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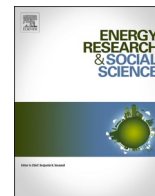
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Original research article

Transformational innovation in home energy: How developers imagine and engage with future residents of low carbon homes in the United Kingdom

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ABSTRACT

Decarbonisation and climate change targets require multiscale sociotechnical energy transitions that include significant changes to housing stock. In the UK, the development of Active Buildings, which directly seek to be efficient energy producers, have zero carbon emissions and provide grid flexibility, has the potential to make a significant contribution to meeting these targets. Active Homes as a particular type of Active Building represent a potentially transformational innovation by altering how energy is produced, distributed and consumed, in addition to how homes are designed, constructed and then lived in. In this paper we draw on insights from qualitative interviews with stakeholders involved in the development of different Active Homes to consider motivations for development, and their views on how residents will reside in and interact with the homes. We highlight a potential conflict between a desire to prioritise the needs of residents with a belief amongst some that to do so, user engagement with technology should be minimised. This has implications for design decisions, which in turn influence how residents experience and live within the homes. In illuminating these narratives, we indicate the necessity of ongoing engagement with residents to understand how Active Homes – with particular emphasis on the operation and control of technologies – are experienced, in order to inform the successful rollout of current and future developments.

1. Introduction

In order to meet UK decarbonisation and climate change targets, significant changes to existing and future housing stock will be required. In particular, a reduction of residential energy consumption is urgently needed [1]. Globally, buildings are responsible for nearly 40 % of all energy consumed and around 40 % of carbon emissions [2]. In the UK, buildings account for 23 % of UK carbon emissions and of the overall emissions from buildings, the majority (77 %) is from residential buildings [3]. With policy commitments to substantial changes in requirements for heat and power for buildings, and increasing focus on renewable energy sources [4], the role of buildings within the energy system is becoming more prominent [5].

Active Buildings have been positioned as a possible solution to addressing UK building decarbonisation targets, as buildings that include renewable energy generation, battery storage and energy efficient building design and fabric [6]. Active Buildings 'generate and store renewable electricity to meet their own needs and intelligently

redistribute the surplus to other buildings and back into the grid,' presenting a flexible solution, with potential to ease strain on energy infrastructure [7]. Active Homes as a particular type of Active Building represent a potentially transformational innovation by altering how energy is produced, distributed and consumed, in addition to how homes are designed, constructed and then lived in. Such homes have been described as 'the houses of the future, offering self-sufficiency, improved quality of life and a tangible economic payback' [7]. Real life examples of Active Homes are currently limited, but insights from research regarding smart homes, which promise similar benefits in terms of resource efficiency [8], are of relevance. Smart homes incorporate internet-enabled appliances, facilitating remote control, monitoring and automation, but do not necessarily hold the capacity to produce and store energy or respond to electricity grid signals, as Active Homes do, whilst Active Homes do not necessarily encompass smart user controls. However, in the wider context of accelerating household interest in battery storage, electricity sharing and trading, and demand response opportunities to better utilise the electricity they generate [9], these

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innovative housing developments may further align in future. Vital to the success of Active Homes is the experience of residents, yet missing from the policy debate on zero energy homes has been a discussion of whether households enjoy living in such homes and feel comfortable with the technologies they encompass [10].

Active Homes are designed with expectations of how residents will engage with them but, if when lived in, this does not correspond with designers and engineers' visions there is a risk that these technologies will not contribute to modulating network loads [11] or otherwise perform as anticipated. Design decisions can have long-term energy consequences [12] and the ways in which technologies are used within buildings has implications for evaluations of energy efficiency [13]. Existing research has highlighted how the ways in which occupants are envisaged 'will play a key role in the visions of a low carbon housing future held by housing and energy professionals and will be crucial in shaping the future of UK housing.' [14: pp37]. As an innovative development in housing design, we contend that it is valuable to understand how Active Home developers envisage future occupants and how this has the potential to impact upon people's lives within the homes, in order to inform the wider rollout of such buildings.

