Part 1. A qualitative evaluation of Thirteen resident perspectives on low-carbon technologies in the home

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Introduction – domestic decarbonisation as a sociotechnical challenge

Space and domestic hot water (DHW) heating account for around 80% of the energy consumption of households in cold-climate regions (such as those in Northern Europe) [1], yet pathways to residential "net zero" remain challenging due to a range of technological, economic, and socio-cultural factors. In the UK, former Prime Minister Boris Johnsons 10-point plan for green industrial revolution to "build back better and build back greener", provided a broader policy framework to improve residential, retail, and industrial building fabric efficiency through insulation and other energy efficiency measures, making changes to the technologies used for both space heating and cooling within buildings and improving the energy efficiency and performance of domestic energy services. Residential building decarbonisation was thus promised to [2]:

> "…help the economy grow, create new green jobs, and deliver greener, smarter, healthier homes and workplaces with lower bills. Delivering energy performance improvements and low-carbon heating systems will create new jobs in all parts of the UK – offering enormous potential to support our 'levelling up' agenda."

Achieving housing sector decarbonisation is made possible through improvements to the efficiency of domestic buildings, changes to UK low-carbon technology supply chains, an array of alternative low-carbon heating technology options for domestic users in both new build and 'retrofitted' properties, and changes to facilitate pro-environmental social practices of energy use in the home. In essence, action is needed across multiple pathways to residential decarbonisation [3] involving a combination of: *energy infrastructure connections* (e.g., centralised, off-grid, feed-in-tariffs); *renewable energy sources* (solar photovoltaics [PV], micro-wind, heat pumps); and *energy-efficiency measures* (including what is often referred to as a 'fabric-first' approach i.e., insulation; changes to building standards, materials efficiency, smart metering, and appliance ratings, and crucially: transformation of domestic energy-saving behaviours) [4, 5].

At the household level, different factors influence the uptake of new low-carbon electricity and space heating technologies (such as solar panels, air, and ground source heat pumps) and fabric changes (such as external cladding to provide insulation). These factors concern: consumer choice, specifically around technology availability for space heating; cycles of innovation (such as the rapid obsolescence of recent to the market technologies); the affordability of new heating technologies; the human resources necessary for manufacture, installation, modelling, project management, maintenance and repair of novel technology solutions; and the social behaviours, habits and practices associated with energy services (e.g. washing, cooking, and entertainment) [5-8]. Understanding the complexity of domestic low-carbon transitions is important if the roll-out of energy efficiency measures is to be successful [9]. Residential decarbonisation plans must be suitable for different housing types, markets, domestic living patterns and social values related to entertainment, cooking, washing, travelling and thermal comfort [10]. This relative complexity of both technological and human factors together, makes the pre-defined selection of the 'best' configuration of technology options difficult to predefine in regional energy policy. However, the range of domestic

net zero transition pathways through a combination of these elements also allows a degree of design flexibility: allowing choice of technology to be adaptive to local climate conditions, costs considerations, energy resource availability, infrastructure, and social and governance conditions (including building regulations, tariffs, and social factors) [11, 12]. Within this, the resident user of low-carbon technologies is a key stakeholder, and so engaging with resident perspectives on decarbonisation pathways is an essential component of the net zero challenge [13].

Case study details

This study concerns a key group within the broader pattern of residential decarbonisation – namely residents of the *social housing sector* (hereafter SHS). Social housing organisations (hereafter SHOs) across the country are, in many respects, leaders in domestic energy efficient retrofit of existing housing stock, in part due to their coordinated capacity to build and retrofit at scale [9, 14]. However, despite this specific funding aimed at the sector for net zero innovation, policy guidance on social housing responsibility for net zero is currently unclear in many areas, and there is a need for a more defined pathway to decarbonisation [15]. Importantly, social housing tenants make up about 18% of the UK's population and are characterised by a lower-than-average-income, relative economic inactivity, higher-than-average prevalence of fuel poverty [16], and as such, represent a vulnerable population whose perspective is often overlooked within energy-related behaviour change research [17, 18]. Researching the experiences and needs of residents in this sector is of critical importance at a time when concerted action from national-to-local scales on residential decarbonisation meets the challenges of a cost-of-living crisis exacerbated by the re-opening of the global economy after the Covid-19 pandemic, and fuel cost increases due to war in Ukraine and resultant economic sanctions across Europe and the United States against Russia.

