Engineering and Physical Sciences Research Council

Decarbonisation of the heating and cooling of buildings workshop

25 March 2025

Report on workshop outputs

1. Introduction

The EPSRC Decarbonisation of the heating and cooling of buildings workshop was held in Birmingham on 25 March 2025. The aims of the workshop were to:

- Define the current and future research and innovation challenges in the area and the current landscape in the context of engineering and physical sciences.
- Understand the barriers to adopting innovation in this area and how they might be reduced.
- Identify and prioritise focus areas for near- and medium-term research and innovation activity in the area.
- Enable networking between those working in different areas and sectors related to heat and buildings

Expressions of interest to attend the workshop were invited from the breadth of relevant communities from the academic, industrial, and public sectors. 40 people attended the workshop, the list of delegates is in Annex 1.

2. Workshop format

Presentations from EPSRC, Antonia Mattos and Graeme Maidment from the Department for Energy Security and Net Zero, and Andrew Smallbone Director of the Network for Heating and Cooling Research to Enable a Net-Zero Carbon Future (H+C Zero Network)[1] set the scene for workshop discussions.

The group then discussed:

- Research challenges in the decarbonisation of the heating and cooling of buildings
- Reducing barriers to implementation and adoption of innovations
- Areas of future focus

[1] A Network for Heating and Cooling Research to Enable a Net-Zero Carbon Future https://gtr.ukri.org/projects?ref=EP%2FT022906%2F1

3. Research challenges

Delegates discussed the current and future science and technological or socioeconomic challenges in the area, and the current landscape in the context of engineering and physical sciences.

Points from the discussions could broadly be grouped into the following themes:

a. Technology system integration / interoperability
b. Resilience of technology and infrastructure
c. Understanding performance (technologies and buildings)
d. Materials innovation/lifecycle analysis/circular economy
e. Decision/planning system integration/regulation
f. Social barriers to adoption

Details of the discussion are in Annex 2.

4. Reducing barriers and priorities to focus on

For each of the themes identified from the previous discussion delegates discussed:

- What are the perceived barriers to implementation and adoption?
- Who needs to be involved / who are the key enablers?
- Where can engineering and physical sciences research make a difference / add value?
- Are there areas which are enabling of other areas?
- Does the UK have research skills and talent to deliver this?
- What infrastructure might be needed to enable implementation and adoption?
- What role might commercialisation have in addressing these barriers?

Delegates were invited to discuss additional areas which may not be covered, two additional themes were also discussed:

- Total distributed systems
- Early incorporation of regulatory input into innovation development

Delegates were asked to identify priority areas for future work by voting on the outputs from the discussion, these are detailed below. The number in brackets indicates the number of votes an area received, higher priority areas are in bold. See Annex 3 for detailed outputs.

a. Technology system integration

- High temperature heat pumps (3)
- Heat networks, including those that integrate waste heat and cool (1)
- **Storage: thermal, electrical, inter-seasonal (6)**

- Smart local energy systems (3)
- Whole system approach (1)
- **Real world test environments (6)**
- Innovative business models (1)

b. Resilience of technology and infrastructure

- **Heatwave resilience (5)**
- Highlight key weaknesses and the impact of cascading failures (3)
- Calculating levels of risks and what is a tolerable level of risk (3)
- Role of flexibility in providing resilience (2)
- **Access to data and collaboration networks (5)**

c. Understanding performance of technology and buildings for optimization

- Spark price differential (2)
- Can't improve performance if don't have monitored data. For example for non-domestic heat networks or electric heating (2)
- More cross-over with innovative industry (2)
- **Establish field trial test homes for research to test real world performance (5)**

d. Materials innovation/lifecycle analysis/circular economy

- Supply chain transparency (1)
- Recycling (1)
- Deconstruction (1)
- Material alternatives and substitution for critical and high impact resources (1)
- **Need to future proof and generate the critical skills and personnel (3)**

e. Decision/planning system integration/regulation

- Integration of tools/knowledge e.g. heat networks, cooling, grid impacts (1)
- Involvement of local authorities and communities (1)
- **Monitoring of heat pump installations (4)**
- Need to link national / local remodeling with real performance operations (1)
- Geospatial modelling tools / skills (1)
- Get skills into local authorities (researchers, support) (2)

f. Social barriers to adoption

- Control systems that are easier to use and appropriately informative (1)
- Inaccurate social media campaigns (1)
- Better automated recognition and diagnosis of problems (1)
- Monitoring to underpin financing, for example to evidence performance (1)