In this paper, we draw on insights from interviews with experts involved in designing and developing Active Homes to explore how they envisage future residents and how this influences design decisions. As Active Homes are at an early stage of development with little research to-date, we begin by drawing on insights from related literatures regarding smart homes and expert imaginaries of energy consumers more broadly. By foregrounding these conceptualisations of residents, our research responds to calls for deeper explorations of the human role in energy systems [15] and work which is longitudinally embedded [16].

2. Visions of consumers

Existing research has considered the role of expert imaginaries concerning the future energy system and its users, and how such visions can have a significant impact on current developments and experiences [17], technology and design [18] – particularly through the 'scripting' of user behaviour and energy use [14,19–21] – and policy development [14]. For example, Sadowski and Bendor describe the smart city imaginary as a future-in-the-making, which is presented as a solution to daunting problems and crises in the present [22]. Such imaginaries are important to consider as they 'encode not only visions of what is attainable through science and technology but also of how life ought, or ought not, to be lived.' [23]. Visions regarding the role buildings and residents can play in providing required flexibility for decarbonising the energy system can be considered 'sociotechnical imaginaries,' which are entangled with norms and expectations [24]. The way in which diverse and sometimes contradictory visions are enacted in the present has implications for efforts to address climate change [25] as well as people's everyday lives. In this paper we focus on how residents, consumers or end users, as they are variously termed, are imagined during the conceptualisation, design, and occupational phases of Active Homes, and the implications this has for the homes' development.

Implicit within energy system imaginaries are expectations of how residents will act and react, which influences how technologies are designed and how experts interact with residents [24]. Expert imaginaries of an increasingly smart energy grid that communicates with other smart infrastructures, including buildings, are often described as a 'smart utopia' [26–28]. In such visions, everyday life is streamlined and made more efficient through the smart synchronisation of the supply and demand of different services. Furthermore, within visions that consider the smart energy grid and the energy sector more broadly, two competing imaginaries of publics persist; an active public engaged with new technologies and a public envisaged as irrational and deficient in knowledge [14,29,30]. Similar findings have been drawn regarding smart home residents, who are often assumed to be either logical,

reasoned and IT literate [26] or unable or unwilling to make lifestyle changes [14,30]. We critically consider these two conceptualisations, respectively termed 'resource man' [31] and 'indifferent consumer' [32], and how they relate to ideas of active and passive residents, which has implications for Active Home design.

2.1. Existing conceptualisations

'Resource man' positions householders as micro-resource managers who use data and ICT to mediate and manage social action and change [26]. The resource man consumer archetype is imagined to be a responsive and rational economic agent, using data to understand and change the way he uses energy, imagined in the image of the male-oriented industries of engineering, economics and computer science which are designing and building smart systems [31,33,34]. The assumed benefit of energy feedback for consumers is that this will raise awareness of their energy use, subsequently encouraging rational decisions to reduce consumption, costs and/or carbon emissions, which Hargreaves et al., refer to as the 'information deficit model' [35]. This archetype is underpinned by the idea that people act in rational ways or respond simplistically to price, yet this has been critiqued in existing literature in relation to smart technology [26], smart grids [18], smart homes [36], low carbon homes [14], and demand shifting [37,38], suggesting the prevalence of this archetype across different sectors.

A further challenge with the resource man conceptualisation is the lack of attention given to household dynamics and the different relationship to technology that household members may have. Strengers argues that the individualistic conceptualisation of energy use evident in the 'resource man' archetype does not correspond with the practical realities of most people's energy consumption [26]. Relatedly, Verkade and Höffken critique a lack of regard for the heterogeneity of prospective users and the actual interest in energy matters amongst all household members [33]. Instead, it is important to recognise households as collective enterprises that are fabricated through patterns of everyday routines and interactions that entail the consumption of electricity [39], as well as to acknowledge the entanglements between energy efficiency and the way people live in their homes [13].