This qualitative case study was co-produced with the Social Housing Organisation (SHO) Thirteen Group (hereafter Thirteen) in the northeast of England. Thirteen manage over 35,000 homes, with more than 72,000 customers from North Tyneside to Yorkshire. Most homes are managed within the Tees Valley sub-region [19]. The Tees Valley, situated in the North-East of England and incorporating parts of historic County Durham and the North Riding of Yorkshire, has long been at the centre of "carboniferous capitalism" [20]. Since the 1970s, waning steel employment became emblematic of the sub-region's steep decline in manufacturing jobs including in the previously expanding chemical industry [21, 22]. This has left the sub-region with a legacy of protracted socio-economic deprivation, especially concentrated in Middlesbrough. The 2019 English Indices of multiple deprivation demonstrate that the local authority is, on many measures, the most deprived in England [23]. Economically, Tees Valley firms remain competitive in advanced manufacturing and the chemical and process industries although these sectors are now characterised by high levels of foreign ownership which presents opportunities (the ability to import managerial and technical best practice) as well as challenges (local capacity to influence investment decisions and the development of a 'branch plant' economy). In 2016, the area formed a "combined authority" (Tees Valley Combined Authority, hereafter TVCA) which holds selected powers and responsibilities over economic development and transport in the sub-region. The TVCA Local Industrial Strategy set out plans to support clean energy, low-carbon innovation (specifically offshore wind energy, carbon capture and storage and hydrogen) as areas of growing output and employment. Action on domestic

low-carbon transition therefore takes place within this broader socio-political landscape of net zero investment.

In terms of housing, Tees Valley private and rental markets are characterised by low densities and a dispersed spatial structure. The legacy of heavy industry means that development land has significant constraints and viability challenges, with distinct gaps between high price and low price areas; and core urban communities suffering from often poor quality housing stock and housing market underperformance relative to national and regional benchmarks [24]. Thirteen as a major social housing provider is notable in its development of a coordinated strategy for housing stock regeneration, including an embedded decarbonisation and domestic net zero emissions plan. At the time of writing Thirteen is embarking upon a scheme of upgrades to around 2,500 of its properties as part of a longer-term £230m retrofit programme [25]. This approach involves an energy transition to low-carbon domestic technologies, with the installation of insulation, solar panels, air source heat pumps and battery energy storage systems. A key challenge for SHOs like Thirteen is understanding how to engage residents to become active stakeholders in energy transitions that affect their homes and personal wellbeing [26], such that energy and carbon reduction performance can be maximised through user social practices in the home. This study explores through qualitative interviews with residents of the Thirteen SHO, the assemblages of decarbonisation currently happening (or about to happen) within this critical case study in the SHO sector.

Methods

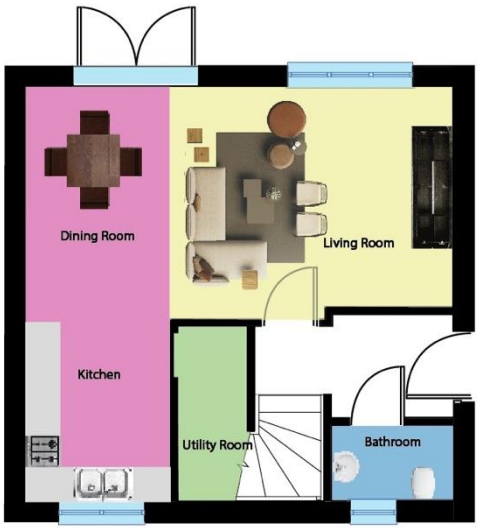
Twenty participants were recruited voluntarily by the SHO's tenant list and through social media posts on the SHO's website. The twenty SH resident participants were recruited (see Table 1): 10 men and 9 women with an age range from 26-75. There was no demographic information available for one participant. All residents lived in the Tees Valley. No incentives were offered to participate. Semi-structured interviews were conducted through a mix of small-group and individual face-to-face or online interviews based upon participants' access needs and challenges related to Covid-19 meeting restrictions. Interview questions followed a semi-structured approach (see Table 2). Before commencing the interview, participants listened to a short introduction by one of the authors on UK Climate Change goals, low-carbon homes, and a short video of a model retrofit home as well as plans and photographs (see Figure 1) with an explanatory live commentary, that demonstrated how a low-carbon technology home would look. The walkthrough video was created by researchers in Teesside University's School of Computing, Engineering and Digital Technology using Autodesk REVIT, 3D modelling software. One of the authors provided live narration to the walkthrough and still images of a low-carbon home and narration. The video was supplemented (from feedback after the first group interview) with a short testimonial from a tenant with low-carbon technology already installed. These two elements serve as an interview *elicitation device* [27] to stimulate participant imagination in visualising and contextualising the domestic low-carbon technology in their own home, making it easier for residents to engage with the technology and provide feedback to researchers.

Table 1. Participants in the interview study.

Participant ID	Age	Gender	House type	No. of bedroom
F1	49	Female	Semi	3
F2	38	Female	Semi	2
F3	64	Male	Flat	1
F4	73	Male	Flat	1
F5	68	Female	Bungalow	2
F6	Not supplied	Not supplied	Not supplied	Not supplied
P1	71	Male	Mid-Terrace	3
P2	74	Male	Flat	2
P3	51	Female	Mid-Terrace	2
P4	31	Male	Flat	2
P5	75	Male	Flat	1
P6	40	Male	Flat	1
P7	26	Female	Mid-Terrace	3
P8	71	Male	Flat	1
P9	73	Female	Flat	2
P10	59	Female	Flat	-
P11	63	Male	Bungalow	2
P12	53	Female	Bungalow	1
P13	40	Female	Flat	2
P14	56	Male	Flat	1

Notes. F: focus group/group interview participant. P: individual-interview participant.

Figure 1. 3D models and plans of the low-carbon home.