- **Learn by doing with real world consumers – people + data + systems + technology (6)**
- Successful case study for someone "like me" (1)
- Process innovations needed to develop business models that help identify multiple interventions in one go and save cost and effort (1)
- Making it desirable (1)

g. Total distributed energy systems

- Vision is for optimal control of domestic heating / cooling / PV / EV that is both installer and consumer friendly – integrated with grid supplied renewable electricity and incorporating thermal and electrical storage for the most cost-effective solution. (3)
- Ventilation – how much is there in real homes? (2)

h. Early incorporation of regulatory input into innovation development

- Create forums and platforms for innovators, end users, supply chain and regulators to meet and work together. For examples in a 'sand box' environment where innovator and regulator can work together and help the innovator to understand the regulatory expectations early enough (3)

5. Reflections

During the final discussion delegates noted that the discussion had been less focused on specific technologies than at a similar EPSRC workshop on heating and cooling held in 2019 which preceded two funding opportunities in this area.

It was also noted that many models use average temperatures, but buildings should be resilient to the increasing extremes of our climate.

Data, its quality and availability were raised in many discussions during the day. For example, collecting and sharing of monitoring data from buildings and heat pumps. It was noted that bad data is worse than no data.

Innovate UK reminded delegates of the following activities:

- Design for Future Climate award reports
- The Energy Systems Catapult living lab
- Net Zero Heat programme

6. Next steps

EPSRC will engage further with partners in UKRI and other stakeholders to develop the future strategy for the area.

Delegates were reminded of responsive mode funding opportunities[2] should they have research ideas for which they want to apply for research funding.

[2] Types of funding we offer – UKRI EPSRC guidance for applicants https://www.ukri.org/councils/epsrc/guidance-for-applicants/types-of-funding-we-offer/

Annex 1: Delegate list

The following is a list of delegates who gave permission to publish their attendance at the event.

Last name	First name	Organisation
Salvador	Acha	Imperial College London
Carl	Arntzen	Bosch Thermotechnology Ltd.
Edward	Barbour	University of Birmingham
Robert	Barthorpe	University of Sheffield
Vivienne	Blackstone	EPSRC
David	Coley	University of Bath
Robert	Critoph	University of Warwick
Xu	Dai	University of Liverpool
Tracey	Dale	ESRC
Danielle	Densley Tingley	University of Sheffield
Jonathon	Elvins	Swansea University
Judith	Evans	London South Bank University
Michael	Fell	University College London
David	Glew	Leeds Beckett University
Rajat	Gupta	Oxford Brookes University
Richard	Halsey	Energy Systems Catapult
Joel	Hamilton	Translating Energy
Matthew	Jackson	Imperial College London
Kat	Kelly	Atamate Solutions
Henrique	Lagoeiro	London South Bank University
Graeme	Maidment	Dept for Energy Security and Net Zero
Catarina	Marques	London South Bank University
Sukumār	Natarājan	University of Bath
Tadj	Oreszczyn	University College London
Jason	Palmer	University College London
Ajinkya	Rao	EPSRC
Renaldi	Renaldi	University of Birmingham
Ahmed	Rezk	Aston University
Kristina	Roszynski	London South Bank University
Paul	Ruyssevelt	University College London
Justin	Searle	Swansea University
Mehdi	Shahrestani	University of Reading
Paul	Shepley	University of Liverpool
Stan	Shire	University of Warwick
Andrew	Smallbone	Durham University

Maximillian	smith	Eluxevo limitedL
Panos	Stavrakakis	Health and Safety Executive, Science Division
Sara	Walker	University of Birmingham
Jonny	Williams	Naked Energy
Zhibin	Yu	University of Liverpool

