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Socio Technical

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Interview Findings

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1 Introduction

As of 24 February 2021 – 74% of district, county, unitary and metropolitan councils have declared a Climate Emergency[1], many have pledged to a net zero emissions target of 2030, and there is much emerging activity in developing decarbonisation pathways for their administrative areas and regions. The sense of urgency is compounded too by the pandemic and the need to restore economic activity but at the same time ensuring decarbonisation objectives are met.

With many proposed low emission technologies requiring or generating electricity, and noting deployment of wind in particular, it is expected that electricity will be used to fulfil a significant share of our energy needs in a low carbon society. Transport, passenger cars in particular, is expected to be electric and new electric vehicle offerings and sales are gathering pace. Heating demand remains a particularly outstanding area but, again, there is a view that electrifying heat will be the way forward in many cases through the adoption of heat pumps. However, there are many complicating factors relating to what future demand for heat may look like and the adoption of various technologies for decarbonised heat and related technologies. There are also wider implications too for electricity networks and what happens to the gas grid.

The UK Centre for Energy Systems Integration (CESI) is a £20M industry and EPSRC funded project looking at the future of low-carbon energy systems, through the integration of modelling across different sectors but informed through demonstration projects. As part of the CESI consortium, this CESI Flex Fund (reference CESI FF4-001) aims to take a prototype socio-technical community energy model developed by Heriot-Watt University (“ParaDwell”[2]), and investigate the extent to which such models are able to incorporate the key changes that communities are likely to see as we move towards challenging carbon targets. Crucially, we wish to understand whether real, “on-the-ground” experiences of households within certain communities are reflected in the type of models used to project future carbon savings across stocks of buildings. Specifically, does the tendency to reference “typical” homes in stock models limit our ability to characterise those buildings (and households) in a useful way?

The first part of this study, described in this report, is a series of semi-structured interviews with a range of stakeholders (industry and academic) with an understanding of the challenge ahead for low-carbon communities, the barriers to low-carbon retrofit, and the complex interaction that householders have with new technologies. The results of these interviews are given below, noting the anonymised responses of the participants involved, characterised by key themes that emanated from the conversations.

This work will also inform the second part of the study, a workshop aiming to explore in greater detail whether key aspects of low-carbon retrofit in communities are adequately

[1] https://www.climateemergency.uk/blog/list-of-councils/

[2] P. McCallum, D.P. Jenkins, and P.Vatougiou, Control event matrices for stochastic heating use in urban-scale energy simulations, IBPSA Scotland uSIM2020, November 12th, Edinburgh

incorporated into quantitative modelling and, if not, what approaches modellers can take to better link theoretical models with real experiences of retrofit.

This report is based on the interviews with representatives from 10 organisations and sectors. These will be referred to with labels A-J in the report, and the background or perspective of each interviewee is shown in Table 1 below.

Table 1. Interviewees

Label	Role	Area/perspective
A	Council – Housing	Orkney
B	Charity	Orkney
C	Industry	Heat pumps
D	Architect	Passivhaus
E	Research	Retrofit
F	Research	Gas Grid
G	Research	Retrofit/efficiency assessment
H	Research	Fuel Poverty
I	Council - Climate	Newcastle
J	Electricity Grid	DNO

The themes that were flagged up in the interviews are outlined in more detail in the sections that follow. These themes, and the opinions expressed in the report, relate to the responses of the interviewees, not the authors.

2 Governance

2.1 General Comments

In one interview it was highlighted that while regulation is decided by central government, it is the local councils that are responsible for implementing it. There has been a restriction on funding for councils due to austerity following the financial crash. This has led to limited resources in councils especially staffing resource, creating problems in implementing regulation due to the large levels of paperwork (A). It was further commented this leads to councils being blamed for lack of delivery (A).

While the majority of councils have declared climate emergencies to deliver on this action is needed to improve the energy performance of all buildings, this depends on funding and resources (A, and E). One interviewee commented that to decarbonise homes needs “good old fashioned government spending” (E).

2.2 Planning

To improve the energy efficiency of homes requires insulating the property – lofts need insulating as well as walls to the outside environment. Where buildings are of solid wall construction this could involve cladding the exterior and therefore changing the appearance that can require planning approval. One interviewee outlined the differences between councils. Within Yorkshire their experience has been that while Leeds and Bradford councils tend to be more accepting of such changes, York and Harrogate resist appearance changes. This creates a barrier to effective retrofitting (see section later) (D).

There is a particular issue with listed buildings and also ones in conservation areas. One interviewee outlined the example where a Conservation Officer would not allow a listed building to have its single glazed windows replaced with double glazed – they had to be replaced with single glazed (D). In another case the planning department would not allow external wall insulation to the rear of the property even though the change in appearance would not be visible from the street (D).

One Council that is undertaking a heat pumps project is working with the planning department to prepare advice to residents on all low carbon technologies as to what is permitted development or requires planning consideration for approval (I). However, it was highlighted while there are problems obtaining approval on homes and small buildings, more ambitious low energy schemes on much larger buildings (e.g. universities) were much easier to obtain planning approval for (D).

On new social housing schemes there is a good deal of council ambition and interest. The Mikhail Riches' Goldsmith Street, Norwich, that won the Stirling Prize in 2019 for example has attracted a lot of council interest (D). This scheme is a development of a row of community focused homes and is currently the largest Passivhaus scheme in the UK[3]. Despite the issues outlined above for planning approval in retrofitting older homes, York Council's Housing Delivery Programme has commissioned Mikhail Riches to design 600 net zero homes[4].

2.3 Policy Ambition & Green Homes Grant

The scale of policy ambition was found to be lacking with current government. While there are moves to improve energy efficiency EPC ratings up to C for rental properties, there is very little political appetite to legislate for owner occupied homes. One interviewee who provided advice for the 2017 Labour Party manifesto commented that although the manifesto had the right level of ambition, legislation for owner occupiers "didn't want to touch it" (E).

In the Labour party manifesto there was a commitment for 60% renewables across all energy vectors (not just electricity but heating and transport as well) by 2030. There was some modelling that suggested this required c.1TWh to be saved from housing energy demand necessitating a move in EPC rating for homes from C-D to B-C and some A (E). Most of these would adopt heat pumps and also there would be a lot of solar PV – average

[3] http://www.mikhailriches.com/project/goldsmith-street
[4] https://www.dezeen.com/2020/11/12/mikhail-riches-city-of-york-housing-delivery-programme/

estimated spend would be £9,500 per house (E). There would also be a ban on gas boilers by the end of the 2020s and a rapid deployment of heat pumps of 1.2-1.4 million per year (E).