Semi-structured questions with open answers (see Table 2), based on the Theory of Planned Behaviour, were used to encourage discussion of ideas. In the Theory of Planned Behaviour (hereafter TPB) approach, the intention within this research was to identify knowledge, skills, attitudes, drivers and barriers towards technology for low-carbon transition within the home. The TPB outlines that human behaviour is guided by three kinds of considerations termed: *behavioural* beliefs, *normative* beliefs, and *control* beliefs. Behavioural beliefs are about likely consequences and experiences, normative beliefs are about ethical and culturally appropriate expectations and the behaviour of significant others, and control beliefs are about factors that may

facilitate or impede action. Together, these beliefs produce a favourable or unfavourable attitude towards the behaviour [28]. This framework was translated into the interview questions outlined in the interview guide shown in Table 2.

Table 2. Interview questions guided by Theory of Planned Behaviour (TPB).

TPB belief		Questions
Behavioural Beliefs	Advantages	• What do you see as the advantages of you living in and using a low-carbon technology home? • What positive feelings do you associate with you living in and using a low-carbon technology home?
	Disadvantages	• What do you see as the disadvantages of you living in and using a low-carbon technology home? • What negative feelings do you associate with you living in and using a low-carbon technology home?
Normative Beliefs	Approval Adopters	• Please tell me about the individuals or groups who would approve or think you should live in and use a low-carbon technology home. • Please tell me about the individuals or groups who are most likely to live in and use a low-carbon technology home.
	Disapproval Non-adopters	• Please tell me about the individuals or groups who would disapprove or think you should not live in and use a low-carbon technology home. • Please tell me about the individuals or groups who are least likely to live in and use a low-carbon technology home.
Control Beliefs	Drivers Barriers	• Please tell me about any factors or circumstances that would make it easy or enable you to live in and use a low-carbon technology home. • Please tell me about any factors or circumstances that would make it difficult or prevent you from living in and using a low-carbon technology home.

The TPB is appropriate to use in this research as it accounts for beliefs that guide human behaviour (behavioural beliefs, normative beliefs and control beliefs) and has been used to qualitatively understand and quantitatively predict people's use of new energy technologies [29, 30]. We adopt this approach to frame the data collection and analysis. A group interview approach was used in the first phase to ensure the questions were understood and the other tools used, i.e., video, were effective for purpose. As the interview guide/questions are the main tool for providing consistency in the generation of qualitative data and, consequently, the conclusion of the research, this group interview was carried out as a pre-cursor to individual interviews.

Group interviews: The benefits of conducting a group interview are to create opportunities for participants to discuss normative assumptions that are typically unarticulated, thus providing insight into complex motivations and behaviours [31]. As the Interview guide or questions are the main tool for providing consistency in the generation of qualitative data and, consequently, the conclusions of the research [32], this focus group interview was carried out to: identify flaws; clarify/modify

questions; try out video use and interview recording; determine the usefulness of the data collection; inform the content of participants' answers/data; confirm participants' understanding of concepts and terminology.

Individual interviews: The procedure was adapted from the group interview. The participants were shown the pre-recorded presentation, including the content of both group interview presentations; then followed a short testimonial, from a tenant with low-carbon technology already installed. (The decision to include this testimonial was made following the results from the group interview where 'lived experience' of tenants currently using low-carbon technology was a high priority for potential acceptance). The interview questions (Table 2) were then asked.

Interviews were conducted and transcribed verbatim by five researchers. In order to avoid preconceptions and bias, three researchers analysed the data from the interviews, checking results against one another to come to a final agreement; this increased the credibility and trustworthiness of the results.

Findings

Thematic analysis was applied to the data sets and deductive coding began with the theory of planned behaviour belief questions on low-carbon homes to identify the broad, overarching emergent themes. Iterative coding included searching the data for relationships, similarities and differences and beginning to organise these into themes. Within the coding and themes, comparisons, frequency and elaborations were considered for determinants of behaviour and specific emerging themes [33]. The three researchers compared and reached a consensus on the codes and themes included in the results, and another researcher checked these for clarity. We present analysis of group and individual interviews separately for clarity below.

Group interview results (6 participants)

Four themes, mentioned in the group interview, which did not appear in the individual interviews include the following.

Control Beliefs

Energy/running costs

The question of running costs emerged as one of the top priorities for participants. This appeared to be the greatest determinant of acceptance of a low-carbon system installation. Participants had varying opinions on the running costs of heat pumps – some believed heat pumps use less electricity

than conventional boilers and would therefore represent a reduction in energy costs; others believed that, as heat pumps are running continuously at a constant temperature, this could increase energy costs. One participant, with solar panels currently installed, outlined the benefits of free electricity, when most of the power was used during daylight hours. Concern was expressed regarding consistent availability of hot water and electricity and the impact on energy bills i.e., effectiveness of solar panel electricity and heat pump hot water generation at varying times, seasons and during high usage.