What Goulden et al., (2018: 180) term the 'indifferent consumer' is described as "effectively everything Resource Man is not – disengaged, lazy, irrational, ignorant", and is an archetype that they found to be more common amongst energy sector experts than resource man [32]. Similarly, in their research on smart grids, Skjølvold and Lindkvist identified a recurrent theme; that experts tend to regard lay publics through a knowledge deficit [29]. Perceptions of consumers as uninterested in or unable to understand control systems can impact upon the information and advice provided by installers [21]. Such a consumer may be regarded as a challenge or 'obstacle' [24] to the energy sector; one which may be seen as potentially subverted by increasing automation, bypassing the consumer and delegating as many tasks as possible to the technology [29]. Automation of smart homes may also be premised on related assumptions of residents' inherent laziness, forgetfulness and busyness [40]. As we have previously highlighted [5], this is also evident in discussions of direct load control, which assumes a passive role for households, as agents outside of the home, such as Energy Supply Companies or Energy Service Companies, network operator or energy aggregators are granted permission to manage a household's energy system [20,41]. By managing a household's energy on their behalf, it is assumed that these agents can more effectively increase household energy efficiency and reduce energy costs. Such visions reflect an objective of 'designing out' occupants through increased automation in order to improve efficiency [14].

Automation is envisaged as desirable for consumers by reducing the burden of energy management and offering financial savings by making it easier to change consumption patterns [42]. This is evident in policy documentation, for example the OFGEM (2017:14) assertion that 'We expect consumers to want high levels of automation, so that it is easy for

them to participate and to realise bill savings.’ [43]. Whilst experts may see automation and smart home services such as direct load control as beneficial, research with consumers has illuminated concerns about loss of control and potential alienation [44–46], which has implications for wellbeing [20].

The issue of control is a critically important concept in relation to smart homes [47]. Although Active Homes do not necessarily include smart user controls for residents in the way that smart homes do, smart meters are required for balancing energy supply and demand. Whilst positioned as beneficial for consumers, studies have indicated that ceding autonomy and independence for increased technological control are the main perceived risks of smart technology in the home [48], with reservations around loss of control expressed across a range of social groups [44]. Concerns about unauthorised access to personal data, data security and privacy [42,44,49], have impacted the take-up of technology such as smart meters [50]. Promises of greater control for the householder assume homogeneity of competences [51], potentially masking control situations within families [20] and concentrating control in and over homes in certain hands and not others [52]. Yet households are differently positioned in their ability to take up and benefit from technologies designed to support energy system flexibility [46]. Important to these debates around control is the argument that the technologies are not neutral [19] but represent the interests of their makers, offering potential benefits to them in terms of access to data [8].

As we have shown, existing literature from a range of energy studies has identified two divergent but often mutually present imaginaries of consumers, which have implications for the way homes and the technology within are designed and realised. Whilst conceptualisations of resource man and indifferent consumer appear prevalent, existing research has highlighted the importance of moving beyond such binary distinctions in order to provide insight into how residents engage with energy production possibilities [8,53]. In research on low carbon housing, both Zhao and Carter [54] and Cherry et al. [14] highlight disparities between developer visions of residents and views of the public or residents themselves, with Cherry et al., suggesting that this hints at tensions that may arise as we attempt to transition towards new socio-technical systems. A more nuanced picture of residents is therefore required.

2.2. Prosumers

Beyond individual motivations to engage with energy, the concept of ‘energy citizenship’ has been proposed [55], which emphasizes energy consciousness and literacy as well as sustainable energy practices [56]. As Goulden et al. (2014: 24) note, ‘In contrast with the consumer, for whom energy is simply a good to be expended in pursuit of personal goals, the energy citizen engages with energy as a meaningful part of their practices.’ [57]. The concept of energy citizenship therefore acknowledges citizens’ active involvement in the energy transition, including as prosumers [58]. This indicates a different conceptualisation of consumers as having new responsibilities and powers in the energy system [59], which goes beyond purely economic rationalisations associated with resource man archetypes.