The UK government published an Energy White Paper[5] in December 2020 and also launched a Green Homes Grant Scheme at the end of August 2020[6]. Furthermore, the UK is holding the UN Climate Change Conference of the Parties - COP26 in Glasgow in November 2021[7]. However there is concern in some quarters about there being a lack of substance behind government announcements.

The Green Homes Grant for example has fallen way short on its ambitions, with the government now closing the scheme to new applicants a year early. The Environmental Audit Committee report on "Energy Efficiency of Existing Homes" outlines how damaging to the building industry this sudden change to the programme has been, and stresses the need for policies and funding to decarbonise homes, otherwise net zero emissions targets will fail to be met (EAC, 2021).

So what has gone wrong with the Green Homes Grant?

In one interview it was explained that there is a pattern with government putting out to tender and awarding to lowest cost bid instead of consulting industry and applying more thought. This has the knock-on effect of low skills employees working on that contract, creating problems in its delivery. In the case of the Green Homes Grant the contract was awarded to a company based in Virginia, US. It was understood from the experience of the interviewee's colleagues that works were being done to homes in good faith but when turning to the awarded company for the voucher reimbursement the quality checks were not appropriate to the job and the process involved answering "stupid questions" (E).

In another interview it was highlighted that building and insulation companies were having trouble registering for the scheme and getting the funds promised by the scheme leading to them to leave registering for the scheme (D). One contractor has so much work they don't feel the need to register for the scheme. One that did register, and has got work through the scheme, commented that it had not been what they expected (D).

The heat pump installer that was appointed by one interviewee was asked if he was in the Green Homes Grant scheme. He said no, he had enough work, and as he is the proprietor with limited support staff does not have the capacity to do the admin (J).

It should also be commented that, if going down the route of external wall insulation, to do this properly neds to be done in the drier months so it is particularly disappointing that the Green Homes Grant scheme is being pulled before the spring and summer months (G).

[5] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[6] https://www.gov.uk/guidance/apply-for-the-green-homes-grant-scheme
[7] https://ukcop26.org/

2.4 Recommendations

There were a number of recommendations that arose in the interviews around the governance theme as summarised below.

There is an overarching need for state coordination – that was considered as key (E). In order to incentivise home energy efficiency improvements there needs to be 3 core things:

- Grant funding for those on low incomes
- Low cost financing for rest
- Regulation on minimum energy efficiency standards

In designing new green deals or any other regulation and incentivisation there needs to be consideration of the length of time to train people (E, and F). Policies need to be long lasting – there is no point making grants available and taking them away again a few months later. The damage from the pulling of the Green Homes Grant has already been highlighted. It was further noted that the rotation of civil servants around government departments can be a problem as skills and understanding of the issues are not developed/actioned on.

One suggestion was to bring the meeting of standards (MCS, PAS2030 and PAS2035) back into building control in local councils rather than relying on self regulation (E). This would in turn, of course, require that local authorities are appropriately resourced (A, and E).

There needs to be a greater level of dialogue with industry to understand the scale of the issues to implement, including in particular how long it takes to train people up and how to attract people to the industry with perhaps a campaign with educational establishments (E).

3 Inequality

3.1 Overview

There are many ways in which decarbonisation of heating can lead to entrenchment of existing inequalities and lead to new levels of inequality. In an energy consumption context there is a focus on fuel poverty but there are many other aspects that need to be considered in addition:

- Social & council housing
- Privatisation of council housing
- Health
- Gender
- Risk of emerging

These aspects are covered in the sections that followed, beginning with fuel poverty itself.

3.2 Fuel Poverty

All those interviewed highlighted the importance of improving thermal conditions and efficiency for those that struggle to afford heating bills. In one interview it was highlighted that fuel poverty is just one issue and there were many other related and overlapping issues such as food poverty and transport poverty (H). While one can choose to put the heating on or to eat or even to travel, we cannot choose not to pay rent as there is a need for somewhere to live. This can leave any remaining budget with hard choices, especially when trying to meet the needs of children too (H). So while improving energy efficiency in homes is good, there are other issues that need to be considered too as this only addresses part of the problem (H).

The measurement itself has been under review in the past and whilst this changes the numbers that are counted as being in fuel poverty, this can obscure the need to tackling the issue and can make the problem to some extent disappear in some cases (if e.g. new metric means the numbers have halved) (H). The new measurement of Low Income, Low Energy Efficiency (LILEE) was felt to be an improvement as it addresses both the problems of income and the condition of homes (H). However, really, the numbers are pretty meaningless as generally those at the lower end of the income scale are going to struggle and be choosing not to heat or use gas for cooking because it is too expensive (H).

In a couple of the interviews there was discussion of the experience in councils. In Orkney for example there are high levels of fuel poverty and also a number of vacant properties. The council offers grants and help for those in fuel poverty to occupy and do up these homes (A). In Newcastle while there is concern about levels of those in fuel poverty (c.10%), there is also a concern that the pandemic could tip the next 10% in fuel poverty as well (I).

It was suggested that there should be a programme of efficiency improvements starting with the poorest and working upwards (H). It was further highlighted that energy companies need to have a better relationship with vulnerable customers (H).

With heat pumps best run continuously, and those who struggle to afford energy bills and control how much any energy consuming item is on or off, then there is a need to break practices and that is difficult because coping strategies have been developed over years (H).

3.3 Social, Council and Rented Housing

As mentioned above, all those interviewed said that those in social housing and/or fuel poverty need to be decarbonised first and this needs to happen in the early 2020s.

While it is generally understood that council and social housing can be in poor condition, what is often missed is those who owner-occupy privatised council housing (H). This type of housing will also be of poor quality and poor energy efficiency and with occupants little able to make improvements.

In a study contrasting trajectories in UK and Denmark, there was the right to buy council housing in the UK and around the same time Denmark passed a new law requiring landlords to use a percentage of rental income to invest back in the property in improvements – the result is now that Denmark's energy efficiency is twice as good as the UKs (H). The difference between the two countries was that UK saw housing as market based (i.e. privatisation) whereas in Denmark it was seen as infrastructure (H).

Housing in the rental market also tends to be poorly performing and in poor condition. Providing the right incentives is a challenge (A, E and H).