> *"With solar most important time you need heating is in the winter, so how will solar panels work, is it viable option."*

> *"If it is going to affect the water, I have 2 teenagers who spend hours in the shower – would this affect the amount of water?"*

Retrofit versus new build installation

Participants cited a variety of possible barriers to retrofitting of properties where tenants are currently residing. The greatest concern was the impact on, and loss of, indoor living space, especially in properties built to a specific size with limited extra available space. The larger size of the low-carbon energy system was viewed as being unfeasible and leading to cramped conditions. Further concerns included the disruption and intrusion involved; logistics of working around current residents or costs for moving them out of the property during retrofit. Spatial consideration emerges as an important determinant of acceptance.

> *"Disadvantages to space, in all the houses. In more modern houses its common sense to put them in now, than rip a house apart to put them in. It's a good system, if I had a different size flat, I would probably say yes, but the one I have now, it wouldn't go in would it. In my living room, nowhere to put the boiler, need space for the boiler, the big comeback with this system."*

Participants agreed that automatic installation of low-carbon systems in new builds was a good idea and more cost-effective. Consideration should be given to choosing the 'right' system for the property, rather than one-size-fits-all.

Ability to control the system

Accessibility of controls was mentioned as a consideration, especially for disabled users, where controls should be placed at a comfortable height to manage the system and for maintenance issues. Participants expressed a desire to have the ability to control the temperature throughout their property and to have access to zoned heating in different areas. Remote heating control options were suggested, such as the use of apps, iPhones, wireless and Alexa.

"I am quite fortunate for my heating, I have 2 thermostats, one does the hallway and living area, the other is in the bedroom and my wet room and the temperature is set at what I want it to be. Now, I can go to either thermostat for which area I am in which means that it is not on all over the bungalow, only where I am …. I have an Alexa and when I don't want to go to the thermostat, I ask her to do it."

Normative Beliefs

Realism of representation (of a low-carbon home)

Participants would like to experience how the system would look inside their home. A solution could include an example from a real home i.e., a video or physical representation of how the system looks when installed in a variety of different property sizes. This would be beneficial to show that not all technologies are applicable to all housing types.

"Get someone on who we can see and show us, I don't want a piece of paper like this to read it, I want someone in front of me, look at my front room, this is what they have done, this is how it looks and how they have installed it, I'd rather see this."

Participants discussed the possibility of visiting a converted showhouse property, which may be valuable to encourage acceptance of the system. Examples of online resources suggested by the participants were Thirteen Group website announcements and examples to reach a wider audience, although this would exclude those without internet access

Evidence of system effectiveness from current users

The lived experience of residents currently using the low-carbon system was high on the priority list of participants acceptance - feedback and information on energy bills and temperatures should be presented as testimonials. Participants would also be interested in being given access to view a video outlining the experience of resident views of living in a low-carbon property. Other evidence from an independent and transparent source i.e., University was considered desirable and should include research trials, data on energy bills and surveys based on a broad spectrum of people and lifestyles.

"You have the opportunity now, you have people using it, get their feedback, that will give you the biggest boost going."

Who should live in a low-carbon home

Participants views varied regarding the question of who would be most suited to living in a low-carbon home. Some believed the system should be for "everyone", whereas others believed it would be beneficial for people with certain medical conditions and low-income tenants, i.e., students and

disabled people. One participant indicated that dry store radiators are of a lower temperature so it would be determined by the temperature a person prefers. Families with 'green credentials' were considered suitable. Another participant suggested that it would be suited to people who have more living space, for example older people or couples. It was considered that there is a lack of information regarding this system to enable them to hypothesise, and further scientific evidence was required.

Behavioural Beliefs

Environmental Benefits

Participants considered that a greener lifestyle would be an advantage of living in a low-carbon home, and they would be motivated by the environmental and health benefits. Consideration should be given to the balance of 'going green' against personal energy costs.

> *"There is a financial aspect to it, but you would be a fool if you said you were not interested in going green. But if it costs twice as much to have and increase fuel poverty you will create a social problem – fine balance between what we have now and what we put in. If it is greener but raises the fuel price by 25%, what effect does that have on people."*

Resistance to the low-carbon home

Participants opinions of resistance to low-carbon installation include lack of faith in the system; being resistant to change in general and 'living in the past instead of going forward'. A certain percentage of people will believe it is effective and will be open to receiving it, and others will not.

> "*It all comes down to prove it, and 90% of people will accept it, always get some that won't."*

Tenant choice over installation

Tenant choice was mentioned by 2 participants. They believed that tenants should have a choice of whether they would like the new system installed, namely in retrofit buildings. This could be mitigated by information on costs, impact on living space, how the system works and the appearance of their home after fitting. If a resident chose not to accept installation of the system, there were fears of the possibility of being moved out of their home. A concern raised by one tenant was an imminent rent rise due to new system installation, although others believed the cost of installation would be covered by the government grant.

> *I think what everyone is saying, there must be an option, good if there were 3 options – not at all, just instal solar panels, or install both. And even if people wanted solar panels, they will be saving money as it's free."*

Other contextual factors: noise and system safety

The question of noise was raised: both inside the property and the possibility of disturbing neighbours. Participants also raised the question of whether the heat pump condensing unit is tamperproof, i.e., vandalism-proof.