Annex 2: Outputs from discussion of research challenges

a. Technology system integration / interoperability

What does current landscape look like?	What are current challenges	What are the future challenges?
Retrofit cost and complexity	Lack of integrated solutions (heat plus storage)	Integrating building and infrastructure with decarbonization solutions
Trends in environmental digitalisation	Integration of waste heat into heat networks	Advanced modelling tools to analyse thousands of building archetypes quickly
Lots of data available but not many attempts to bring them together to support implementation	Electrification at scale- system scale	Integrate heating and cooling solutions to wider energy network (systems issue)
Lack of monitoring data for new technologies performance guarantees	Housing/building stock is too hard to retrofit	Non vapor compression (systems issue)
Growing interest in deployment of heat pumps at high density	Performance gap between expectations and outcomes (fragmented system)	New grid characteristics and new energy networks require demand management through technological innovation to ensure efficient and reliable energy supply as well as managing the use of different electrical systems
Stagnant installation costs and lack of awareness on integration opportunities	Fragmented commercial models	Practical implementation to realize benefits of new tech
Lack of understanding of cooling demand with respect to future building comfort	Waste heat energy recovery (systems issue)	Thermal energy storage
H2 boilers that work (not commercial yet)	Thermal storage heaters significantly outsell heat pumps	High temperature heat pumps
Knowledge of ability of gas network to transport H2	Electric grid side increase Energy demand switching	Research is needed to facilitate transitions from F gas refrigerants to natural fluids such as CO2 and propane.
Loads of storage in gas grid (3 days) very expensive electricity (spark gap	Micro-renewables impact in health and safety building safety (resources and whole life carbon)	We need strategic planning for very large thermal (interseasonal) storage and heat networks

Access to data (more different/availability)-AI as a tool	Low refrigerant use/transition	How to decarbonize flats? Currently, they are using electrical heaters or electric storage heaters. Alternative technologies?
A lot of technologies are there, but installation/cost is a barrier. Intelligent control to inform reduce cost-effective installation.	Control of flexible assets (from home energy management that integrate generation/conversion/storage and to aggregate at network level to city level	Cooling demand is growing, how do we balance passive vs active solutions
Solar thermal market dropping (it is hydrogen now).	Solving air quality and humidity management alongside energy efficiency and air tightness	

b. Resilience of technology and infrastructure

What does current landscape look like?	What are current challenges	What are the future challenges?
Occasional heat waves-uncertain cooling need	Heat networks-retrofit challenges	Role of natural gas and hydrogen for heating
Building ventilation issues	Health plus energy interface plus interactions and associated risks plus benefits	Integration of heating and cooling to make it smart and the role of flexibility in enabling this
Energy security more critical to public	Part load operations for most systems, this will change in future warmer world.	Impact of extreme heat impacts on heating and cooling decarbonization
Diminishing role for hydrogen for domestic heat	Operation of existing and emerging technologies mean network grid need to prepare for an uncertain transition	Moving heat demands>3 days
	Lack of access to the building energy data with high resolution	Excessively loading one metric can generate unintended consequences
	What will be the AC demand in terms of infrastructure readiness	Ground storage of thermal energy (intraseasonal)
	Research infrastructure has been put into place (over 5-10 years) for • Labs (H&C testing) • Buildings in labs (replaced industrial labs)	Lack of adaptive capacity in relation to climate change

	• Unoccupied buildings	
	Adaptation to future climate (overheating) -understanding impacts of it	Adaptation-building turnover and potential to adapt, climate adaptation
	Use of heat pump and EV simultaneously could restrict use of EV batteries to balance grid	Compelling commercial case for low temperature heat networks/positive energy districts
	Greater interaction with mainland electricity grids and unknown management of supply across interconnectors	

c. Understanding performance (technologies and buildings)