3.4 Health

Several of those interviewed highlighted that health is related to the condition of the home or building. This is largely driven by energy needs and can also be related to other issues such as fabric condition, whether relating to damp/mould.

Some research in Scotland has looked at the links between home heating performance and health impacts (C). "If you are living in a home that is poorly heated, or poorly ventilated you are more likely to succumb to health issues and that adds another burden of costs to public finance in terms of treating those conditions" (C). Hence it can be argued that improving the thermal conditions in homes is a public health cost saving (C).

One commented that where elderly population are struggling to heat homes, in some cases they have to spend time in hospital because their homes are cold and damp (F).
The pandemic has particularly posed challenges with the lockdown restrictions closing schools, and so those who would save on heating bills while children are at school are not able to do so or go to bed early to stay warm, with knock-on impacts on ability to do schoolwork (H).

Being vulnerable due to not being able to afford the right energy services can arise due to a variety of causes. Two examples are disability and single parent families – disabled households tend to be poorer than non-disabled households, and single parent families too are poorer than two parent families (H). The disability may mean that the person has additional needs; e.g. inactivity may mean a need for a higher level of thermal comfort, or needing more electricity to run nebulisers and so on (H). Single parent families can be vulnerable too, which can be seen as a gender issue since single parent families are usually mothers (H).

Raising energy efficiency standards is good but only solves part of the problem: "you could be in a A rated house, and you could still be cold" (H). It is the additional needs that need to be considered in the net zero emissions transition.

3.5 Other

There is inequality in capital availability to improve homes. For example, if spending a lot of money on heating this impacts on the ability to save up for spending on the home (B). In rented properties the tenant has no ability to change the way the house is heated. Council housing in Orkney, for example, have many on a system called Total Heat Total Control (THTC) where control of heating is with SSEN, not the home occupants (B). There are attempts underway to try and replace THTC with a fairer, more competitive system (B).

In owner-occupied homes there can be a limiting factor as to the value of a home – and this will depend on its location. If there has been an uplift in house value (and/or a rising market) the owner-occupier may be prepared to spend more on measures such as thermal efficiency than they would otherwise (D). The availability of low-cost financing and grants is also an issue (B and D).

While maybe not being "tech-savvy", those that struggle to afford energy bills are very economically savvy to a level of detail where they are able to say that a wash cycle costs £2.60 (H). For the pre-pay meter, on the one hand it is more expensive but on the other provides a massive amount of control over bills when every penny counts (H). Also, people like the fact that they are not having to speak with energy companies due to previous experiences of energy companies saying they have not paid enough (H). If all is smart enabled and managed, that loss of control would be a big deal (H).

Relational stories can be influential such as a story that a particular energy company was nice to a sister when they got in debt, or stories around technology and insulation as well (H).

Vulnerable households are often stigmatised particularly in this country, and there is a lack of "anti poverty activism"; e.g. in Spain there are movements to prevent people ever being cut off the gas or electricity grid (H).

The value proposition and need for easy/intuitive usage was noted; while it is much reported that people love their gas boilers, the thermostatic controls for gas boilers are terrible and very difficult to understand (E, and F). Tado and Nest are user-friendly devices that communicate with boiler and internet and have learning algorithms (E). The digital side is really important (A, B and E).

Orkney internet is patchy leading many in rural areas to rely on mobile signal and satellite internet (A, and B). All the equipment used in the Orkney projects – Heat Smart Orkney, Smile and Reflex – make use of internet connections and this, in cases, is an issue with some properties not having enough bandwidth (B). Occasionally have had to say if the connection of the equipment is affecting internet connection in the home, then need to disconnect equipment (B). In the Reflex project equipment was rolled out with backup sim devices (B).

4 Buildings

4.1 Energy Efficiency

Almost all interviewees commented on the problems with the method of assessing building energy efficiency through SAP or rdSAP models to produce Energy Performance Certificates (EPC). However, it was also acknowledged that as some sort of indicator as to energy efficiency in homes it was all there was (E, F – other?).

The housing market does not (currently) reflect the level of energy efficiency performance. While an EPC is needed in order to sell or rent a home, there have only recently been moves to enforce minimum requirements and, at the moment, only for landlords. For landlords both in England and in Scotland from April 2020 a new tenancy cannot be drawn if the property is assessed as EPC F or G. Following this there is some divergence between England and Scotland. From April 2021, new tenancy needs to be minimum EPC D and then from April 2025 minimum for all private tenancies in Scotland, whereas in England EPC C minimum applies for new tenancies from April 2025 and all tenancies from 2028. However, there is no requirements for an EPC minimum for owner occupiers or holiday/Airbnb lets – as pointed out previously, there appears to be lack of political appetite to do so (E).

Several of those interviewed felt that owner-occupied was the sector of the housing market that needs to have a minimum energy efficiency requirement as well (A, B, E). There is a concern that all it will do is that landlords will sell their worst performing stock (without improving it) (A). It was also pointed out that there are many landlords that are accidental or circumstantial landlords, rather than operating a business (A).

It was also mentioned that it is not the new builds that we should worry about but the great proportion of older housing stock whose thermal efficiency performance is “terrible”, not just from an energy consumption but also comfort viewpoint (F). There is more than half the housing sector with poor quality insulation and there needs to be something done about it (F). There may be a misconception as to the extent of improvements needed for suitability for a heat pump – an EPC D house, for example, may be able to run one (E). However, the better insulated means a less powerful heat pump can be installed and that may help to not create problems with local electricity grids. There needs to be a street by street, house by house appraisal as to what is available and what needs to be done (I).

The potential economic benefits to require owner-occupiers to improve the energy efficiency of their home when doing substantial other work is huge. However, there would need to be support – interest free loans, say, or reduced/zero VAT (see Skills below). While this might look like a tax revenue hit, it might actually bring more building jobs onto the books anyway so hard to untangle (E).

One interviewee pointed out that EPC measures energy efficiency on a cost basis rather than an environmental one which means it makes gas boilers look favourable (E). Also, because the emissions factors for electricity have not been updated for some time, EPC assessment makes electricity heating (space or water) look poor (J). The SAP model that EPCs used not only has out-of-date carbon figures in it but also some questionable building physics assumptions and very rigid behavioural assumptions.

However, when a survey is undertaken for a heat pump it is very specific to the fabric and size of the building (J).

