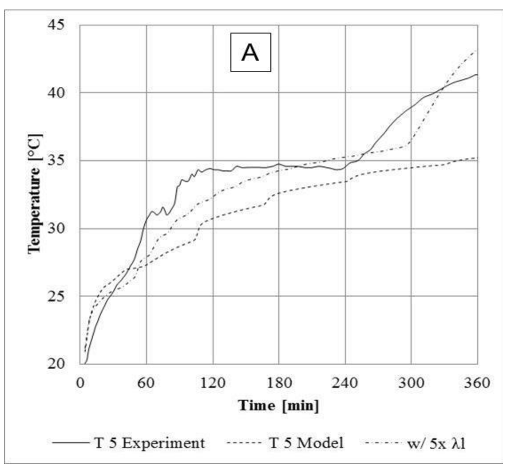
Compact latent heat store Container analysis + Model calibration

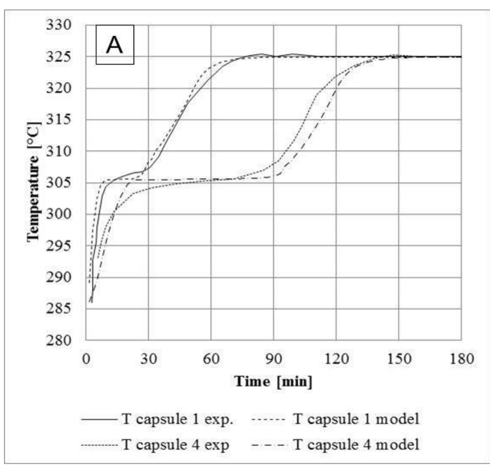
- Tube in tube
- Packed bed
- Staggered cylinder

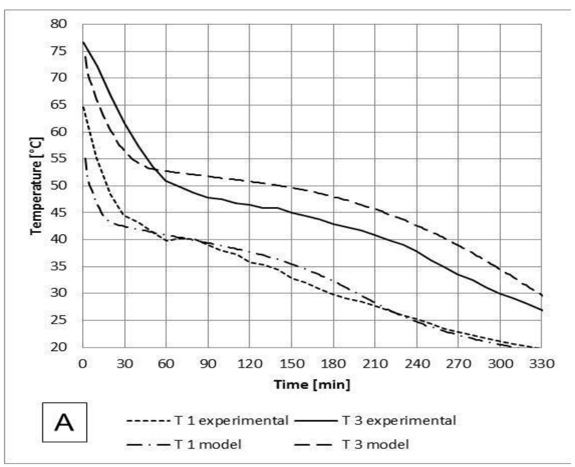












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Projects in Space Heating

Task
Compact chemical heat store
Compact latent heat energy storage
Advanced electric heat pump integrated with store
Next generation gas powered heat pump
Heat emitter study

Advanced electric heat pump

Challenge: To design robust and flexible control algorithms and reliable but efficient hardware based on improved cycles

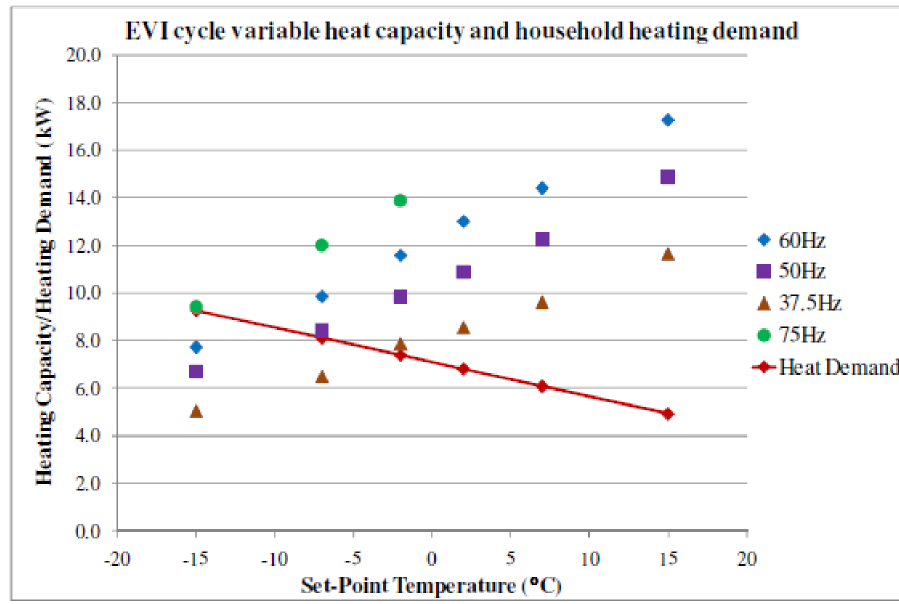
Objective: Demonstrate an air to water heat pump in the field that is consumer friendly and delivers a seasonal COP > 3.0

Rationale: Present electric heat pumps perform well below laboratory levels in real applications and can be improved by cycle modifications and advanced control

Advanced electric heat pump (Ulster)

Previous Work:

Economised Vapour Injection

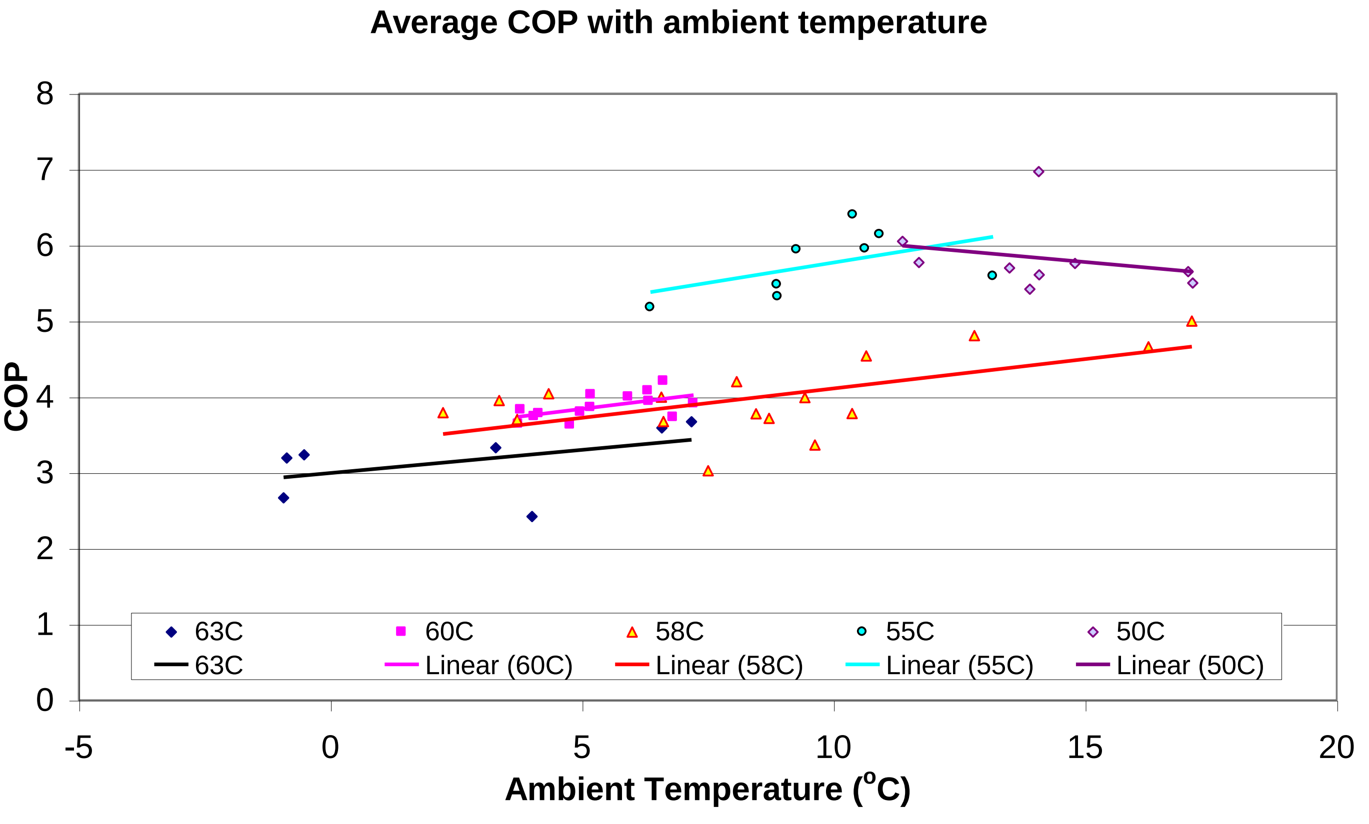


Advanced electric heat pump (Ulster)

Previous Work:

Energy
For a Low Carbon Future

Field Trial



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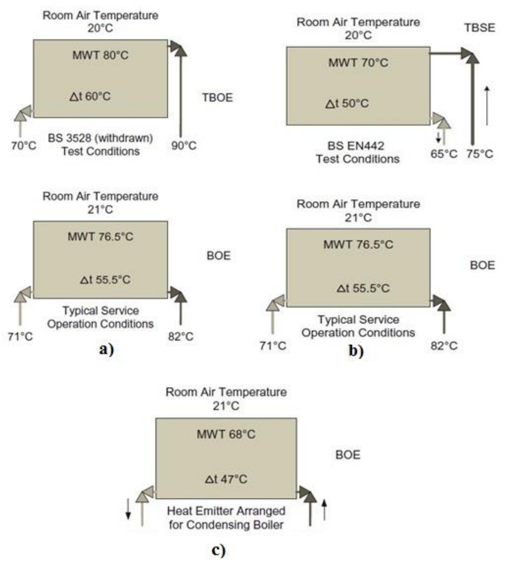
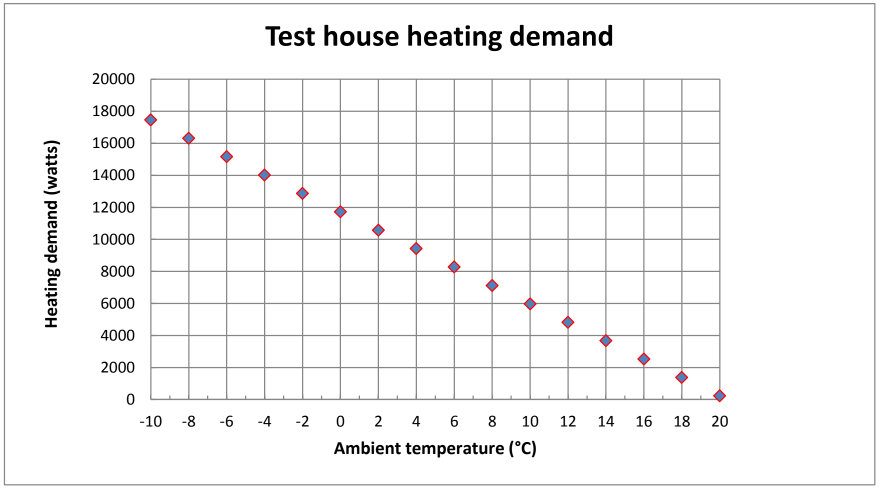
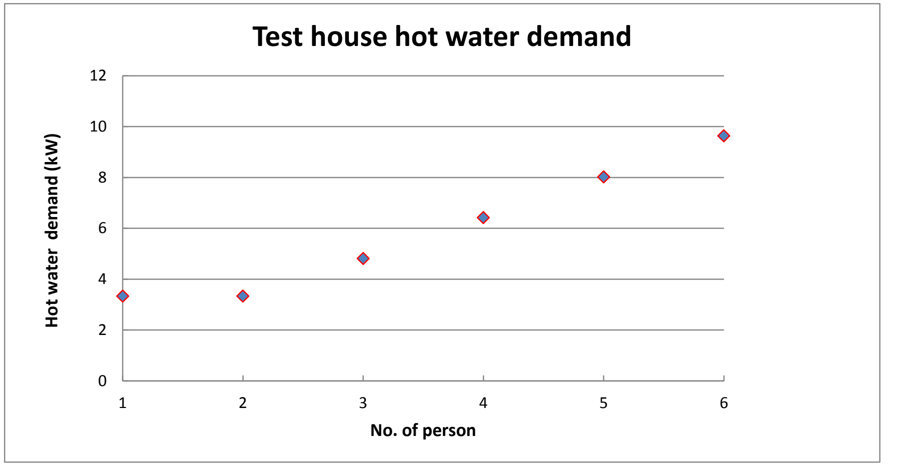
Advanced electric heat pump (Ulster)