Active Homes, like other energy system technologies that involve energy generation, can reposition people as prosumers – both producing and consuming electricity [12]. Prosumption has the potential to transform people’s relationships to energy through increasing awareness of energy use, creating opportunities for consumers to become energy citizens [60] as technologies require active administration [20]. However, this transformation may partly rely on accompanying technology to monitor the ebbs and flows of energy [12,60], in order to facilitate prosumers’ active engagement [53,59], which again arguably relates to an assumption of a rational resource man [26]. Existing research into prosumer households has largely focused on those who have chosen to install technology, reflecting a sample who are energy-minded and engaged [61]. An exception is Winther et al.’s study, which distinguished

between householders who had chosen installation and those who had moved to homes with technology already installed [53]. They found that those moving to ‘ready-made’ houses related more passively to energy generation technology (in this case solar PV), than those who had chosen to install it, ‘only lightly’ incorporating this into everyday life. Research that acknowledges a diverse range of resident experiences and relationships to technology can therefore make an important original contribution.

Given the ‘active’ nature of the homes in our study, where energy generation is key, we consider how experts envisage residents and which imaginaries prevail. Active Homes will be occupied by a variety of residents; from those who have chosen to live in a home that generates energy to those for whom the ‘active’ nature of the home is of lesser significance than the home’s size, price or location. This suggests that experts will need to consider a range of residents in the design of Active Homes. Whilst previous studies have considered individual or few technologies, studies which explore the impacts of a number of technologies, and how they interrelate, via a longitudinal design are exceptional [62]. Thus, our research into Active Homes has the potential to make a significant original contribution to this field.

3. Living well in low carbon homes

The transformative elements of Active Homes, including the changes to energy and building infrastructures, changing roles and responsibilities of energy companies, and building occupants, the emergence of new energy agents, as well as the changing energy policy and regulations, means that in the UK, real-life examples are limited to small-scale demonstrator developments [5]. Our Living Well in Low Carbon Homes (LWLCH) research incorporates five of these innovative developments in different locations across South Wales, which are outlined in Table 1, enabling us to consider a range of Active Homes built according to different principles. Our case site selection focused on novel developments that in different ways encompassed energy efficiency, renewable energy production and capacity for intelligent communication between users, the buildings and national grids [64]. Our expert interviewees identified Wales as a particular locus of

Table 1
Case sites.

Features of all case sites:	
•	Highly insulated
•	Battery storage
•	Solar Photovoltaic (PV)
•	Electric heating
<i>Case site 1:</i>	
	225 homes (2–4-bedroom houses) for private sale in a peri-urban location. Homes have a traditional appearance but include ground source heat pumps, underfloor heating and electric vehicle charging. Residents can sign up to an energy service.
<i>Case site 2:</i>	
	15 homes (1-bedroom apartments and 2–4-bedroom houses) for social rent and private sale in a rural location. Homes are timber clad and designed to passive solar principles. Homes include electric vehicle charging.
<i>Case site 3:</i>	
	16 homes (1-bedroom apartments and 2–3-bedroom houses) for social rent in an urban location. Designed with the concept of homes as power stations, the buildings are capable of producing a significant proportion of the energy required for the homes at certain times of the year. Homes include electric vehicle charging and Mechanical Ventilation Heat Recovery (MVHR).
<i>Case site 4:</i>	
	35 homes (2–4-bedroom houses) for private rent in a semi-rural location. Currently under construction, the homes will be built according to passive design principles and will be clad in locally sourced materials. Homes will include electric vehicle charging and MVHR. Energy service will be included in tenancy contract.
<i>Case site 5:</i>	
	50 homes (1–3-bedroom apartments) for social rent and private sale in an urban location. Currently under construction, the homes will be part of a mixed-use building designed to biophilic principles. The building will include air source heat pumps, heat recovery units, MVHR and rainwater harvesting.

innovation in housing development, partly down to financial support via the Welsh Government's Innovative Housing Programme [65], which makes case sites in Wales relevant for research attention.

Common to all our case site developments is the inclusion of solar PV, battery storage, high levels of insulation and electric heating (either via under floor heating or electric radiators). Two of the developments will also offer residents an opportunity to sign up to a form of direct load control, whereby an energy service aggregates the individual energy production, storage and demand of the homes at each development, and manages it in line with signals from the national grid. At these case sites the aim is to achieve low household energy costs and low carbon emissions whilst maintaining household comfort and providing grid flexibility. LWLCH is part of a broader social science work package that forms part of the Active Building Centre Research Programme.