The importance of installation skills and the 'skills gap'

Participants identified the issues of skills gaps in terms of gas fitters and heating engineers. Upskilling/retraining of current staff was suggested, along with putting in place a support network. This was viewed as an opportunity for existing workers to gain new skills and a method of creating apprenticeships and new jobs for young people.

> *"The other thing, be a good idea to those leaving education, should have a choice of apprenticeships to train them up alongside qualified people. Thirteen, in a way, creating more jobs."*

Participants identified issues with skills gaps in the construction industry; they suggested upskilling and retraining of current staff. Benefits of this were viewed as creating opportunities such as apprenticeships and new jobs.

Individual-Interview Results (14 participants)

Control Beliefs (barriers and motivators to living in a low-carbon home)

Environmentally friendly (13 participants)

All participants, bar one, specified environmental reasons as drivers to living in a low-carbon home. Three participants mentioned the environment 3 times and six participants cited it 2 times during their interviews. Participants referred to reducing carbon emissions, saving the planet, using less energy, being good for the environment, burning fewer fossil fuels and the benefit to climate change.

> *"It would help the environment. And this would have a massive effect on the environment in the long run." [P3].*

According to three participants, the benefits to the planet coincided with personal benefits such as being cheaper to run and having more comfortable temperatures within the home.

> *"Obviously the saving the planet issue, but from a personal point of view I hope it would be more comfortable all year round and it would be cheaper to run and then obviously if it's cheaper to run, it's using less energy, therefore saving planet. [P1]"*

Multi-occupancy building/flats (3 participants)

Three participants felt that people living in multi-occupancy buildings or flats would experience problems with low-carbon technology. Their concerns were around how individual heat pumps would work and how solar panels could be fitted and used for example in a ground floor flat, although one participant felt that it would be straightforward to fit solar panels to the building. The question on consensus of all residents relating to agreement to using low-carbon technology, along with the questions of service charges and costs of communal electricity was raised.

> *"I live in sheltered accommodation and there are 23 flats within this complex and looking at that video I can't see how 23 heat pumps would work in this building. [P5] I can't see how individual heat boilers would work but it would need a re-jigging inside the whole building to make it work for all the flats [P5] Well, to live in this particular building, we need the consensus of everybody. And if somebody's going to sit on the fence, we might not be able to get things changed round. You know, we need everybody's consensus and the moment everybody seems to be feeling that way, that we've got to do something about, particularly the service charges that were being faced with yearly." [P5].*

Up-front costs (5 participants)

Barriers

Two participants viewed the initial up-front cost of the low-carbon technology as a barrier. Recovery of costs would be in the long term and would be difficult to cover, especially for one leaseholder participant. One participant felt that the initial outlay of costs would not be recouped due within his lifetime.

> *"I'm a low user of particularly gas, I mean my gas bill for the year is less than £150 a year. So, I don't see how a heat pump can improve on that from a financial point of view, particularly considering the capital cost involved, which from what I understand is several thousand pounds." [P2].*

Motivators

A further two participants viewed the up-front costs as a barrier initially, but considered that if the cost issue could be resolved, there would be long-term financial benefits and a sustainable energy source:

> *"Initially you have to pay a higher purchase price [P4]. It's proven that of course, if that cost of entry could be handled somehow then on the long term then we would probably benefit, be beneficial in terms of finances too, so it's just a yeah, there's definitely a list of advantages." [P4]*

Retrofitting versus new build (3 participants)

Barriers

Two participants were not convinced that retrofitting would be suitable in their homes, largely due to the lack of insulation and other measures being required before fitting low-carbon technology. One suggested upgrading the property alongside a retrofit.

> *"Retrofitting it into a house like mine would not be cost effective because it is poorly insulated for a start off. Even the existing windows are very draughty, etc. So, there would have to be a lot of insulation to the home before the low-carbon side of it would work" [P1].*

Motivators

One participant felt that it would be easier to incorporate low-carbon technology into a new build property and one suggested upgrading a property alongside a retrofit

> *"I suppose that would be easier if it was a new build, you know what I mean?" [P6]*

Disruption (2 participants)

One participant mentioned disruption several times during her interview and felt it was a main concern, due to mental- and physical-health issues. The other participant was concerned about the disruption regarding time required for the installation.

> *"My main concern is the upheaval. Because I didn't go ahead with the boiler. Not the boiler, the air heating that that, that there had done four years ago, because of the disruption to the house, I wouldn't be able to cope with the stress. […] but my main concern would be the disruption, because I don't work, and I live at home all day with two dogs and I do have mental health and physical health problems. So that's the only thing that worries me." [P3].*

Insulation (5 participants)

Three participants agreed that insulation is essential to the effectiveness of low-carbon technology within the home and to stop heat escaping. One linked the requirement for insulation and draft proofing to the lower temperature output of heat pumps. One participant felt that costs could be reduced by 25% with efficient insulation.

> *"Insulation, draft proofing and everything else, because obviously the low-carbon stuff tends to run at a lower temperature, so the heat output is much lower." [P1]*

Running costs

Identified possibility to reduce costs or save money (presented in Section 4.2.1) could act as control factors (facilitators) or as behavioural beliefs (advantages).