Stage 1: House Evaluation







Energy
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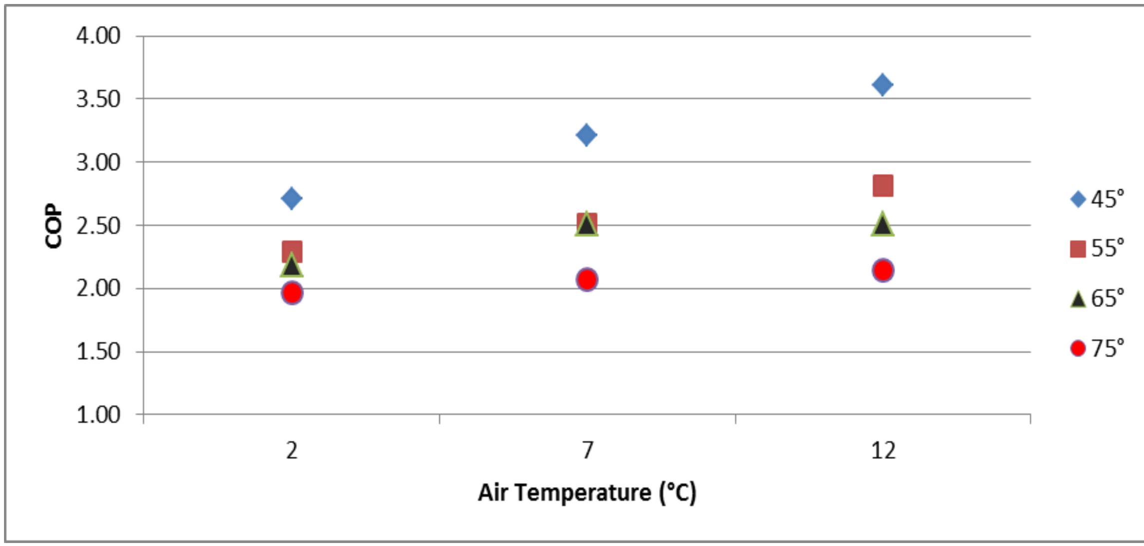
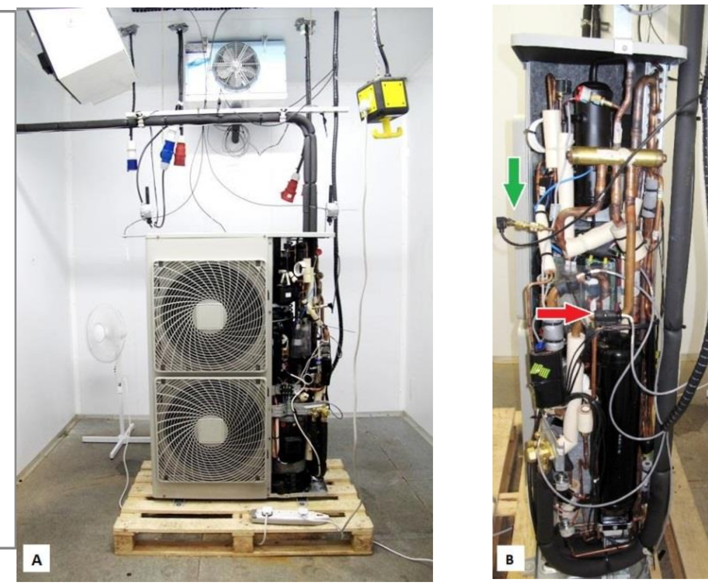
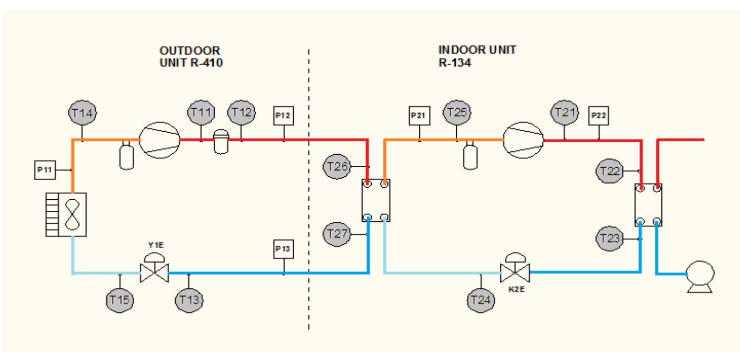
Advanced electric heat pump (Ulster)

Stage 2: Heat Pump Evaluation

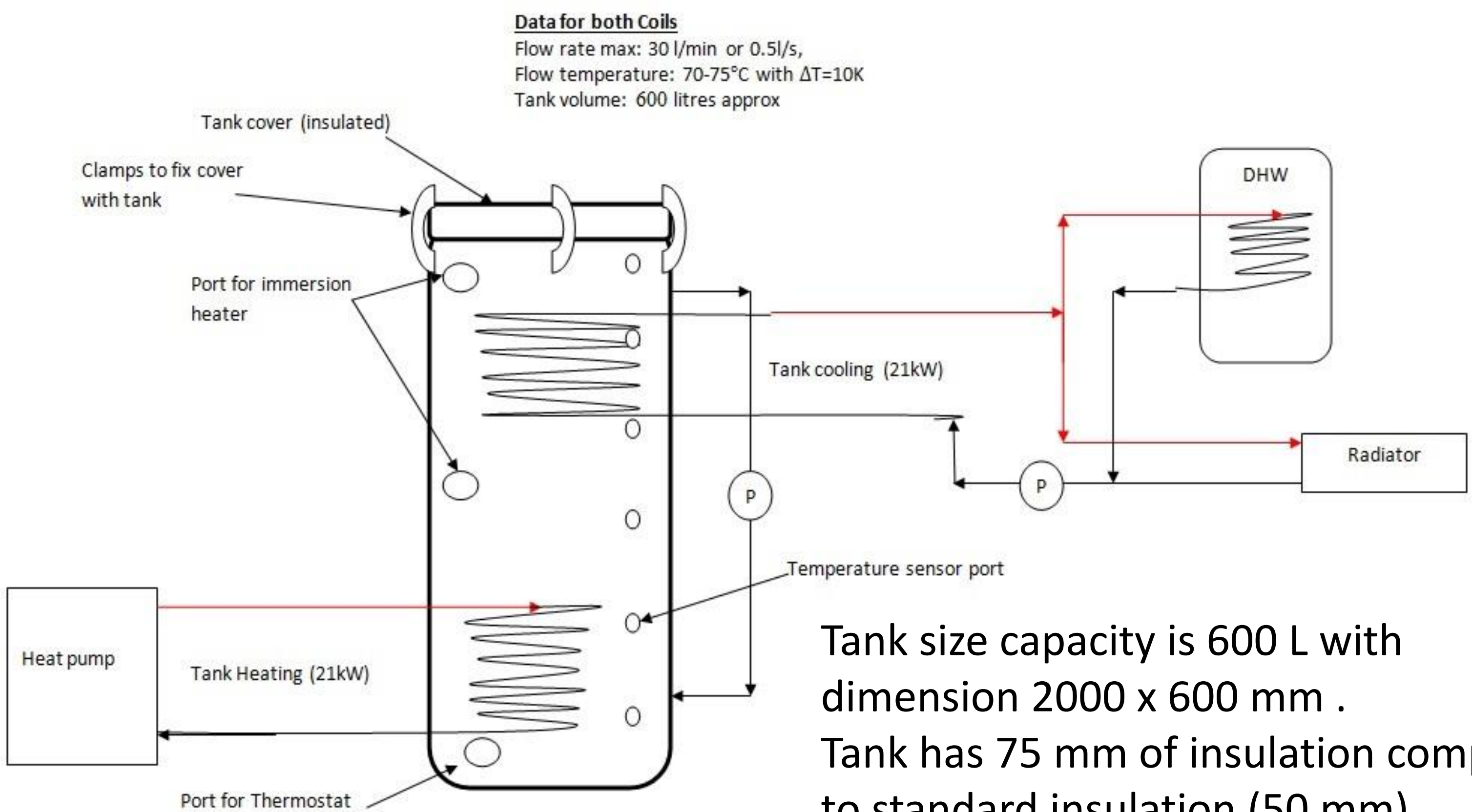






Advanced electric heat pump (Ulster)

Stage 3: Heat Storage



Tank size capacity is 600 L with dimension 2000 x 600 mm .
Tank has 75 mm of insulation compared to standard insulation (50 mm)

Advanced electric heat pump (Ulster)