What does current landscape look like?	**What are current challenges**	**What are the future challenges?**
Low energy storage adaptation	Ventilation plus controlled insulation	Building windows too small for 2050 cooling requirements
Low adoption of heat pumps	We need to work on how automation and human action can work together in complex energy/tariff landscape	UK will need an alternative to A/C
Limited interpolation of heating and cooling	Lack of real-world case studies regarding UK building stock	Sourcing new datasets, for extreme weather, price, occupancy
Investment in cohesion- UKCRIC, Active building centre- How can they come together	Need convincing demonstrator projects- build confidence (fragmented system)	Wider impacts of no action regarding future building comfort
Flawed EPC standard	Covalent energy user sharing	Thinking of climate throughout lifespan of H/C technology wrt to future building comfort
Lack of smart intelligent building centers and controls	Whole system performance plus cost	Energy resource management
Good thermal insulation understanding of how to use and workforce to install	Lack of clarity in direction and social integration wrt to Interface between occupant and heating system and Industrial cooling and refrigeration	Passive cooling with integrated energy retrofit

Change in methodology in monitoring/measuring performance of innovation	Better recognizing poor Heating and cooling systems performance	Passive cooling knowledge
Understanding retrofit approaches of different buildings (fabric)	Control integration in energy/environmental systems in buildings	Deep or shallow retrofit fabric balance needed between heating and cooling wrt to building comfort
Lack of live data on building performance	Control/running strategies for district heating	Some tech have different lifetimes and performance over that lifetime is not understood
	Challenge of understanding people behaviors in homes Doing research in actual homes (cost, logistics, disruptions- understanding behaviors	Built in monitoring not standard
	Ventilation (air quality) relates to understanding performance	Demonstrating role of heat pumps plus advances thermal storage in homes increases in HP performance
	Greenfell report new regulations building safety act	Lack of accurate energy efficiency of UK house stocks and we need reliable data of heating demand
	Reduce solar generation to limit cooling need and solar PV film on windows	
	Cooling through natural vegetation (saltwater consumption)	
	Lack of adaptation strategies	
	Addressing challenges building stock – high density, poor fabric and space consumers	

d. Materials innovation/lifecycle analysis/circular economy

What does current landscape look like?	**What are current challenges**	**What are the future challenges?**
PCMs for thermal storage and insulating	Implementation of deep energy retrofits to reduce energy demand (future cooling)	Data centre plus AI and Quantum growth linked to cooling

Range of thermal storage materials (R&D) limited commercial systems	Validation of metals for monitoring/ accessing performance	Reduce need for source code higher grade, flexibility related to cooling technologies to avoid surge in demand (system challenge)
	Embodied resource implication of geothermal energy	Correcting past installations of retrofit
	Ensuring place-based approaches such as climate or resource specific installation (wind in Scotland, insulation in high wind west coast etc.	Building control (impact of extensions on energy efficiency
		Recyclability of new equipment/tech
		New technology- No foam homes-aerogels New insulations novel fabrics, alternative materials, biobased. Materials innovation-metamaterials
		fire safety risk during retrofit, novel materials knowledge/evidence goes for health and safety important
		Automated detection of high-risk materials that could be used in retrofit

e. Decision/planning system integration/regulation

What does current landscape look like?	What are current challenges	What are the future challenges?
Weak supply chains	Insufficient installers	More market players coordination challenges
Fragmented markets	It is cheaper and easier to model heating and cooling systems rather than test demonstrate them	Upgrading outdated building management systems and integration with low carbon technologies
Established business models	Bespoke localized energy community framework analysis design plus operation solutions	Reduced biodiversity due to more buildings being made and developed

Increased DESNZ R and D funding, HPR	Quality assurance plus trust (fragmented system)	Management of demand flexibility to support decision making
Need for net zero consensus now being challenged	Commercial arrangements (Lack of standardisation)	Insurance products for heat pump/PV/heat network
More demanding new building standards	Accurate characterization of future cooling demand	Lack of domestic manufacturers of technologies needed for decarbonization of heating and cooling
How innovation will meet regulatory compliance (building safety	England and Wales have overheating map for 2030/2050/2080 but we need better understanding of local cooling needs	
New testing standard to meet building safety regulators	Better easier interoperability and Monitoring to unlock financing, example for HAAS and easier to operate optimize performance	
	Very fragmented landscape of infrastructure lab	
Regulating the heat network/shared asset base sector		
Challenge of training a dispersed sole trader industry to ensure quality of installation		

f. Social barriers to adoption

What does current landscape look like?	What are current challenges	What are the future challenges?
More low carbon heat business plus offers than 5 years ago	Perception- value of comfort is subjective	Consumer understanding getting more complex
Fragmented technologies being without socio-economic research on implementation challenges	Socioeconomic driver-needs?	Aging population
Policy landscape more enabled now- current barrier a enabler	Policy driven- race to bottom	Community energy network platforms (context: New grid characteristics and new energy networks)