Behavioural Beliefs (advantages and disadvantages to living in a low-carbon home)

Running costs (13 participants)

Advantages: reduced costs (10 participants)

For all participants, low cost, reduced costs of bills, lower running costs, value saved and saving money was a huge benefit. One participant referred to solar panels producing free energy and electricity. Five participants mentioned reduced costs twice during their interview. The idea that costs of home-heating and hot water could be reduced could be a positive consequence of using low-carbon technologies (heat pump and solar panels) in the home or a motivator for the acceptance of domestic low-carbon technology.

> *"Well, it's going to be cheaper fuel, that's the big factor isn't it" [P9]*

> *"In here we have a fairly inefficient boiler, it is going flat out even to keep the house warm at the moment, at a high cost. So, I'd certainly be delighted to have anything that altered that." [P1]*

Disadvantages: cost concerns (3 participants)

For three participants, cost was a concern – for one participant this was a major factor; for another participant indications of low cost-effectiveness from a neighbour with heat pumps currently installed was a concern. One participant expressed concern regarding whether low-carbon technology could match the current monthly low cost of their gas bills.

> *"My concerns are cost – my utility bills for gas and electricity at this minute are £27 per month, so I'm a low user, particularly of gas, I mean, my gas bills for the year are less than £150 a year, I don't see how a heat pump can improve on that" [P2]*

Environmentally friendly

See 'Control Beliefs' 4.1.1

> *"I think I can help me to warm more ecological and reduce my carbon emission and all that." [P7].*

Using solar energy (6 participants)

Using solar photovoltaics (solar-PV) as an energy source is seen as free energy and solar panels would be easy to fit. One participant viewed them as giving assurance, where another had concerns regarding the lack of sun in the winter in the UK. Battery storage was recognised as an advantage. One participant felt that solar energy could be generated by panels in multiple ways to how we are using them currently.

> *"People forget windows act as solar panels, why aren't they being used – tinted windows, actually solar panels. The whole window, but they are not used. Roof tiles can be interlinked so the whole roof becomes a solar panel – there are so many times but we only use the fat ones on the roof in UK". [P14]*

Temperature Regulation (7 participants)

Advantages

Low-carbon technology was perceived to be easy to use and would keep the home warm and comfortable all year round. Constant temperature and hot water were seen as benefits. One participant suggested that, with temperatures rising in the UK, air conditioning could be built into the heat pumps.

> *"Well, they'd be warmer. They'd just run constantly. Don't have to mess about with the thermostat or anything like that. They'd be set with the weather." [P12]*

Disadvantages

One participant expressed concern over the ability to manually regulate the temperature to have zoned heating. Another participant finds that gas central heating is almost instant, but understood that heat pumps, running at low temperatures for a long period of time may take longer to heat the property.

> *"I just don't want to have my bedroom heated or anything. Can it be switched off from there?" [P9]*

Technology flaws (4 participants)

One participant believed that there may be issues with the battery I.e., for maintenance and reliability but stated that the rest of the system would be efficient; another thought that the system lacked stability due to a lack of sunshine in the UK in winter which would reduce warmth in the home. New technology was viewed as negative as, when first launched; there may be flaws because it is less tested to a certain extent, compared to when it has been in circulation for a longer period. Another participant saw learning how to use the new technology as a disadvantage, although acknowledged that it was a requirement for an eco-friendly home.

"…But I suppose the negatives are, you know, it's new technology is often a bit, there's often a bit flawed when it first launches, you know, sometimes it takes a while." [P6]

Loss of storage space (1 participant)

Only one participant thought lack of storage space would pose an issue as there was no place to install the large storage tank and equipment. However, whether the storage tank would take up more space, the participant would be happy to have low-carbon technology installed – the barriers could be overcome very easily.

"You have to get used to the fact that the air source heat pumps could produce much lower temperature things, you'd lose a bit of wall space, perhaps with the size of the radiators, but I would say none [disadvantages] that you couldn't overcome very readily." [P1]

Maintenance (2 participants)

Two participants believed that there may be issues with maintenance i.e., may be a lengthy and expensive process. If the system fails or develops a problem, would there be a system in place to contact a technician.

"So, when it comes to maintenance of systems like this it might be might be a bit long and costly but that's it really." [P4]

Normative Beliefs (Important Referents)

Who would approve of/live in a low-carbon home?

1. People who can afford it (1 participant)
   "People who can afford it because it's very new technology so it doesn't seem to be being introduced into the new build properties at the moment, so the only people I see who can afford it at the moment are people with a higher income bracket than me, because the initial installation cost is very high, and the return can be very long term." [P1]
2. Younger People (4 participants)
   "Younger people tend to move around more into new home, they are concerned about environmental issues and would want and expect that type of housing"

   "I think all the young people are really concerned about the importance of safe energy and all that."
3. People on low income (3 participants)
   "Surely all nursing homes and that should be. because it will put down their bills as well. The annual fees, what the residents are paying, that must surely cut down, mustn't it" [P9]
4. Environmentally Conscious (4 participants)

Political parties with a green agenda – "The Green Party, for example. People who are conscious of the environment and are more ecologically minded:
"A lot of people from my generation, I mean, at least most of my friends, are really conscious when it comes to using sustainable energy and, obviously, we know the reasons for it." [P4].