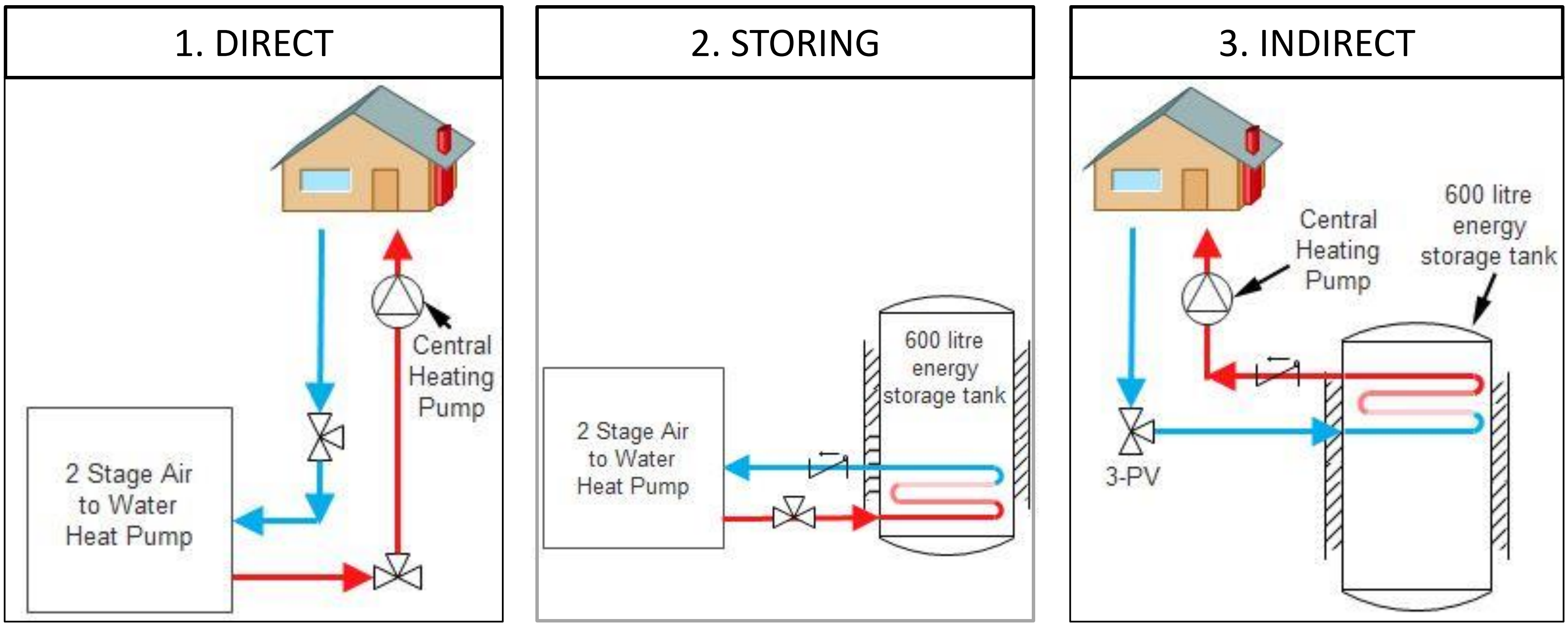
Stage 3: Heat Storage

Advanced electric heat pump (Ulster)

Stage 4: Integration

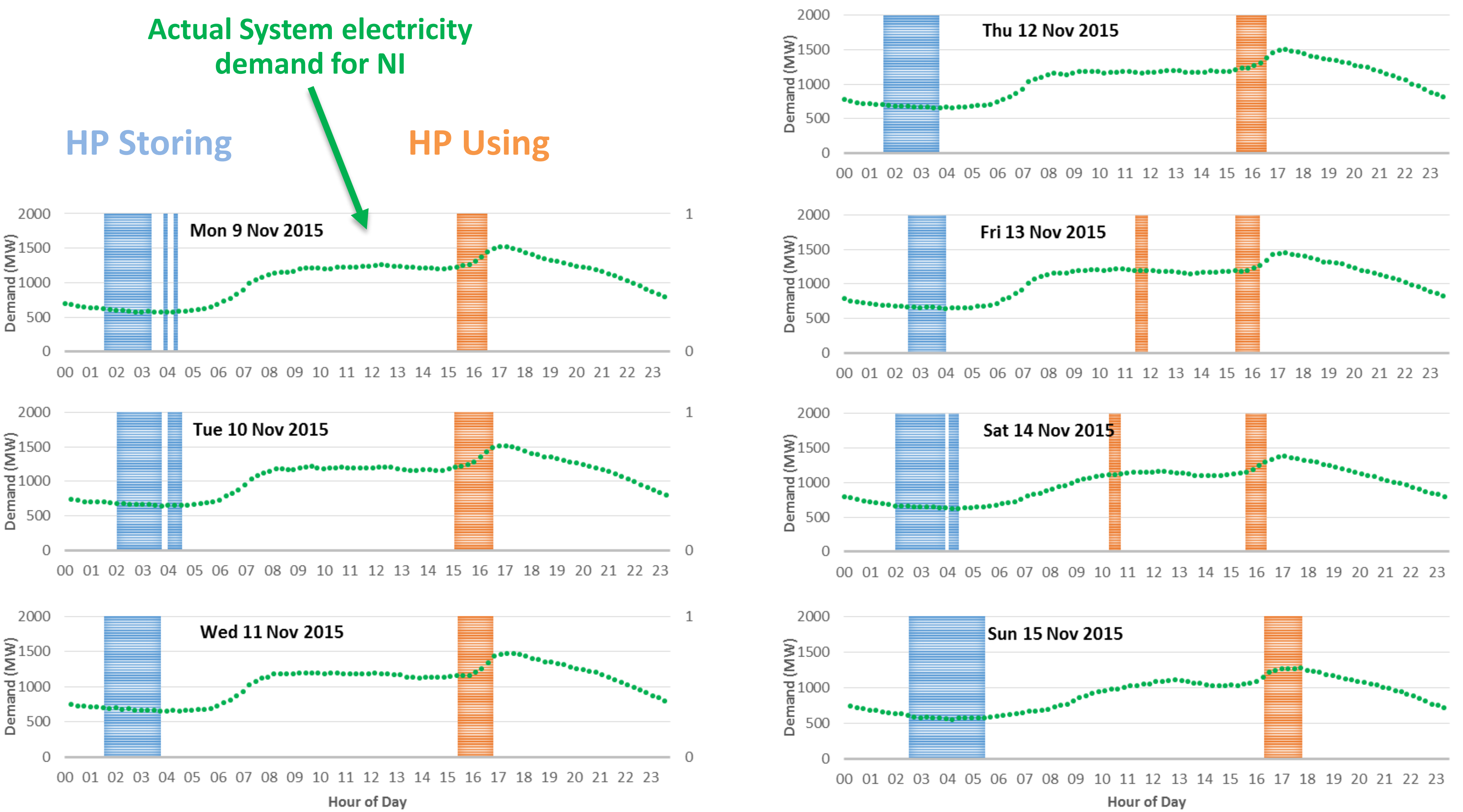
Model of Operation

1. Direct heating of house via electrical heat pump (DIRECT)
2. Heat pump stores heat in 600 litre tank (STORING)
3. Heating of house from storage tank (INDIRECT)



Mode of Operation

Energy
For a Low Carbon Future



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Projects in Space Heating

Task
Compact chemical heat store
Compact latent heat energy storage
Advanced electric heat pump
Next generation gas powered heat pump
Heat emitter study

Next generation gas/heat powered heat pump

Rationale

- Up to 50% reduction in CO_2 emissions compared with domestic condensing boilers
- Inability of electricity supply system to cope with an 'all electric' future with all homes heated by electric heat pumps – gas (inc. biogas) still has a role to play

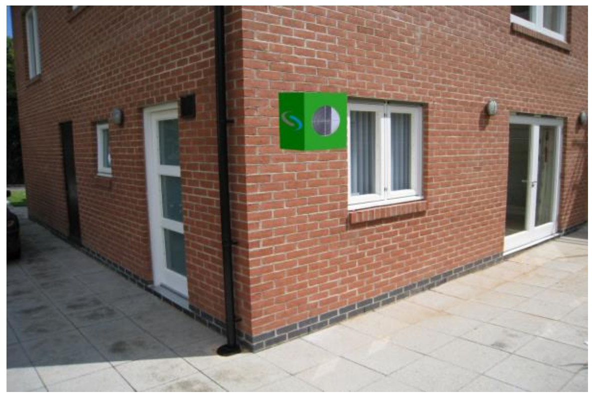
Technical options

- Engine driven heat pumps
  - Small sizes have maintenance and noise issues
- Sorption cycles [A**b**sorption and A**d**sorption]
  - Very few moving parts
  - Potentially low cost