The LWLCH project incorporates qualitative research interviews with both stakeholders and residents [64]. Qualitative interviews with relevant stakeholders or experts aim to understand their performance ambitions for the homes and how they imagine future residents, given, as discussed above, this directly affects the materiality of the homes, and subsequently how residents live day to day. The primary areas of expert specialism are listed in Table 2, although some experts covered multiple roles and case sites. Qualitative longitudinal interviews with residents provide a detailed exploration of their experiences over time. Residents are initially interviewed a few weeks prior to moving into their Active Home and twice within the first year of occupation. This enables us to consider their initial motivations and expectations for moving, as well as their lived experiences of residing in the homes. Such long-term perspectives on how residents settle into a position as prosumers are exceptional [62].

Information about the research project was distributed to all future residents of our case sites, either by housing sales teams or by RSLs, with individuals invited to contact the research team if they were interested in taking part. Relevant experts were identified from initial contact with case site representatives and invited to participate, with the sample snowballing as further relevant experts were identified. Thus far, 26 experts and 35 residents have been interviewed, with later stages of resident interviews ongoing. Due to the Covid-19 pandemic, all interviews have thus far been conducted remotely by members of the research team, using video conferencing software or telephone. Interviews are audio recorded and transcribed verbatim, and transcripts are coded thematically using NVivo software. Coding is an iterative process involving both a priori and inductive codes and is conducted by multiple members of the research team, with regular discussions to ensure coding compatibility.

4. Expert expectations of residents

In this section we draw on insights and extracts from expert interviews concerning the expectations stakeholders had of Active Home residents. Whilst we do not include extracts from resident interviews, as part of a qualitative longitudinal project our analysis is informed by knowledge of this wider data set [51], which includes resident experiences. To ensure anonymity, experts are referred to numerically

Table 2
Experts.

Areas of expert stakeholder specialism	Experts
• Architecture and building design	1, 5, 24
• Technology/engineering	2, 22
• Housing policy	3
• Housing development	4, 8, 9, 10, 11, 14, 17, 18
• Sustainability	13, 20, 21
• Project management	6, 23, 25
• Resident liaison (including sales, customer service and RSL housing officers)	7, 12, 15, 16, 19, 26

alongside their area of expertise.

4.1. Information and education

Across our expert interviews, a commitment to “customer satisfaction” was evident, as experts recognised that without this, Active Homes could not be successfully realised. In some instances, this required not adopting the most efficient way of running the homes because of perceived limits to what residents would consider acceptable. Managing this “conflict” through design decisions about the heating system and how it should be operated was seen as important in ensuring that the homes were well-regarded by residents, and therefore an essential element of a successful transition to low-carbon housing. However, there were recognised limits to the ability to accommodate resident preferences:

“[I]f there was any physical element of the build, if someone so far had said to me ‘I don’t kind of like this’ or ‘I don’t get this’ or ‘this is too different’, it is the underfloor heating ... you can use [radiators] but underfloor is better for doing it, that is the reality ... if it is then let’s articulate it and go through that actually a pair of slippers is going to save you a significant amount of money and make every other element of your home more comfortable I think people will get it. But that’s not to say we shouldn’t consider if there are any other alternative technology that might achieve the same level of efficiency but have a smaller change in how people are seeing their homes, aid that transition to a new cutting-edge system.”

(Expert 12 – resident liaison)

In this extract, Expert 12 indicates the view that explaining the rationale behind the choice of technology to residents may lead to their acceptance of it, which is important for the seemingly inevitable “transition to a new cutting-edge system”. This is echoed across other expert interviews where the importance of “education” was emphasised:

“I think there’s a bit of a bad impression of electric heating, to be honest with you, but that again comes down to education, doesn’t it ... seeing how the batteries help support that and all the other things, all the other technology that’s been built into these homes, is that going to help keep bills low? ... If it doesn’t, that behaviour of individuals in those homes, rather than the actual technology. In other words, they’re not using their electric wisely.”