5. Big Families (4 participants)
   Big families with a lot of children, at least 2-3, who would like to set an environmental example to their children – it would be beneficial and save them money.
   "I think a couple with at least two to three children I think would benefit be beneficial to them." [P8]
6. Those who see other people with it (3 participants):
   "Neighbours in the surrounding areas and residents who have seen another householder with low-carbon technology installed, they would find it interesting and possibly follow in that direction. Visitors to the home would be interested and it would be a positive impact on them. It would be an advert to other people who haven't had the opportunity, who may then follow in the footsteps of low-carbon installation."
   "My surrounding neighbours. And possibly some other residents in the village once they've seen somebody else."
7. Councils, Social Housing Provider and the Government (3 participants):
   "…But it also feels like they think good to hit government targets. So maybe like you know the establishment would approve of it, the politicians of the day." [P6].
8. Friends and family (4 participants):
   Four participants thought that their family and friends would approve of low-carbon technology in the home:
   "If they think I'm making the wrong decision, my daughter, she will speak up and say so. But in a case like this, I don't see a problem." [P8]

Who would disapprove of/not live in a low-carbon home?

1. No-one would disapprove (9 participants)
   "I don't anybody who would disapprove."
2. Older People (4 participants)
   "Old people like me. People can't see the payback. You know, I would see anybody in their late 50s onwards would say this is not for me because it's unaffordable and you know, I wouldn't get the payback. Younger people? Yes." [P2]

Other Themes unrelated to the Theory of Planned Behaviour

Politics (5 participants)

On the politics of renewables and the environment, one participant believed that politics is complex and there are wider issues around environmental initiatives, they may not be resolving the issue which may need more radical/economic change within society. There is a feeling of pressure to 'be

green' and 'politically correct' but expressing negative views on sustainable energy is 'bad'. The issues around low carbon are complex, so who do you believe, what is right and wrong? Two participants felt that a national plan is needed for renewables and infrastructure, along with more social housing. It was expressed by one participant that most people who care about the planet are doing their best to be involved with environmentally friendly initiatives, for example low-carbon housing. The issue for this, and another participant was that government funding should be made available, but this may not happen unless the public make themselves heard.

> *"Most green people doing their best to get these houses done. Anyone that gives a hoot about the world. You don't have to be part of an organisation to care enough to think I'm going to do something here. We all can help the planet and help our pockets by doing something or speaking about it. The more we yell at the government the more they will think they've got to do this." [P14]*

> *"Sometimes environmental initiatives can sometimes be a bit, there's some people who know more about than I do, or sometimes will say things like. Well, you know, this is not resolving the issue really needs radical change, there needs it needs to be to economic change and all these little things don't help actually hurt because they are distracting. I don't know, probably that's going outside my area of expertise a bit." [P6]*

Further information on low-carbon technology and instructions on use (7 participants)

Four participants felt that they did not have enough information to decide on whether low-carbon technology would function correctly or be suitable within their home. One participant queried whether the property would retain the same home comforts currently enjoyed, another inquired about whether the low-carbon technology would fit in their homes and how it would look (the aesthetics). There was concern on how this technology would work in multi-occupancy buildings/flats, and one participant speculated as to whether it would be cost-effective but said, in principle would be happy to have low-carbon technology installed. One participant recognised the scarcity of public knowledge of low-carbon technologies but felt that further information would lead to positive attitudes. Two participants would benefit from information on how to use the system effectively and one outlined the fact that the information is available if you search for it:

> *"I don't know whether or not you have the same sort of heating that I've got in my home at the moment, which is under floor heating, you know, I mean, maybe you can, you can't, I don't know, but maybe the radiators are different and what not, and I'm not sure how all that would … you know what I mean, so that's a potential, that would be like a question mark for me" [P6] Alright, my neighbours had the air pump installed. I think there was three or four of them and they haven't noticed any difference in their bills. But I don't think anyone's been out to actually show them how to use it properly." [P3]*

Social housing/Income inequalities (4 participants)

Participants felt that if low-carbon technology was installed in private builds, in exclusive areas, they would be more expensive to buy and would exclude people on low incomes and 'price them out of the market.' One participant was of the opinion that it would be less likely to be installed in rented properties and that, in reality, people will not have the opportunity to choose whether to live in a low-carbon home. It was felt that if the technology was installed in social housing it would be of benefit to people with low incomes. One participant mentioned 3 times the belief that people on low incomes would not find it affordable but should have the same benefits as those on higher wages to have the luxury of living in a comfortable warm home. One participant felt that people on higher incomes were less likely to need it than people on low incomes but were the ones more likely to benefit having it. The solution for some was for social housing to buy and install this technology.