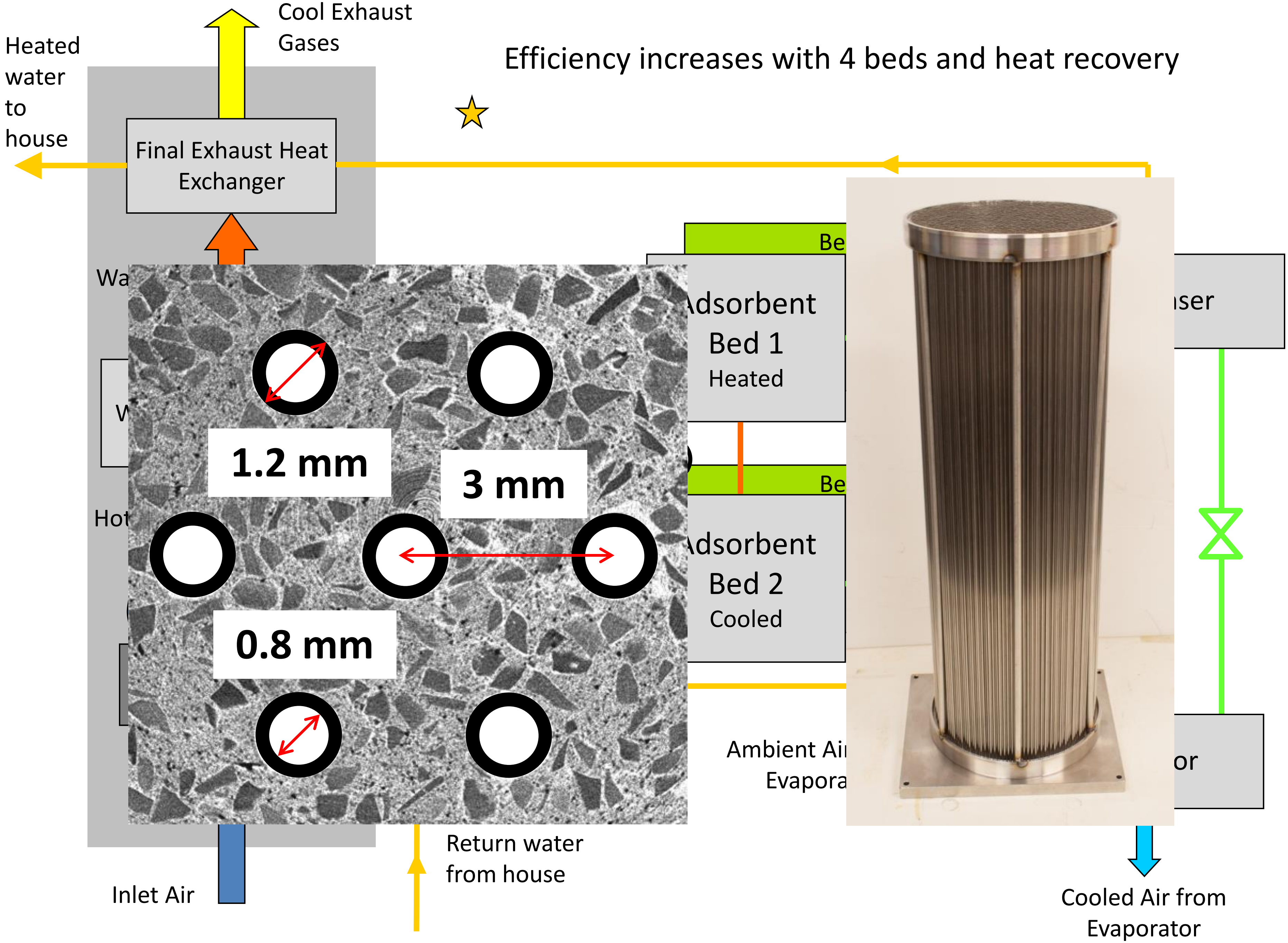
Gas-fired heat pumps

Current research on i-STUTE

Present concept 'split system', evaporator outside house, other components within 'look and feel' like a gas boiler



- Box-for-box exchange for old boiler
- Fits into standard wall-mounted casing
- Fuel savings 30-40%
- Designed for retrofit market >90% of annual sales

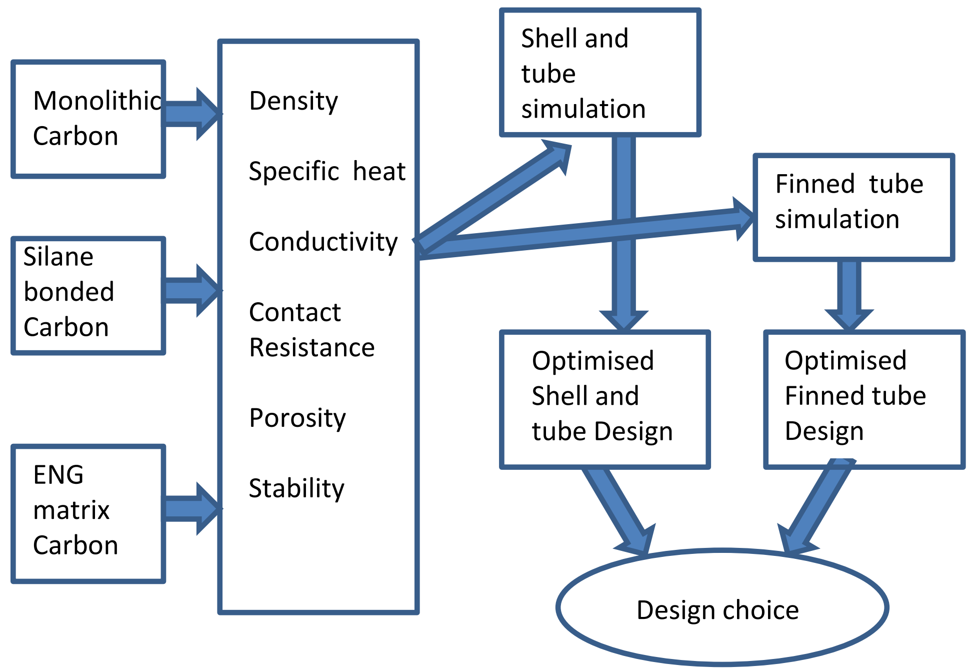


Efficiency increases with 4 beds and heat recovery
Cool Exhaust Gases
Heated water to house
Final Exhaust Heat Exchanger
Adsorbent Bed 1 Heated
Adsorbent Bed 2 Cooled
1.2 mm
3 mm
0.8 mm
Ambient Ai
Evapora
Return water from house
Inlet Air
Cooled Air from Evaporator

Two strand strategy:

1. Prove existing prototype system / compare against predictions to demonstrate ability and feasibility.

2. Evaluate alternative materials and generator designs to further reduce size and capital cost



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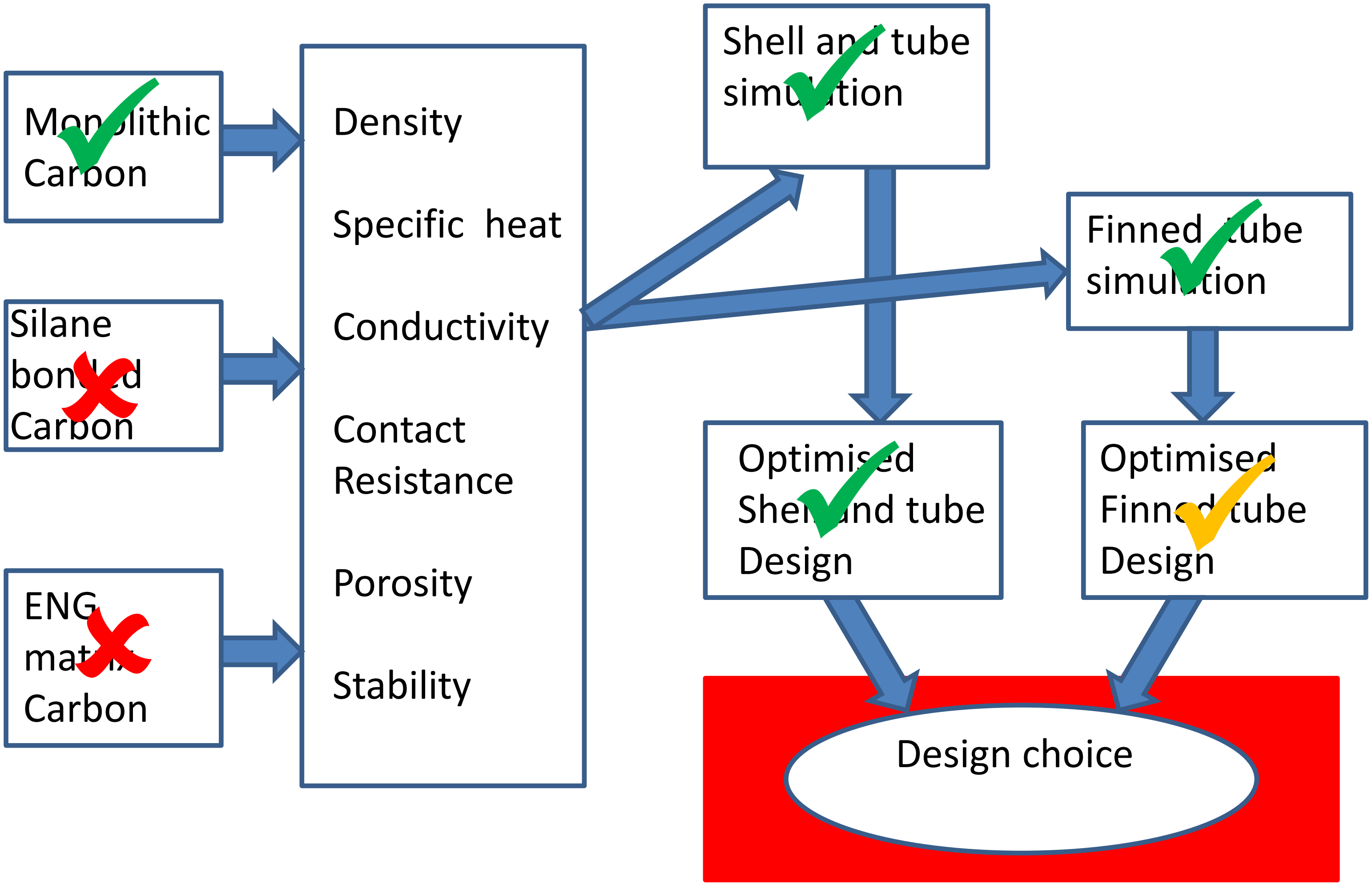
Targets for past six months:



Next six months:

Shell and tube

New project on DHW starting, supported by Baxi and Spirax-Sarco

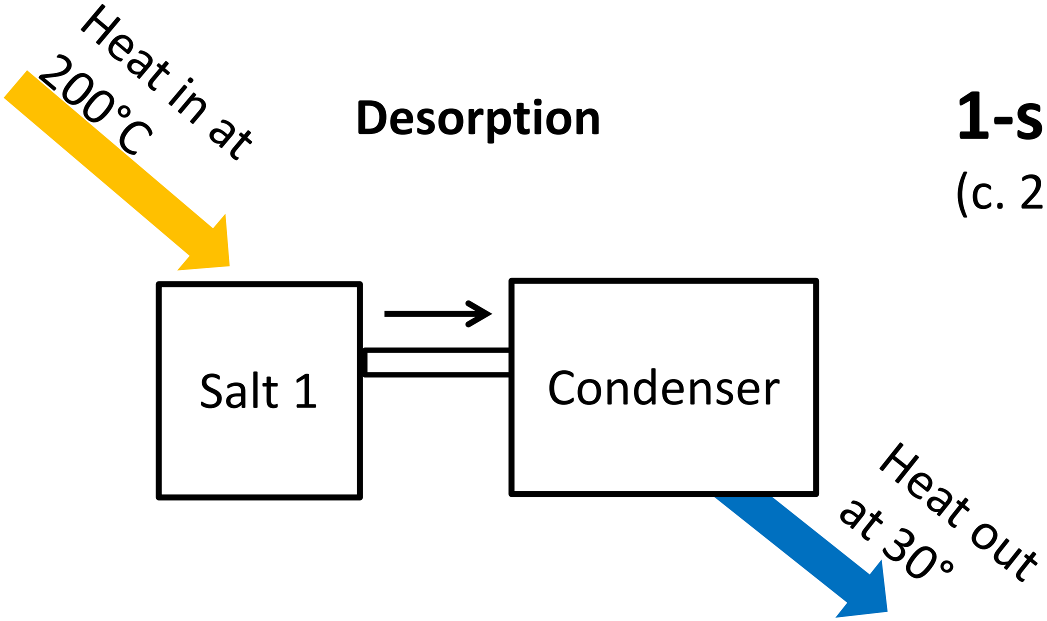
- Will use new design for rapid response
- Fast response + advanced store + smart controls to match combi advantages

Projects in Process Heating

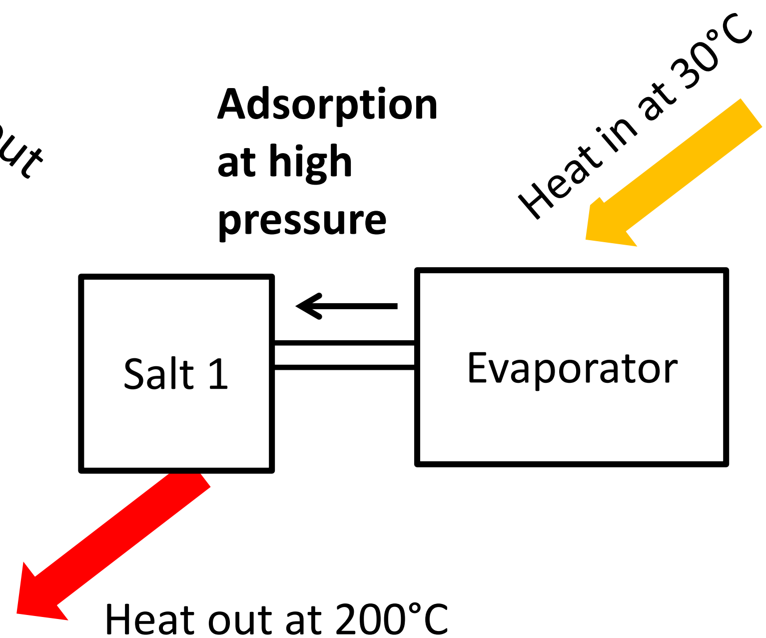
Task
High temperature heat pumps
Process heat storage
Thermal transformers