In undertaking an assessment for an EPC, there is scope for a lot of interpretation by the assessor putting numbers in the software (G). Therefore, the EPC can vary from one assessor to the next (G, J) and if using the streamlined SAP model - rdSAP - it can change again (G). Discrepancies are an area of research and the results are being fed back to government (G). For example, in testing air tightness, in rdSAP you can only say you have done draught proofing, so essentially only the bristles round the windows and doors which is a poor representation of the extent of a retrofit (G). The software used for Passivhaus appraisal (PHPP) is more complex and more purely based on building physics, and there is a lower level standard EnerPHit (D).

With regards to technical standards, it is felt there is enough on that front; MCS, PAS2030, PAS2035 and what came out of the Bonfield Review (E). What is the issue is that there are not enough people being trained up to it (E).

4.2 Retrofit

One interviewee is part of a team undergoing testing of various retrofits; floor, windows, internal and external insulation and what happens at party walls in terraces etc (G). The research is about the building fabric rather than occupancy but this is simulated (G). The homes are being run through various types of measurement including SAP and rdSAP, and for air tightness using the new Pulse Test rather than Blower Door (G).

If you want to improve energy efficiency, it depends on (D and G):

- How much money available
- How much disruption prepared to live with
- How much funding from grants such as Green Homes Grant

Retrofit can be difficult when a mixture is involved (e.g. half suspended timber floor and half concrete floor (D and G)). A quick, easy, and affordable win is insulation in the roof (G). If you can get all walls to an even temperature you can feel more comfortable (D).

To improve a house to Passivhaus standard this usually attracts a certain sort of client (D). Cost is a big factor as there is only a finite budget; there is the value of the house and then how much someone is prepared to spend in excess of this (D). For older properties it is recommended to go for breathable fabric for insulation (e.g. a wood wool bat with lime finish), but most jobs use Kingspan insulation at the moment (D). Anything with an air gap behind will compromise the air tightness a bit (D).

Further, due to the horrific Grenfell disaster, Housing Associations are not wanting to insulate with anything that poses a fire risk (G). So even for external walls, this means looking at mineral wool or rock wool so that cladding is not flammable material (G and D).

One interviewee pointed out the lack of research into overheating and the SAP model does not handle this well (E). For example, if a building is south facing with lots of glazing and insulation there is a potential risk of overheating but one could adopt measures such as shutters/blinds (E). It was also noted that if you go for internal rather than external insulation this loses out the thermal mass from the brick (releasing stored heat back into the room) (E).

Not many can afford an architect to manage and check on the process (D). It can also be difficult to shift some builders to new ways of doing things (D).

There was a project on “Super Homes”, i.e. deep retrofit of 200-300 homes, that looked at user satisfaction and comfort. It is going to help inform Irish Government on deep renovation strategy (C). For a typical residential home renovation, this is looking at €30-40,000 for insulation, windows, ventilation system, solar PV, and a heat pump, but still a lot of money (C). Trying to scale up needs help with the financial costs – this is being looked at in Europe as renovation is seen as a stimulus to the economy (C).

5 Occupancy/demographics

A knowledge and understanding issue was raised when having undertaken a retrofit of a property (G). It is important that tenants/occupants know which walls they cannot hang their TV from or how best to attach any fixtures so as not to compromise the insulation (G). Ideally there should be an information pack on, for example, sale of property and new tenancy, such as what happens in office buildings - a guide produced on what you should/shouldn’t do (G and D).

There also needs to be accessible easy guides for low energy installations: what to do when such and such happens (G). To decarbonise heat there could be a range of new technologies installed in a building; heat pumps, storage batteries, mechanical ventilation and heat recovery systems.

In terms of updates to homes, what features highly in desirability is an open plan kitchen/diner/lounge with bi-fold doors, also with a wood burner with underfloor heating (D). It was noted that underfloor heating very difficult to get right due to time lag/response (D). In addition - lots of insulation plus a wood burner plus under floor heating makes for “a sauna!” (D)

In reflecting on own experiences it was observed that when just adults are in the home they were happy to have a wood burner on and not the heating and having cooler temperatures in bedrooms upstairs was fine (G). When they had a child that changed and had heating on for child sleeping upstairs – it was then too hot to then have wood burner on as well (G). Therefore, personal circumstances can lead to shifts in energy demand.

There can be a gender side to energy demand as females are generally colder than males and therefore have higher thermal need (G and D).

It was pointed out that there are lots of interesting research on adaptive user response. Just by giving people a choice or doing some suggestive things can make people feel more comfortable (D). For example, putting a temperature dial on a wall that doesn't work – just providing the person with the feeling that they have control can make them feel warmer (D). "Soft landings" is another building design approach – where getting people involved in the design and decisions on energy usage can mean willing to compromise (D).

For offices, and also applying to home working; if people are not comfortable they won't work and people will go to some lengths to get their own comfort (D). It was also mentioned that at home temperature is usually set to c.21°C whereas in offices it would typically be set to 18°C (D). With social distancing offices must feel very cold at the moment (G).
There is also an issue around types of homes and attracting types of residents and potentially their families. For example, in Orkney the population is ageing rapidly and there is a need to attract and retain a skilled workforce (A). These tend to rent and then buy but there are not enough homes (A).

In old buildings, habits may have been developed over long periods of time that need to be unlearned if switching from gas or oil heating to a heat pump. Common practices are only using the gas boiler when needing it, or heating a single room in a home (C). Heat pumps however are designed to keep the home at a comfortable temperature all the time and some people may find that change in behaviour difficult, and in some cases energy consumption may be a little higher – but it makes for a more comfortable home (C).

6 Energy system

6.1 Orkney

On Orkney there is no mains gas grid, oil heating is expensive, and the price of oil can be unstable. When replacing the oil-based heating with a heat pump, price parity was found at about 60p per litre for oil (B). It should be noted that Orkney, too, has the highest electricity prices when compared with mainland UK (B).

Following the Feed-in-Tariff incentives there has been the deployment of lots of small-scale wind turbines and also some solar PV (A). Other renewables include tidal and a bit of wave on Orkney (A). There is a surplus generation of renewable electricity and therefore it makes sense to harness for heating/EVs (A, B).

Note that in Orkney batteries would fill up very fast from surplus wind power but more slowly from surplus solar PV (A).

6.2 Hydrogen

Virtually all interviewees gave a mix of opinions on hydrogen; some with scepticism and some arguing a case for hydrogen, if not as a solution in particular locations.