> *"The only people I see who can afford at the moment are people with a higher income bracket than me, because the initial installation cost is very high, and the return can be very long term. So, I would say at the moment, sadly, the people who will be living in low-carbon homes for the people who least need it, I would argue, certainly from an economic point of view. The people who need it most are the people who can afford it least." [P1]*

> *"I do, of course care about the environment too. So, it's just the money and it's just a bit more expensive, it's not really affordable for people, well, you know, people in my kind of demographic [P4].*

Current rise in energy prices (3 participants)

The current rise in energy prices, and the possibility of further rises, is a source of worry for two participants, in relation to heating within the home, especially if their heating runs on electricity. The costs of electricity in communal areas of multi-occupancy buildings or flats are a concern for one participant as lighting is commonly left on by other residents in the building which may lead to higher costs in electricity itself or service charges. For another, the current rise in bills would be a motivator for low-carbon housing. Low-carbon technology is viewed as a lower cost and healthier option

> *"Cost of energy going up [P4]"*

> *"As we are at the moment heating your flat, apartment, house or whatever, the bills have just gone through the roof, as you well know, and to me this would be the option and would be healthier as well" [P8]*

Discussion

The aim of the research was to explore social housing tenants' beliefs about living in and using a low-carbon technology home. The purpose of the project was to inform Social Housing provider Thirteen Group's commitment to converting their housing stock to low carbon by 2050, contributing to the broader objectives of the Tees Valley energy transition. For this study, the Theory of Planned Behaviour has been used to identify favourable or unfavourable attitudes amongst social housing tenants regarding living in and using low-carbon technology homes. The most frequent findings were located within the participants' behavioural and control belief answers and related to a common belief that low-carbon technology in the home would provide benefits to the environment and impact positively on the planet. For some, this was a benefit that came alongside low-cost energy benefits. Another factor mentioned frequently by participants was that of reducing the cost of energy bills, with most participants mentioning lower running costs as a perceived advantage of low-carbon domestic technology. Both environmental concerns and a reduction in energy costs appeared across the interview in both questions centred upon control beliefs and behavioural beliefs, indicating that there was a lack of clarity in the questions asked within the interview for the participants.

A motivator identified by several interview participants was the need for better insulation to be fitted in the home to enable low-carbon domestic technology to work efficiently. The barriers that were identified by interview participants seemed to be much broader, but the frequency of these responses was fewer than those that identified motivating themes. Barriers identified most often were potential upfront costs, unanimous decision-making required for multi-occupancy properties, a need to first insulate properties better, and the disruption of the installation process itself.

In relation to behavioural beliefs that highlighted the advantages to living in and using a low-carbon home, tenants valued the idea of reducing costs, regulating the temperature of their homes and the health and environmental benefits associated with living with the new technology. Given the emergence of this new data, Thirteen Group might consider working with tenants to share existing and new evidence to ensure the indicated advantages are commonly communicated.

Based on the frequency of responses in association with tenant' behavioural beliefs, strategies to reduce disruption and manage concerns around installation costs, useability and reliability of the new technology could be developed. Disadvantages are likely to improve if tenants are engaged with regularly on how to use the new technology to ensure it operates efficiently. The research findings presented here highlight a shortcoming of existing energy change research, as Hafner et al. [34] have stated, the UK social housing sector is a vulnerable population that has been overlooked.

In connection to normative beliefs, findings suggest tenants believe those mostly likely to approve of living in and using a low-carbon home, are those who can afford the installation costs are younger and environmentally conscientious or are driven by keeping costs to a minimum due to low income or having a large family to support. Approval from friends and family was expected and influences, such as neighbours who choose to have the new technology installed may also increase adoption rates within communities.

Many participants felt they did not have enough information on low-carbon technologies to allow them to make an informed decision. Scarcity of tenant and public knowledge was mentioned as being an issue, but it was felt that further information would lead to more positive attitudes. This need for engagement strategies to be in place for households living with and using low-carbon domestic technologies is identified by Chadwick et al. [26] in their work on energy transitions. Equally, concern was expressed about the legitimacy of claims made about low-carbon technology reducing costs. The importance of energy efficiency reducing financial costs for social housing tenants is corroborated by the work of Desvallées et al. [35]. Furthermore, participants voiced income inequalities as a barrier to adopting new technology, sharing the opinion that high earners would be able to invest in the new technology sooner, potentially pricing those within a lower income bracket out of the market.

Conclusions

Based on the above findings and if not already applied, registered tenants might benefit from Thirteen Group implementing new practices, such as publicly reporting evidence to show improvements to tenant wellbeing, including the physical, environmental, and financial advantages to adopting the new technology. Research and assessments such as ‘lived experience’ prior to and following the new technology being installed is likely to increase understanding and uptake within Thirteen Group’s communities. Many themes arising from the results could be traced back to lack of knowledge or the desire for more knowledge.

Trust in an organisation can affect behaviour positively and lead to changes in social practice; it can also affect an individuals’ behaviour and change towards energy. If strategies were also put in place for training; spreading knowledge; holding meetings to discuss the old systems and potential of the new systems; rent and tenancy rules following fitting of low-carbon technology, then this would aid and support tenants in ‘behaviour change processes’. It is important to include different audiences, social groups and to consider individuals while making efforts to adapt to their reality. This would encourage a successful interaction between the new energy technology and the individual.

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