1-salt thermal store

(c. 2 MJ/litre)



Phase 1: Storage of heat at 200°C



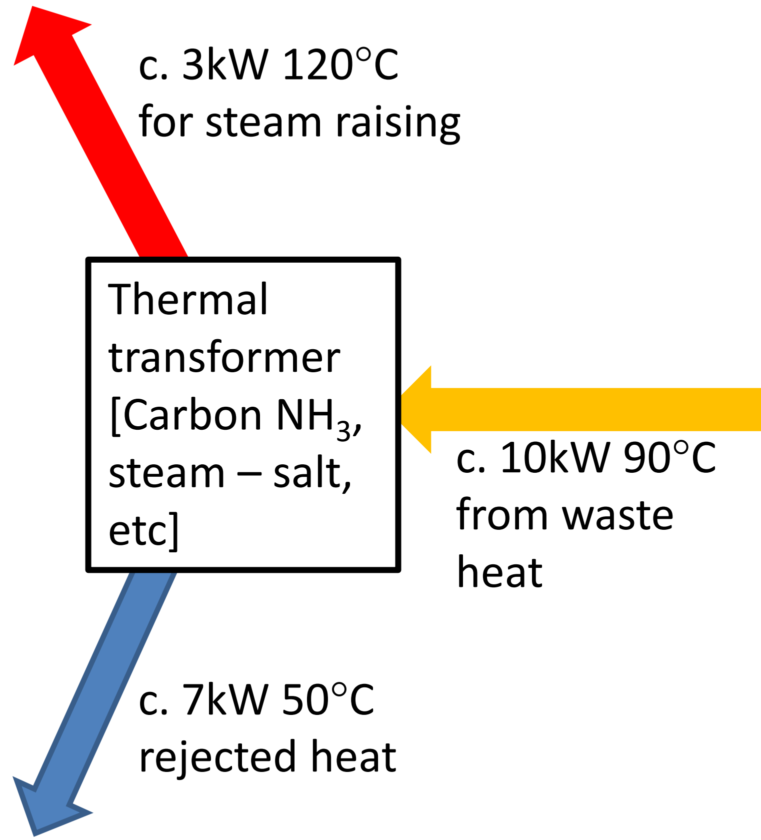
Phase 2: Discharge of heat at 200°C

Thermal transformers

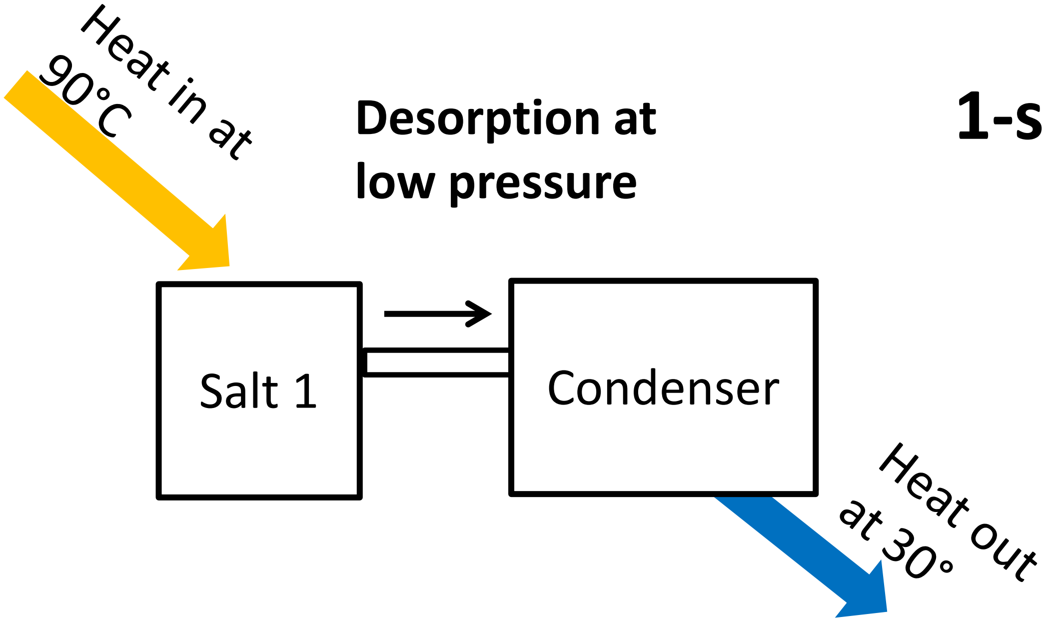
Rationale: Industrial processes commonly reject heat at temperatures of 90ºC or higher that cannot be utilised close to their source. A thermal transformer can transform some of this heat to higher useful temperatures, rejecting the remainder at close to ambient

Challenges: Identifying suitable economically viable major processes that would benefit. Identifying physical or chemical reactions best suited to the major needs

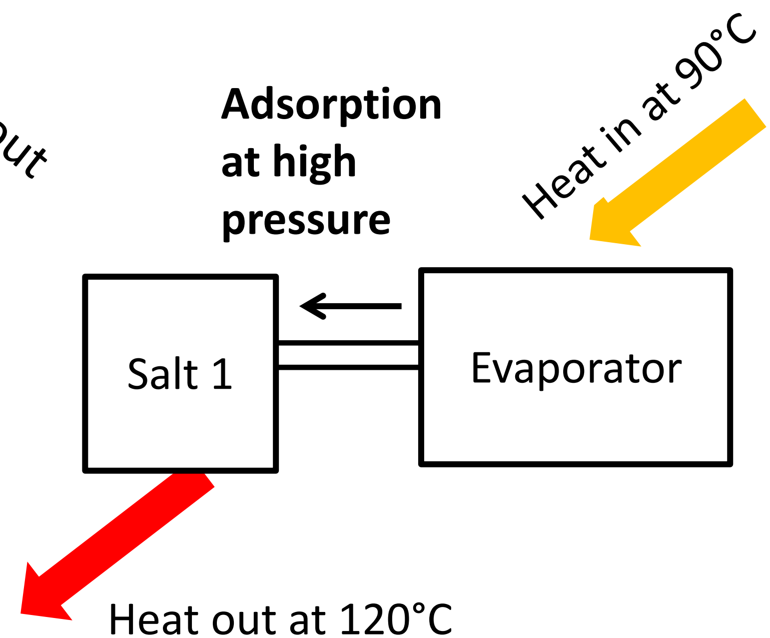
Deliverables: Identification of process needs and matching reactions with potentially high efficiency. Construction of laboratory PoC to investigate heat and mass transfer limitations