Scepticism arguments:

- Efficiency of converting renewables to gas just not a good use of renewable electricity
- Blue – so natural gas with Carbon Capture and Storage (CCS) means adding a cost without revenue – if crack cost of heat pumps, this will become vanishingly unimportant

Another argued the case for hydrogen in terms of need for BioEnergy with CCS (BECCS):

- Start with needing to get to net zero
- This means significant BECCS deployment
- Most efficient is gasification of biomass that produces hydrogen

For hydrogen via electrolysis it is expected that the cost of electrolysers will drop substantially, though it was acknowledged it would need a lot of wind to produce this type of hydrogen (F). Then when looking at the state of the existing housing stock it "all adds up to the future looking pretty bright for hydrogen" (F). Producing hydrogen through gas reformation is viewed as a transition technology (F).

Reductions in heating demand, quality of housing and various ways to produce hydrogen mean there is a lot going for hydrogen. It is unlikely to see hydrogen for all transport, however most likely in rail and some HGV sectors. EVs are winning the race in the transport sector. A hydrogen car is £60k; then how to fuel it?

Note that BECCS can be fed by any type of organic matter, clean refuse or crops (F). If it is organic it can be gasified and can produce a number of different fuels including hydrogen, and including what could be used for planes (F). It should be further noted that there is a transportation issue for biomass this means that locations for the plant are more likely to be by coast or transport routes, but there are issues with the need for CO2 capture infrastructure with the interviewee wondering about a nationwide collection point (F).

There is a possibility that ferries on Orkney could be hydrogen (B). The existing fleet is very old fleet and currently runs on diesel. If they are replaced this would lock into the fuel choice for another 30+years. Project "High Seas 3" is considering hydrogen ferries with a local supply of hydrogen. A couple of Orkney islands are using electrolyser for hydrogen for local electricity demand due to grid limitations. EMEC (European Marine Energy Centre) has grand ambitions for hydrogen (B).

One interviewee commented on green hydrogen as being wasteful – they said that renewable energy is an important resource and it is more preferable to use a heat pump which is much more efficient (E).

6.3 Demand Side Response

In a project that looked at demand side management, such as control algorithms, there is a need to not create uncomfortable situations such as not heating water when needed (C). In another European project there were only small shifts in heating, and because heat pumps run better over long periods at a lower temperature, switching off for half an hour or so, people did not notice – heat pumps are designed to run continuously really (C). For heating water, as long as storage is present, it can shift the heating of the water quite a bit before people notice (C). Because heat pumps are designed to run continuously can shift space heating quite a lot (C). This can amount to a lot of shift when aggregated across all buildings (C).

Demand can only shift so much however, and so need storage solutions – there are arguments for hydrogen as storage and also there is battery storage (C).

6.4 Business Models & Tariffs

There are many parts of the system with electrified heating, transport, and storage and they all need to talk to each other (C). The business models of utilities and grid operators will be in competition as they all try to profit from the future electrified energy system (C). Existing market structures and business models need to be transformed for the adoption of electrified heating and transport (C). But this is starting to happen with, e.g., Octopus Agile Tariff which incentivises consumption off peak (C).

There might be resistance/wariness of sharing consumption data through installing a smart meter in the home and might end up paying for it somehow (C). It is the more hobbyists and tech savvy that are seeing most shifts in behaviour (C). But with some of the projects being worked on, there is no need to know about the heat pump; certainly no need to know what demand side response is as it is all managed through the connectivity (C).

Some cost-conscious consumers have run a heat pump with the Octopus Agile Tariff to maximise off-peak tariffs e.g. https://trystanlea.org.uk/ (C).

Diversity in time of use can be used to try and avoid the need for reinforcement of the grid (C). But if lots of people use at peak times then the peak price is going to go up rapidly (C). Towards the end of this decade expect, e.g., Agile Tariffs to be the norm (C).

Time of use charges and tariffs is a big threat to vulnerable households when time of energy consumption cannot be shifted due to particular needs (H).

Could do heat as a service model where finance comes up stream from the heat pump (B, E). The supplier of heat is the one that controls the heat pump and optimises for the grid. For example, if you want it to be, say, 21°C at 7pm then the heat pump is run efficiently to do that. This would necessitate the need for two meters in the home; one for electricity and one for the heat pump (so a separate bill for heat).

6.5 Electricity Grid

The low voltage electricity grid supplying homes was not designed to meet the electrification of all energy needs in the home (C) – it will be expected to supply electric vehicle charging and heating as well as the current main electricity usage. A responsive and interactive electricity grid is a big opportunity for intelligence and smart control (C).

While for most users there are no issues, internet use in homes can be variable, e.g. multiple members of the household watching different Netflix films, or how the router is setup, and this could affect connectivity to access "smart" features and agile tariffs or demand side response mechanisms (C). But can rely on the GSM network instead (C).

One project is installing a range of technologies but doing as much self-sufficient consumption as possible, with the grid as a last resort. So solar PV is used within the home and if it cannot all be used then sold to a neighbour. If there is still some left, it goes to a (EV) car club and then a local battery storage facility (and if full only then back to the grid) (I). This project looks at the flows between the grid and a community neighbourhood energy model – if there is mass uptake of EVs and electric heating in the scenario modelling "the grid buckles very quickly" and so the project is trying to look at ways to avoid that (I). Also, there is the value aspect that any generation is retained and used within the community (J).

There is a massive disparity between what is paid for electricity from the grid and what a household can get if sold back to the grid (I). Might be able to sell electricity to a neighbour for somewhere in between – benefits both sides – and also retains the money within the community as well (I). It is thought this will also help with fuel poverty (I).

There is variation in the grid in terms what average maximum can be drawn off the grid at any point but because of deindustrialisation there is capacity on the high voltage grid (J).

It is difficult for DNOs to make anticipatory investment so in advance of need due to regulations (J). But, then again, do need to draw up plans for a number of years ahead so this creates a "tension" (J). At the moment looking at what the take-up of EVs or heat pumps is expected to be, and then what we as a DNO need to do and draw up an investment plan of what, when and where that depends on (e.g. where expected "hot spots" of activity are) (J).

If people run heat pumps and plug in EVs in a very unconstrained way, then we end up with very big peaks in demand requiring a much bigger grid and therefore much bigger generation capacity (J). Running heat pump at lower temperatures for longer and flexing when charging the EVs can supress that peak and therefore the level of investment required in the grid is less (J).

6.6 Heat Pumps

Not running the heat pump continuously and more on demand like a gas boiler is not good for a heat pump as it will need to cycle harder (C) . The greater the difference between the ambient temperature and the temperature wanted, the harder the heat pump will have to work and more energy it will consume (C). An analogy is driving a car if doing lots of speeding up and slowing down rather than at a constant speed going to consume more fuel (C).