Consumers have lot of techs in their homes. Legacy control for heating no consistency in perception.	Aesthetics? What are people prepared to pay for? Perception of value to EPC (real metrics of building performance)	Bringing flexibility to the most vulnerable (context: New grid characteristics and new energy networks)
Who has ownership? Many owners of buildings (social housing, landlords, commercial buildings	Consumers habits are strong cannot be fixed by filling an information deficit	Regulations and policy Research needed in Different household tenures ownership/renting
	Widening gap between energy efficiency plus fuel poverty	Policy Research needed in Heat network regulations
	Public engagement in net zero and technologies.	Policy research needed in Better local heat planning
	Lack of trust from consumers transitioning away from boilers	Equitable access to winter heating, energy heat cooling justice
	Consumers don't care really – it is cost over CO2 emissions	What other problems we need to adapt to (health, climatic, cultural)
	Community trials bring forward socio-economic political barriers	Challenge of understanding people behaviors in homes
	Energy poverty, security plus link to health now more politically motivated	Political challenges of how things being framed
	Isolated approach to net zero (by sector)	Embodied energy is not regulated at all
	Lack of complete policy certainty Challenging political environment Social acceptance of new technology	Difference between new build and retrofit (different approaches, decision makers and policy drivers)
	Perceptions of heat pumps and district heat networks	lack of energy security -how to respond to blackouts?
	Regressive/progressive financial implications with respect to electricity grid	Public engagement/acceptability for now/different energy sources
	Greenfell report new regulations building safety act.	Social desirability of air source heat pumps vs ground source.
	Keeping costs down for heat network customers through improving network performance.	Access to data- how to get public access, how to standardize

	• Consumer acceptance of change • Skills plus training -lack of expertise to apply the adaptations. • Financing, paybacks. • Operational costs, installation costs- owner occupier landlords • Lack of empirical data on nondomestic heat pump use	
	Data management ownership, privacy, governance and security	

g. Additional points

Current landscape	**Current challenges**	**Future challenges**
More online shopping (more convenience stores less large supermarket)	Customer confusion (no central advice routes)	Business models that can flex and adapt
Initial platform for research and collaboration (7) • Developing platforms for relevant research • Large population of gas engineers	How to incentive household take uptake through mortgage products	
No/ low carbon solution for distress purchases which is 60% of market		
Missed opportunities for new build		

Annex 3: Detailed outputs from reducing barriers discussion

Research / innovation area discussed:
Technology System integration

What are the perceived barriers to implementation and adoption?

- Cost
- Retrofit complexity
- Conservative decision making, “fear of failure”
- ‘Closed’ software environments
- License costs
- Limitations
- Installer skills and knowledge
- Knowledge of available technologies
- Business models
- Spark gap

Who needs to be involved / who are the key enablers?

- Auditors
- Professional bodies
- Installers
- ESCOs
- Consumers
- Policy makers
- Local authorities

Where can EPS research make a difference / add value?

- High temperature heat pumps: ownership of control; cheaper, simpler, more efficient
- Heat networks with waste heat and cooling integration
- Multidisciplinary research
- Whole system approach
- Demonstrations -> build trust
- Innovative business models
- Coming up with radical new ideas

Are there areas which are enabling of other areas?

- Heat networks
- Storage: thermal; electrical; inter-seasonal
- Renewable power
- Smart local energy systems
- Data on demand: use and technical performance
- Geothermal / underground energy storage

Does the UK have research skills and talent to deliver this?