(Expert 15 – resident liaison)

Here Expert 15 indicates the importance of understanding resident experiences of the homes but suggests that if the homes are not operating efficiently, this may be related to individuals “not using their electric wisely” a situation that could potentially be addressed by “education”. This is reminiscent of arguments in the literature outlined above; that providing people with information will enable them to make rational choices about their energy use in order to use it more efficiently. Expert 1 similarly intimates that providing information to residents via an in-home display screen will lead to greater “awareness” of energy use.

“[i]t’s just giving that awareness to people ... they can see the screen and see oh, it’s sunny and we’re generating this much, let’s stick something on, let’s plug the car in. And if they can see the batteries are full, they’ll probably want to try and empty the batteries so that they can put more in ... I think having the display screen, having something that connects people to their energy usage is really, really good.”

(Expert 1 - architecture)

However, also evident in expert discourses was the suggestion that information was not of interest to consumers, with both perspectives often present in the same interviews. For example, whilst highlighting the benefits of information about battery usage above, Expert 1 also stated “[residents] don’t need to be worried about how full the batteries are

and that kind of thing.” This view appeared premised on an assumption of the technology working correctly, and of automation or control by external experts as beneficial for residents in removing the burden of worrying about their energy system, echoed by several experts:

“I think because we try our best to make it as simple as possible, not bombard them with technical information, and explain to them that you can kind of just sit back and let it run itself. I think they're pleased to know that they don't have to do anything, because it's already stressful enough, you know. Buying a new house. I think they think, “One less thing for us to worry about.””

(Expert 7 – resident liaison)

“I guess the key thing here is taking what is more complex as a building but then actually making it even more simple and convenient for the customer because you know, we've got access to more data because there's more and we've got access to better controls. So we can use that information to improve the experience for the people that live there ... I think we're very much a services provider to them. And then the conventional supplier that electricity is a behind the scenes activity... the real goal there is to improve the customer experience and to guarantee that these projects are a success.”

(Expert 4 – housing development)

Expert 7 highlights a view that smart home technologies need to be invisible to the consumer due to programme complexity [44], which allows the home to “run itself”. Similarly, Expert 4 refers to technical complexity for experts in contrast to simplicity and convenience for residents. Here, access to data is seen as meaningful for the energy service provider, who then takes the burden of managing the energy system “behind the scenes,” and as not particularly meaningful to the resident. This perceived disinterest in data was also evident in some experts' discussion of in-home displays as having minimal impact on consumers and therefore not necessarily relevant to provide:

“All the research on [in-home displays] tends to suggest that you ignore them within three to six months and so they don't have a long-term behaviour change impact ... we just recognise that most people don't care about it, if brutally honest. So what they care about will be the outcome of when which room is at which temperature.”

(Expert 5 - design)

The view that residents were uninterested in information and data links with important concerns about potential loss of resident control, as discussed in the literature cited above (e.g., [44]). Rather than being of potential concern, experts often cited this as a benefit for residents through removing worry. However, this assumes technology that functions and performs as expected, which is not always the case. In such instances, residents may have cause to be worried, particularly if lack of clarity about their energy system and usage is associated with concerns about high bills [66], a theme we return to in the final data section below. This discrepancy in views of whether residents were expected to do things differently in response to education through information, or whether they were seen as disinterested or incapable of understanding, led to wide variation between case sites in the level of information offered, which in turn also appeared related to expectations of behaviour change.

4.2. Behaviour change

The apparent inconsistency in whether information is desirable for residents or not reflects a broader concern with whether resident “behaviour change” (as the experts themselves termed it) was expected. In some expert accounts it appeared that asking residents to make changes to their lifestyles and energy practices was undesirable and that the attractiveness of Active Homes would be in their ability to enable residents to continue their existing lifestyles, with the homes and

technology making this more sustainable in a “behind the scenes” way “not assuming that they have to live any differently” (Expert 4 – housing development) as “anyone could live in the homes, there's no two ways about that” (Expert 26 – resident liaison).