It was commented that there are some "myths" around heat pumps (E): There is no need to do extensive insulation for a successful heat pump installation, and a possible rule of thumb is that a minimum of EPC D rating is fine. Further, the home does not need to be an air tight Passivhaus either. However, there is a need to consider a range of factors in the building such as the physics and the temperature differential between inside and outside plus the combination of size of radiators and required temperature to determine how hard the pump will have to work.

The acceptability of noise from a heat pump (50-60dB if all running) depends on where you are living - if in the country, don't want the noise of a heat pump (F). In some projects there have been concerns about noise of heat pumps running overnight. Some have suggested it depends where it is located, though newer models are much quieter: "you barely hear them running" (C). This is to comply with strict German noise regulations (C).
Network reinforcement may be required depending on the size of the heat pump install. In a study by Imperial College based on an average size heat pump of 8.5kW for a reasonably insulated house [note that in the Orkney case it was 3-6kW heat pumps], it was found that if you can go instead with a 5kW hybrid heating system, you can avoid needing to reinforce the grid (F). However, a hybrid heating system would use gas: but what if gas is banned and what about when hydrogen might be available instead? (F) The interviewee could not see why you would not just go for a heat pump rather than a hybrid but pointed to the need to do reasonable size trials to find out (F).

One international heat pump manufacturer is considering air-to-water heat pumps as being applicable to the UK due to the majority of homes having a radiator system (C). While in some cases air-to-air heat pumps may be preferable, if deploying an air-to-water along with underfloor heating you can obtain the required thermal comfort levels (C). Need the underfloor heating to increase the area since a gas or oil boiler will be supplying to radiators at, say, 55°C temperature, heat pumps will be supplying at a lower temperature of 35-40°C (C).

Expectation that heat pump installations will increase dramatically, going from 20-30,000 per year to 600,000 per year by 2028 (a 20 fold increase). There are already a lot of market incentives in place and the installation of gas and oil boiler banned in new builds from 2025 (C). However, scaling to the level required is going to be a challenge not only in terms of insulation but also installation (C).

We are going to see the development of a range of different heat pumps to suit different circumstances (C). In Mitsubishi alone there used to be just a couple of models now there are seven different ones for homes (C). There is the option of hybrid heat pumps, but there are question marks over whether that would be a good solution and it depends on the extent of the retrofit (C).

On discussing the size of heat pump with the degree of energy efficiency in the home, a 4kW heat pump may be sufficient for an A rated modern home. For an old solid wall home, there is a need to make sure windows and doors are as air tight as possible, and would need a bigger heat pump to compensate for the loss through the walls (maybe a 8kW or 11kW heat pump depending on size of the house) (C).

Heat pumps that have smart controllers that take price information are available on the market now (J).

For a project installing 250 heat pumps in Newcastle, 200 of these are owner-occupiers, 50 to social (I). 1800 applicants took part in the project and this was whittled down to 250 following technical surveys (I). Experience in the technical survey stage: one had a passageway 0.5m too narrow for air to flow properly, another found his 60 amp supply would be insufficient for a heat pump (when already having an EV and electric cooking present would cost £2,500) (I). Will need to do a "lessons learned" at end of the project as to reasons why applicants didn't proceed to install as this will indicate feasibility at scale (I). One that applied decided not to go ahead with the fear would annoy the neighbours (J). Noise reduction boxes for heat pumps cost £3,000 which seems extortionate (J).

Looking at the possibility of some land being used as shared ground arrays for ground source heat pumps (I).

6.7 Using a Heat Pump

The coefficient of performance (ratio of unit electricity consumed to units of heat generated) can vary depending on temperature required, difference with the ambient temperature, and whether running all the time or in stop/start mode. It should be possible in the majority of cases to achieve a COP of about 3 but some can be much higher and some lower.

In selecting a heat pump an interviewee went with one that heated water to 45°C but was also offered ones that heated to 50 or 55°C, but these higher temperature ones had a poorer coefficient of performance (J).

Ground source heat pump is probably more efficient through winter but is more expensive to install and needs to have sufficient land area to install it – horizontal need 3x footprint of house (J) and vertical needs to be 3m from boundary (author).

If a heat pump is not installed and maintained correctly could be more rattly and noisy (J).

Some have fiddled with the controls of a heat pump and ended up with a huge electricity bill from “mismanaging the system” (I).

Two schools of thought are apparent on this (E). Either;

1. Run having thermal storage for both heating and water and run heat pump for a shorter period of time, charge like a Sunamp battery when power is cheapest, and use in bursts morning and evening
2. Run all the time: this is less capital intensive as no need for a thermal store, but have radiators on all the time and the temperature in the house doesn’t dip below, say, 18°C. That way might turn off 5-8pm in the evening as already got all the residual heat in the house when power more expensive. This seems to be how most people are operating them.

6.8 Orkney Experience

The information here is based on the interview with B.

In Orkney there have been a number of projects; Heat Smart Orkney / Smile and Reflex projects. In one, 65 homes were offered to take part in a pilot project which involved replacing their oil heating with a combination of heat pump and thermal store system. This has been running for a little while and the most immediate reactions from those taking part was to try and understand the much higher electricity bill. For these users, consumption costs in the oil-based system was hard to determine because oil is delivered three times a year. Therefore, had to make some assumptions as to consumption rate to compare costs. For electricity, however, data on consumption is collected at least minutely. Overall, think that there is price parity between oil-based heating and the heat pump system but still investigating.

In this project it should be noted that they chose to install the higher temperature heat pumps and these do consume more electricity. The reason for this was that they wanted to be able to respond more quickly if there is an abundance of wind and therefore potential curtailment of wind power – note that this may only last a short time (say a couple of minutes). Another reason given was that a high temperature heat pump would be more easily comparable to an oil heating system that is being replaced. Further investigation is needed to determine whether these homes could have had a lower temperature heat pump system installed.

For the management of the systems installed, part of the agreement was that those running the project would manage the heat pumps for the homeowners, and this would be handed over to homeowners at the end of the project if they decide to keep the system. In this project the contractors for install were RS Merriman which began in spring 2019. It is very difficult to get a local contractor on Orkney.