- Yes but….25 year problem, 3-year funding opportunities!
- Risky new technology projects are hard to cost and end up being expensive

• Engineering skills are 10 x more expensive that China / India • Multidisciplinary skills: materials; heating and cooling; renewable power; social science • Thermo-mechanical engineering
What infrastructure might be needed to enable implementation and adoption?
• Real world test environments • Grid reinforcement • Shared data platforms
What role might commercialisation have in addressing these barriers?
• Spin-out leaders with skills and motivation • Access to £10m + to reach market • Knowledge Transfer Partnerships (KTPs)

Research / innovation area discussed:
Resilience of technology and infrastructure

What are the perceived barriers to implementation and adoption?

- Heatwave resilience – 40°C summers are the new normal
- Complex engineering systems
- Multi stakeholder engagement
- Identifying the cost of "doing" nothing
- What are the impacts and where and when we might experience – who is impacted?
- Who pays for flexibility and resilience?
- Data available and data security / trust
- Low adaptive maturity to adapt change
- Agreeing where vulnerabilities are
- Who is more deserving of 24/7/365 power/heat
- How to survive Heathrow x 10?

Who needs to be involved / who are the key enablers?

- Which end users are at risk? Who at the stakeholders in the system?
- Multiple network failure – who owns it?
- Risk SWAT force: IT; water; energy; transport; waste
- Cross government to prioritise
- Network operators
- Major infrastructure: air; rail; road.
- Insurance industry
- Failure, mode, probability, impact, stakeholder, risk owner

Where can EPS research make a difference / add value?

- What is an acceptable amount of resilience per consumer?
- Highlight key weaknesses and the impact of cascading failures
- How to adapt and create resilience – who, when, where?
- Calculating levels of risks and what is a tolerable level of risk
- Role of flexibility in providing resilience

Are there areas which are enabling of other areas?

- Security
- Health and safety
- Economy
- Telecom
- Energy infrastructure, security and bottlenecks
- Energy digitalization will also require digital resilience
- Protection for undersea cables: to facilitate x-links; more reasonable energy is the answer to almost everything!

Does the UK have research skills and talent to deliver this?

- Interdisciplinary research essential
- Access to data and collaboration networks is key

• Data is sensitive. Can it be published for security reasons? • Working with industry is key
What infrastructure might be needed to enable implementation and adoption?

• Networks, grid and control systems demonstrators for research
• Access to data
• Energy / thermal storage
• High power computation
• Planned networks
    ○ District energy resilience
    ○ Action plans at national / local level

What role might commercialisation have in addressing these barriers?
• Humanitarian vs commercial decision making • Accelerate and optimize delivery or real-world solutions • Significant role

Research / innovation area discussed:
Understanding performance of technology and buildings for improvement / optimisation

What are the perceived barriers to implementation and adoption?

- Availability of relevant data streams
- Privacy / confidentiality preventing data sharing
- Getting access to building specific demand data
- Getting access to heat pump control system to enable interoperability / integration with other systems, for example storage
- Confidence / trust / accuracy of methods, for example SMETER
- Lack of perceived benefit
- Spark price differential
- Can't improve performance if don't have monitored data. For example, for non-domestic heat networks or electric heating
- Incompatibility of data systems from different sources

Who needs to be involved / who are the key enablers?

- UK data archive / National data library
- Trustmark and other compliance / QA organisations
- Technology providers to provide heat meters
- EPC assessor organisations
- Data controllers for example energy suppliers, smart DCC, DNOs
- DSIT

Where can EPS research make a difference / add value?

- Fund building physics and unintended consequences research
- Fund validation trials for SMETERs and potential to influence EPCs
- Known unknowns, installation data for example uninsulated pipe runs
- Defining what "performance" and "optimal" mean in a decarbonising energy system with half hourly electricity pricing
- Through a central data repository analyse heat network data on a large scale
- Comparison of all different building performance evaluation methods
- Better prediction or cooling energy demand in homes
- Quantifying (and then using) degree of flexibility provided by a building -> interaction with wider network

Are there areas which are enabling of other areas?