The assumption that it was not beneficial to provide residents with information appeared to be partly based on the idea that systems were more efficiently managed by external experts, with minimal resident involvement:

“[w]e've taken a very unashamedly technology approach to it, so there's not much in the way of thought about how users are going to interact because we don't want them to, essentially.”

(Expert 2 – technology/engineering)

“To be honest, there's nothing they really need to know ... because it was set up to maximum efficiency, they didn't need to touch it ... basically [instructions] said, ‘Don't touch anything, leave it as it is, it's fine,’ but as I said, they don't read it.”

(Expert 26 – resident liaison)

These extracts suggest a perception of residents as incapable of comprehending the technology and being disengaged from information about its operation, as discussed above, although this assumption may also mask issues with the usability of technology. This relates to work by Larsen and Gram-Hanssen (2020:19), who highlight the importance of domestic smart technologies that occupants find meaningful and have the necessary competencies for controlling ‘otherwise, occupants will quickly become reluctant to use them or create workarounds in order to make their everyday lives less complex or to achieve contrary goals.’ [11]. Some experts gave examples of building occupants being unable to understand control systems, which was one rationale for limiting their control:

“[w]e had a little display screen in it which showed, you know, how much energy we were generating at any one time, how much we were using ... and do you know, the problems we had because they just kept phoning up or emailing to say ‘it's not working, the system's not working’. So I'd go over and I'd say ‘well, you know, you haven't switched the system on’. I had to like type out instructions and put them next to the screen. And still people couldn't use the system. It was incredible to me that, you know, what I thought was quite intuitive. So it made me think that the controls and that user interface need to be so simple and so clear. Because they basically just needed on-off.”

(Expert 1 - architecture)

In such instances where experts suggested it was preferable for residents to have limited control, there appeared to be little expectation of behaviour change. In part, the inclusion of battery storage in all the developments was seen to negate or reduce the need for residents to adjust energy use to maximise the use of renewable energy that solar PV generation would otherwise require. However, some elements of the homes' new energy systems did require residents to do things differently, which was particularly evident in relation to heating and the sites that offered an energy service:

“So the resident is absolutely in control, but it's them telling us the outcome they want rather than them telling us the process to get the outcome. And it's in terms of behaviour change that's probably the biggest single thing ... we say to the residents, tell us which rooms you want at what temperature at what time, tell us when you want hot water and tell us when you want miles in your electric vehicle. And we take all of that and then through the optimisation platform we're forecasting wind generation, we're forecasting solar generation, forecasting prices and all that sort of stuff. And we will then pick the optimum moment for that home to charge the car or for it to fire the heat pump. So the behaviour change point is about getting

residents to understand they're not saying when something starts happening, they're saying when something actually has happened ... So that's the behaviour change really with that bit. But I think once we've got them through that on each individual home, once they've got their head round that, it means that we can then run the home much more efficiently for them,"

(Expert 5 – building design)

In this example, the expected behaviour change relates to the resident taking a much greater degree of forward planning. This was particularly important in relation to the operation of an energy service, where experts wanted “to get our user interfaces designed around customers planning ahead a little bit.” (Expert 4 – housing development). However, again this focused on perceptions of resident interest in “outcomes,” with control of the system most efficiently managed by external experts, as discussed in the section above. This level of forward planning was recognised by some experts as a significant change to the way many people usually managed their heating:

“Most people don't really have a set schedule. Most people get home and they turn the heating on, and then if it's getting a bit warm, they turn it off. To ask people what they'll want the house to feel like next Thursday, they were just like, ‘I don't know.’ It's an ongoing process with the residents to change the way they think,”

(Expert 6 – project management)

The assertion that it is an “ongoing process” suggests a period of adjustment as residents settle into life in a prosuming household [62], which indicates the need for ongoing dialogue between residents and developers about life in an Active Home.