In the project there were four different configurations:

1. Replace hot water cylinder with Sunamp batteries charged electronically by an existing boiler or modern pellet boiler
2. Heat pump and heat batteries – in some properties there were five batteries installed to do heating and hot water, and in some homes the batteries installed just do water heating
3. Heat pump and hot water cylinder – this install is closest to a conventional set up
4. Heat pump and hot water cylinder with a lithium-ion battery that can independently charge during the curtailment period and monitor what the heat pump is doing and also discharge (to the grid) at the time heat pump using electricity (so like a net zero electricity draw)

It should be noted that there was no budget for any retrofit work. The only insulation that was undertaken was for the pipework that was installed. The energy efficiency performance of the homes in the trial was about an EPC C rating but there was not a recent EPC for all the homes available. The experience in doing the install was that each house had "unique problems" or issues to resolve. They were all detached homes except for a pair of semidetached (neighbours), and all the homes were in rural locations.

Most of the occupants were families and it was observed that there was some correlation between type of household and the building suitable for the heat pump installation. It was homes that were already well insulated that were most suitable and these tend to be occupied by families or those that are more well off, and those that are more climate change aware. There was no single person dwelling included in the trial.

It is expected that most of the homes will decide to keep the system at the end of the trial. This is mainly due to the physical burdens of filling up oil tanks for the oil-based heating system. Much more convenient to be able to control heating with simply a switch in, say, the kitchen.

In terms of the configuration of the systems, they might want to reduce some of the complexity for homeowners at end of the project. For example, there could be an improvement in energy storage between heat pump and radiators, since this does add more control loops and this means there are more losses as a result. One finding is that consumers do "love the idea of being able to offset energy used at peak time with an off peak tariff".

In terms of behaviour in using the system, depending on use, the heat pump can be cycling quite a lot and need to look at stopping the ramp up and ramp down. One curious observation was that even with one well insulated house, which was open plan, really high levels of energy use was recorded. This level of use was comparable to another property that has old stone walls and flagstone floor with underfloor heating. The findings are that there is a large range of daily energy consumption for the heat pumps installed.

There is the possibility that some may be using more heating because it is renewable but this needs more investigation. Also, one particular home that was previously a resistance electric heating system are now achieving a heating ratio of 3:1 and are very pleased with that.

The installation configuration with five Sunamp batteries has not been well received. Those that have the hot water cylinder are happier – this is simpler and easier. On reflection, this may have worked better with just one battery.

In terms of challenges to do with location, one of the island's properties are also off mains water as well and these homes have to use private bore holes for their water. This water is very hard water which has the potential to destroy immersion elements in a very short space of time, possibly within a month. Also, some properties right on the fringes of National Grid, when have taken oil heating system out and replaced with a 10kW heat pump, there has to be some electricity network upgrades to enable that system to work.

The need for electricity upgrades was also discussed. For car charging the standard is 7.2kW at peak and then depending on the heat pumps in this project they were in the range 3.5-6kW. Therefore, if both are running at the same time there could be a need to upgrade the grid. This can be negated to some degree with smart technology.

On Orkney generally there are around 10-20% currently using heat pumps. Note that heat pumps are not suitable for installation in flats. In cities with limited outside space – i.e. no garage/driveway and so park wherever there is a space available - there can be problems in charging for EVs. It will be interesting what might happen to house prices.

Note that in new builds that are small in Orkney (1-2 bed) there is a move away from installing heat pumps. What is being installed instead are well-built and air-tight build and extremely good insulation with mechanical ventilation and heat recovery, with a panel heater and solar PV. This is seen as a better option due to being easier to use and also for ease of ongoing repair and maintenance.

6.9 Existing combi boilers?

Everyone who currently has a combi will need a new store or mechanism for water heating as there is no way for instantaneous heat in the same way (E). The options could be heat batteries (like the Sunamp batteries in the Orkney project) or through putting water tanks back in homes (E). In terms of logistics and space, note that the heat pump will need to be located outside and so in place of current location of a gas boiler a Sunamp could go on wall. The size of a Sunamp is the size of a small fridge and costs c.£2.5k (E).

6.10 Capital Costs

Gas boilers has are very complex but make so many of them that is why they are so cheap. Heat pumps need to stop costing £10-15k (E).

Noise dampening covers for heat pumps are very expensive as well – one estimate £3,000 (J).

6.11 Climate Change

One interviewee thinks that reductions in domestic space heating as a result of warming have been underestimated (F). With improvements in EPC towards C and 2 degrees warming this leads to 33% reduction in heating demand by 2050 (F).

7 Practical obstacles to decarbonisation of heat

7.1 Skills

Orkney has a shortage of heating engineers – really struggling for PAS2035 accredited insulation installers in Orkney (A).

A couple of interviewees pointed out too that external wall insulation is good but only if it is installed right (A, G).

There are massive opportunities for the building industry if incentivise – if builder doing work on home can do improvement measures and will be zero VAT (or whatever incentive) which would also bring jobs onto the books as well (E).

Reinforcing the network (which distribution engineers had not done before) is a mammoth task: converting 20k per week to 2050 is a massive undertaking (F). Not enough being done because we don't know what we need to do; while government made a clear commitment to EVs not made such a commitment with heating homes (F).

Note that decision-makers tend to be plumbers – when gas boiler breaks down should be looking at replacement but then usually at a time need heating so quickest and easiest is a new boiler - plumbers need training up (F).

Training the workforce – Takes 5 years to train someone to do a degree and train, and potentially another 5-6 years after that depending on the skill level. So don't have much time (F).

Mitsubishi have at least 7 training centres across the UK "training hundreds of people every week to convert from oil and gas installers to heat pump installers" (C). But if going to get up to 600,000 per year installs need to train a lot more people for the installation and service personnel as well (C).

The "stop/start nature of programmes like the Green Homes Grant doesn't create an environment in which any organisation can look to build the skills capacity" (J).

Undertaking building work and installing a heat pump was complicated and described as like a "rubiks cube" – for the heat pump needed a specialist contractor as builders and electricians do not understand the technology (J).

7.2 The route to decarbonisation

In one interview there was the following proposed (E).

1. Hard targets are needed:
   Early 2020s: Social housing first – it is the easiest to do
   Mid 2020s: Private rented market (which are being done and seems to be at right speed)
   Late 2020s: Owner-occupiers cannot sell house unless minimum efficiency standard and cannot sell house if below a performance level
2. Funding
   30-40% of this has to come from government – nonrepayable grants – like infrastructure expenditure
3. Governance/delivery
   Local authority resource – staffing. Find all those ways into people – community networks, churches and mosques etc. – flag up regulation is coming and can do such and such….