- More research into social learning and self help groups to provide aftercare for supporting optimization
- Understanding building performance -> improve heat pump design and operating performance
- Fund model calibration, for example make dynamic thermal models properly represent flexibility
- Control interfaces for people for optimization to be successful

- Home energy management systems. Balancing cost, carbon, comfort. Taking advantage of TouTs, flex services etc.
- “Performance” should also mean ventilation / indoor air quality, avoiding over heating

Does the UK have research skills and talent to deliver this?

- Yes, however increased support for involvement in IEA projects would gear up UK research enormously
- More cross-over with innovative industry
- Train a new wave of building physicists

What infrastructure might be needed to enable implementation and adoption?

- More research into early majority, their needs and motivations
- Socio-technical approach to optimization
- Establish field trial test homes for research to test real world performance
- Increasingly need common platforms to store and make available data
- Standardised sensing hardware / framework for data gathering, for example modalities, sample rates
- Define ‘buildings’ as a research and not falling between physics and engineering

What role might commercialisation have in addressing these barriers?

- Standardised methods and metrics (including analysis uncertainty)
- De-risking through real-world trials to try and overcome valley of death

Research / innovation area discussed: **Materials innovation / lifecycle analysis / circular economy**
What are the perceived barriers to implementation and adoption?
• Can you meet primary demand and secondary supply – supply chain transparency   o Does the material supply exist? • How to cover end of life – recovery, reuse, or disposal • To what extent get recovery with critical resources? • What is the scalability approach -> how to translate from lab to commercial • Specific material demand -> need to look at lifecycle impact and replacement options • Toxicology – what is the environmental / health and safety impact?
Who needs to be involved / who are the key enablers?
• Relevant material supply chain – designers and developers • Regulatory bodies / government as key enablers – breakdown of systems • Health and Safety Executive – regulate • Know what is in the system – materials breakdown
Where can EPS research make a difference / add value?
• Better understand data / data gaps for systems -> have a database for systems -> open databases • Use of data sheets • Theoretical evaluation of material issues and scalability • Recycling and reusability and deconstruction • Recycling: theoretical and actual understanding – logistics embedded infrastructure • Knowledge of future infrastructures • Material alternatives and substitution for critical and high impact resources • Research on waste as a resource (cross sector)
Are there areas which are enabling of other areas?
• Chemical sector – sustainable feedstocks, use of tech for substitutes • Construction sector – recycling and hopefully reuse
Does the UK have research skills and talent to deliver this?
• Yes, materials science is strong in the UK • Need to future proof and generate the critical skills and personnel • Skills gap for long-term operating and downgrading systems / buildings
What infrastructure might be needed to enable implementation and adoption?
• Practical infrastructure • Education of operators • Potential for job growth – need to retain within UK • Long term remanufacture of heat pumps - scale up barrier within this
What role might commercialisation have in addressing these barriers?
• Socialization vs. commercialization • Proof of the scale – proven the concept has worked and has an applied business model.

Research / innovation area discussed: **Decision/planning system integration/regulation**
What are the perceived barriers to implementation and adoption?
• (In)stability of the landscape (political, leadership, intervention) • Access / availability of data • Integration of tools/knowledge e.g. heat networks, cooling, grid impacts • Unintended consequences and not taking items in isolation. For example, Grenfell, moldy retrofit homes, power cuts)
Who needs to be involved / who are the key enablers?
• Local authorities • Local communities • National Systems Operator • DESNZ / MHCLG • Energy Systems Catapult • Installers (QA) • Big waste heat owners for district heat
Where can EPS research make a difference / add value?
• Monitoring of heat pump installations • Monitoring of real 'normal' projects and demonstration projects – learn as doing to de-risk • CBA of different government interventions (EEE, retrofit, replace building stock) • Heat network performance • Reuse of gas network for heat transfer (waste heat / boreholes) – heat zoning
Are there areas which are enabling of other areas?
• Economists • Socio-economic research
Does the UK have research skills and talent to deliver this?
• Need to link national / local remodeling with real performance operations • Local planning • Geospatial modelling tools / skills
What infrastructure might be needed to enable implementation and adoption?
• Communication platform to link enablers / researchers / local needs / users • Standard format for household connections to heat network • Data sharing / standards, infrastructure and access protocols (synthetic data through AI
What role might commercialisation have in addressing these barriers?
• Get skills into local authorities (researchers, support)

Research / innovation area discussed:
Social barriers to adoption

What are the perceived barriers to implementation and adoption?