1-salt thermal transformer



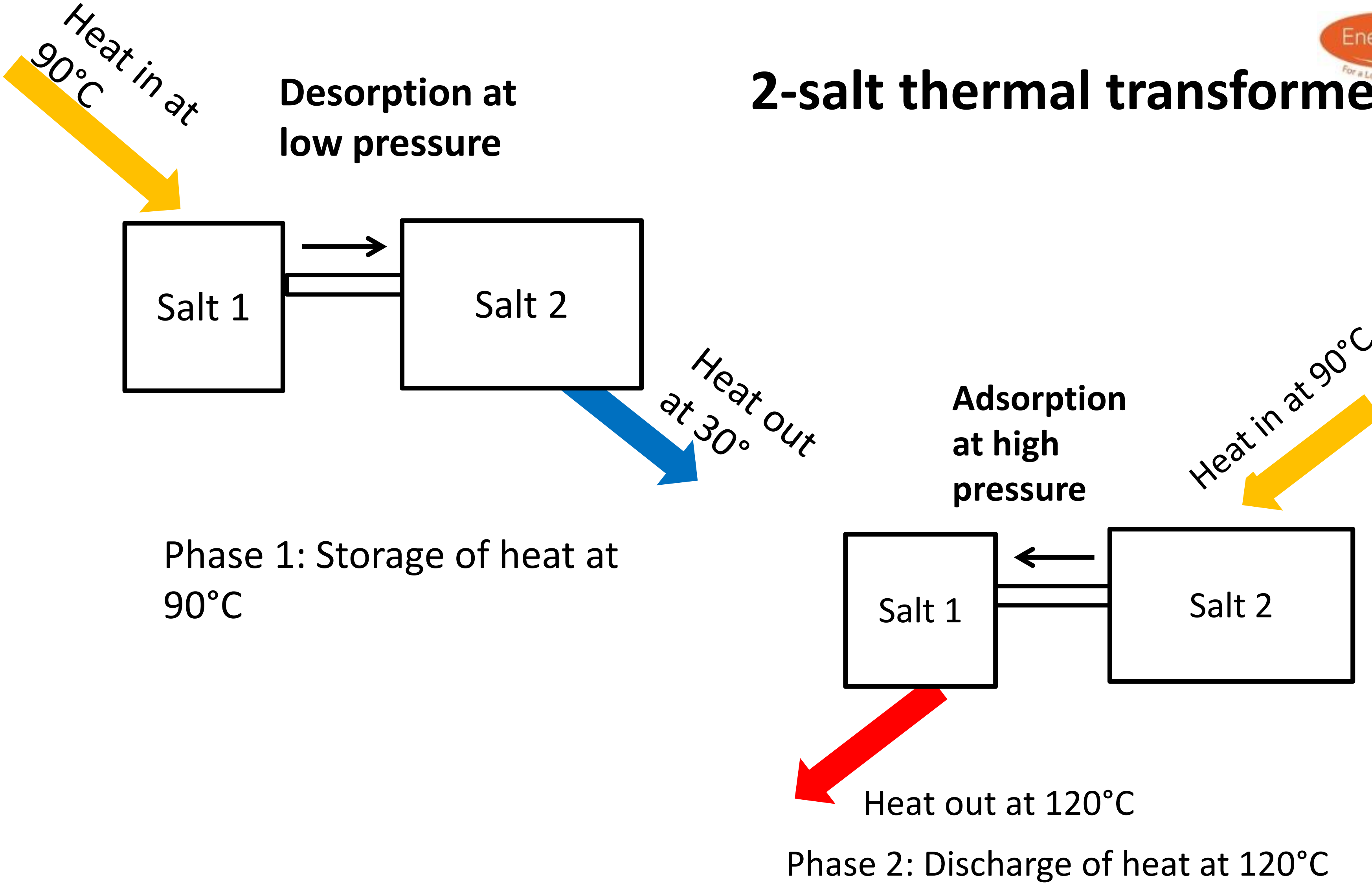
Phase 1: Storage of heat at 90°C



Phase 2: Discharge of heat at 120°C

Heat out (120°)/Heat in (90°) = 0.35 ?

2-salt thermal transformer



Business and Consumer Behaviour in i-STUTE , Case Studies:

1. Thermal stores (LU)

   Determination of user requirements for domestic thermal stores

2 Heat emitters (LU)

   Review of human factors surrounding heating emitters for heat pumps

3 Smart displays & Control (WBS, leveraging Innovate UK funded work)

   Understanding planned behaviour & norm activation in design of display choices

   Effect of temporal distance on future thinking about domestic temp. control

4 Perception Gaps (WBS, leveraging Innovate UK funded work)

   Presentation of Peterborough Council and University of Warwick Studies completed

   Next study now confirmed by Honeywell – Schools in Peterborough

Determining user requirements for domestic thermal stores

Hypothesis: Thermal stores have the potential to supplement the delivery of heat from heat pumps, but householders need better information about their status/use

Work completed to date:

35 in-depth interviews with householders (combi-, conventional and solar systems)

Exploring use of hot water storage as a proxy for future thermal stores

Focusing on interaction between householders, the hot water system and how it is planned/controlled

Heat Emitters

Consideration of the human factors relating to heat emitters for retrofitted domestic heat pump systems

Hypothesis: Low temperature heat pump systems require changes to heat emitters to deliver the required thermal performance in homes, but these changes may not not acceptable to householders.

Work completed to date:

- Review of heat emitters and identification of relevant human factors, e.g. noise levels, power requirements
- Review of the ‘Heat emitter guide for domestic heat pumps’
- On-line survey about heat emitter use (n=290)

Tentative insights so far…. Practicalities and preferences represent barriers to retrofitting fan-assisted radiators

Psychological barriers to behaviour change

Promoting Behavioural Change to Reduce Thermal Energy Demand in Households

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Abstract (199 words)

A reduction in thermal energy consumption in buildings is vital for achieving the reductions in CO_2 emissions that are part of EU-2020 targets. A key challenge faced by behavioural scientists is to understand what encourages people to adopt more efficient ways of achieving a satisfactory thermal experience. We review the psychological barriers to reducing thermal energy demand in the context of energy-efficient technology adoption, and discuss ways these barriers may be overcome. The barriers include: demand on cognitive resources due to decision complexity; the tendency to procrastinate and discount future consequences; deferral to simplifying strategies including repeating past experience and copying the behaviour of others; the desire to act in ways that maintain a positive self-image; and inertia due to fear of regret that one's decision might be wrong. We discuss behavioural approaches to overcome these barriers, such as emphasising public choice of "green" technology, reframing of benefits, simplifying and optimising the choice environment, focusing on symbolic attributes of new technologies, and changing the temporal structure of costs and benefits. We provide a framework of suggestions for future research which together constitute an important first step in informing behaviour change efforts designed to reduce thermal energy consumption in buildings.

Keywords Behavioural science; sustainability; energy-efficient technology; demand reduction; behaviour change; choice optimisation

Action inertia: Why do I have to change?

Social norms: What do my friends or neighbours do?

Messenger effects: Who told us?

Emotions: How does it make me feel?

Perceived behavioural control: Can I do it?

Temporal discounting: When will I get it?

Habit: What do I usually do?

Summary

i-STUTE is a collaboration of engineering, business and behavioural experts looking for sound, economic, acceptable solutions for the supply of heating and cooling.

Our projects include:

Task
Compact chemical heat store
Compact latent heat energy storage
Advanced electric heat pump
Next generation gas powered heat pump
Heat emitter study

Task
High temperature heat pumps
Thermal transformers
Process heat Storage

Task
Supermarket refrigeration
Data Centre Cooling
Refrigerated transport
Integrated heating and cooling

Summary

The future of heating probably involves ALL of:

- Electric heat pumps
- Gas heat pumps
- Smart controls
- Consumer behaviour
- Micro CHP
- Fuel cells
- Innovative business models
- Storage

Plus things we have not thought of yet, integrated but affordable, used appropriately, appealing to the customer. No pressure…

Thank you!

Questions???

www.i-STUTE.org