   Really need people adopting low carbon heat as soon as possible (E). Could do what get away with – loft and windows but we cannot keep burning gas (E).

   Need reasonable sized pilot trials that involve thousands of homes so can start to take these big decisions (E, F). Last thing we want to do is commit to a type of heating tech and find that makes people uncomfortable - heat and comfort make a big difference (F).

   In another interview the following was outlined (F):
   In this decade, i.e. 2020s: There needs to be a reasonable size scale of deployment – it

was acknowledged that this would be tough to do within 10 years (as many points made above confirm) but this is necessary. Reason being is that it will indicate what technological solutions will help the transition. Also, what is needed this decade is a programme of training the required workforce.
In the 2030s: This should be about rolling out and needs to be of reasonable size. Need to be "pretty busy towards end of 2030s".
In the 2040s: In order to be on track for reaching net zero emissions target at 2050 there needs to be a "peak" of activity at 2040. This interviewee also stressed the need to avoid doing the wrong things and there was a concern expressed that we may rush to put things in just to hit the 2050 target; the implication being we would suffer the results of this later.

What is key is what happens with building insulation improvements and when they are installed – e.g. double glazing for windows has improved a lot over the last 20 years (F). There appears to be a need for a minimum energy efficiency requirement for homes and leaving this to the market will only have a limited effect (F). A ban on gas boilers may help with decarbonising heat but there will be a lot of costs associated with such a ban (F).

A further note is that people are unable to determine differences in what has generated heat "so it does not matter if it came from heat pump or hydrogen or something else" (F). At the moment people are mostly used to gas boilers and little experience of anything else (F).

8 Issues for energy modelling – a summary

Based on the collected material from the above interviews, Table 2 aims to categorise these in a useful way for modellers. Whilst this collation is partly subjective, it aims to highlight factors where energy models could currently be described as being effective, those where improvements are necessary (or, at least, possible), and those factors that generally exist outside energy models (and should not be targeted for model improvements).

Table 2. Summary of key issues from interviewees

Theme	Factors well represented	Factors poorly represented	Factors outside energy modelling scope
Governance	• Linkage to formal climate targets • Reflecting policy that is directly concerned with EPC ratings • Large-scale trends in technology shifting	• Impact of different funding streams on technology take-up over time • Importance of local aesthetic and effect on decisions for deep retrofit • Influence of local planning regulations on community-specific energy models • "Solving" competing visions of decarbonised heat (e.g. Hydrogen vs Heat pumps)	• Devolution of decision-making between Government and Councils • Promotion of energy efficiency schemes • Communication with contractors • Scale of available funding for consumers to adopt technologies
Inequality	• Linkage to formal fuel poverty metrics	• Effect of local planning strategies and regulations on tackling fuel poverty • Targeting fuel poor households • Reflecting heating requirements of vulnerable households (elderly/disabled/single-parent families) • Impact of capital availability on the uptake of energy efficiency measures	• Impact of house condition/heating & ventilation practices on occupants' health • Assessing public acceptability of new heating technologies
Buildings	• Assessing energy efficiency performance of the existing stock • Reflecting cost and environmental benefit of new technologies	• Impact of housing market regulations and property value on the uptake of energy efficiency improvements • Impact of tenure on retrofit decisions • Impact of house condition on heat pump's applicability/effectiveness (need for retrofit in order to install heat pumps)	• Roll-out of incentives for owner-occupiers to improve energy efficiency • Scale of available funding for home-owners to implement deep retrofit solutions • Effect of discrepancies on EPC assessments

Occupancy		• Accounting for adaptive thermal response due to occupants' age or gender • Shifting common heating habits and behaviours to adopt new technologies • Impact of retrofit measures on overheating	• Impact of occupants' disruption due to retrofits
Energy system	• Contribution of heat pumps to demand-side response • Impact of coupling heat pumps with thermal/battery storage on load-shifting potential • Solutions for creating a flexible electricity grid • Impact of different technological solutions on transition scenarios	• Addressing issues around the best use of renewables (e.g. produce hydrogen vs run heat pumps) • Household suitability to adopt time-of-use tariffs • Interaction of consumers with time-of-use tariffs and acceptability of smart home heating controls • Impact of heat pump size selection on the electricity grid • Influence of capital cost on the large-scale adoption of heat pumps • Impact of climate change projections on space-heating demand • reduction	• Impact of internet quality on accessing smart features (tariffs, DSM mechanisms) • Impact of regulations on DNOs' investment plans • Addressing concerns related to increased noise from heat pumps • Establishment of regulations to stimulate the roll-out of low carbon heating (e.g. ban boilers)
Practical obstacles		• Influence of central and local government planning on the route to decarbonisation • Informing policy on how to prioritise retrofit actions and plan technology roll-out over the next 10,20 and 30 years	• Scale of available funding from government to achieve decarbonisation targets • Impact of current business skills on the quality and roll-out of low-carbon technologies/retrofit measures • Impact of grants' uncertainty on the willingness of companies to create a skilled workforce

9 Projects & Programmes

This is a list of some of the research projects and governmental programmes interviewees referred to:

Scottish Government. Home and Fuel Poverty: Energy Saving Home Improvements: https://www.gov.scot/policies/home-energy-and-fuel-poverty/energy-saving-home-improvements/

UK Government. Green Homes Grant: make energy improvements to your home. https://www.gov.uk/guidance/apply-for-the-green-homes-grant-scheme

Orkney SMILE https://www.h2020smile.eu/the-islands/the-orkneys-united-kingdom/

Orkney ReFLEX https://www.reflexorkney.co.uk/

Heat Smart Orkney https://www.communityenergyscotland.org.uk/projects-innovations/heat-smart-orkney/

UKERC "Going Dutch" - taking Gröningen off the gas grid. Dr Matt Lockwood and Dr Richard Lowes: https://ukerc.ac.uk/project/going-dutch/

UKERC "Whole Person, Whole Place" Dr Stephen Hall. [No web presence found]

Newcastle CC – Electrification of Heat
https://www.newcastle.gov.uk/heatpumps
https://www.gov.uk/government/publications/electrification-of-heat-demonstration-project-successful-bids/electrification-of-heat-demonstration-project-winning-bids

Leeds Beckett University / Leeds Sustainability Institute – Retrofit Performance Evaluation
https://www.leedsbeckett.ac.uk/research/leeds-sustainability-institute/retrofit-performance-evaluation/