- Unfamiliarity and “lack of fit”
- Cost
- Relative improvement to quality of life
- Capacity and capability to engage
- Trust in performance
- Inaccurate social media campaigns
- Disruption -> need to more of “transition moments” such as extensions or other works [to buildings]

Who needs to be involved / who are the key enablers?

- Users as co-designers
- Local authorities
- Community groups
- Intermediaries for example builders / installers etc.
- Consistent policy and steer for future
- Disruptors – new ideas and ways of doing things

Where can EPS research make a difference / add value?

- Control systems that are easier to use and appropriately informative
- Smooth onboarding
- Inclusive design
- Better automated recognition and diagnosis of problems
- Better integrated service design
- Designing processed that make it easy to do the right thing
- Monitoring to underpin financing, for example to evidence performance

Are there areas which are enabling of other areas?

- Monitoring and interoperability -> user experience but also system coordination
- Be aware of connections, avoid silos in research areas
- Tax rebates for “open house” examples of good local heat pump installations

Does the UK have research skills and talent to deliver this?

- Co-development of social science and engineering projects
- Learn by doing with real world consumers – people + data + systems + technology

What infrastructure might be needed to enable implementation and adoption?

- Get installers and contractors or building control / planners to highlight opportunities for multiplying intervention opportunities. For example, install heat pump when extending
- Working smart meters
- Successful case study for someone “like me”

• Poor installation quality will jeopardise acceptability (low COP), high COP is essential. People won't want to later update to a "better" system
What role might commercialisation have in addressing these barriers?
• Process innovations needed to develop business models that help identify multiple interventions in one go and save cost and effort • Making it desirable • Important for scaling up, must be commercial

Research / innovation area discussed:
Total distributed energy systems

What are the perceived barriers to implementation and adoption?

- Vision is for optimal control of domestic heating / cooling / PV / EV that is both installer and consumer friendly – integrated with grid supplied renewable electricity and incorporating thermal and electrical storage for the most cost-effective solution.
- Ventilation – how much in real homes?

Who needs to be involved / who are the key enablers?

- Government / utilities to enable easy flexible electricity
- Import / export
- Technology researchers
- House builders / providers

Where can EPS research make a difference / add value?

- Provide hardware at low enough potential cost / good performance and AI systems to integrate with 'Energy cloud'. Optimisation needs to be at UK level, not just consumer level.
- Optimal store size: individual / small community / town???

Are there areas which are enabling of other areas?

- Thermodynamic systems
- AI
- Business models
- Consumer behavior / acceptance

Does the UK have research skills and talent to deliver this?

- Yes

What infrastructure might be needed to enable implementation and adoption?

- Utilities need to be on board and engaged

What role might commercialisation have in addressing these barriers?

- Energy pricing mechanisms, for example time of use tariffs, peak penalties

Research / innovation area discussed: **Incorporate regulatory input into innovation development**
What are the perceived barriers to implementation and adoption?
• Meeting [regulation] compliance to enter the market
Who needs to be involved / who are the key enablers?
• Innovators • End users • Supply chain • Regulators
Where can EPS research make a difference / add value?
• Create forums and platforms for above stakeholders to meet and work together. For examples in a 'sand box' environment where innovator and regulator can work together and help the innovator to understand the regulatory expectations early enough
Are there areas which are enabling of other areas?
• Cross-sector factors, for example technology from one sector can be used in the built environment • Inter-regulatory approach e.g. safety regulators can work together to suggest innovations
Does the UK have research skills and talent to deliver this?
• UK has excellent record in developing regulatory frameworks • UK government – industry – academia – regulators can work together
What infrastructure might be needed to enable implementation and adoption?
• Establishing the sandbox regulatory environment
What role might commercialisation have in addressing these barriers?
• The technology / innovation will be ready to enter the marketplace = compliance, trust and assurance