4.3. Energy citizens?

Thus far, the expert quotes have focused on individual households and perceived motivations of efficiency and personal comfort. A more unusual refrain in the expert interviews was the suggestion that people were motivated to make changes to their lifestyles because of broader concerns about climate change and energy use.

“I think, there's certainly a thought about, we shouldn't think that people need to heat up to what they have, and they need to act, and they need to live a little bit differently. And I think that's certainly becoming more and more evident in people's thinking these days ... nowadays, you know, for children, they're growing up extremely anxious, and concerned about issues such as climate change, and CO2. So I think it's, it's really getting, the message is really getting across now. And especially with the younger generation ... So I think that we're hoping that that message will get translated in these properties and people will really realise that they need to, as well as just turning their energy down, they need to also be, be aware that they can't keep it to a paradox of using more energy because it's cheaper.”

(Expert 22 – technical/engineering)

From this perspective, active homes can be seen as a response to people's desire to live differently, rather than the homes themselves instigating this. The desire to live differently because of concerns about climate change, rather than just individual household gains such as saving money, could reflect a kind of energy citizenship where people are becoming more actively involved in the energy transition.

In discussions of resident choice about how to live, it is important to consider the extent to which the active nature of the home was a significant part of the decision to move to the property, given residents are likely to have different motivations [53]. Whilst some people choose Active Homes because of their low carbon and energy saving credentials, for others it is a case of the right location and size of home, with the active nature of the building a less significant consideration. The extent to which residents make an active choice to live in Active Homes may

therefore have an impact on the way they engage with the home and technologies it encompasses. Whilst many experts talked about residents in general terms, it was apparent that some identified different user types [21], which reflected a perceived distinction between active and passive householders:

“So at present we find that some are like ducks to water and jump in and start looking at how their property is performing instantly. The majority, when it's explained to them that they have this tablet, but there's nothing to do with it other than you can look at it for your information, they're generally quite relieved that there's not an extra thing to do, and they're not that fussed. So I think it's almost changing the paradigm initially so that people are used to these types of technologies before we introduce another step of, ‘You can manage this.’ Some people are already there, the majority don't seem to be,”

(Expert 17 – building development)

“I think with the public you'll get those sort of, you know, geek type people like us maybe who'll want to try new things and are happy to try things and see if they work. Then you get those people who are a little bit wary and pull back and think oh, I don't want to break it. I don't want to break it. And I do think you get those almost opposites with people... it's a complete sort of mind set change ... people like what they know ... but I think it's our role, if you like then, to change that and to make people realise that a), it has to happen, and b), it can be better. But I think there's some massive challenges around that.

(Expert 1 - architecture)

These two extracts distinguish between those interested in new technology, who resemble the resource man archetype, and those who are disinterested or fearful of technology. Again, this perceived disinterest or fear may indicate issues with the usability of technology, or reflect legitimate concerns about the suitability of technology for particular households [51]. Of interest here is Expert 1's perception of the role of designers and developers in bringing about essential change. This was partly achieved through design decisions, including where to site technology:

“if people can just about hear something it raises curiosity and raises awareness into how is their house operating ... I think a lot of clients like to lock things away but sometimes having something on display ... they're always a, a visual indicator and almost like a little surreptitious reminder to save energy.

(Expert 22 – technical/engineering)

In this example, seeing and hearing a battery is seen as potentially prompting resident behaviour change. Beyond design of the homes and their encompassing technologies, developers may also be influential through an ongoing relationship with residents, reflecting the “ongoing process” of change raised by Expert 6 as residents adjust to life in their new homes. Such a relationship is possible in sites where developers continue to have a role in operating an energy service, but less likely in sites where homes are sold or managed without this. For some sites, whilst ongoing relationships with residents were present, it was with registered social landlords (RSLs), who may lack the technological expertise to address issues related to the technical specification of the homes. Whilst experts responsible for the design of the homes and the technology within appeared confident that this would be sufficient to lead to energy efficiency and resultant financial savings, of particular concern for those with ongoing relationships with residents was the implications for residents of homes not living up to these expectations:

“You know, a lot of this technology relies on you not doing your washing when you want to but doing it when you have the power to do it in an affordable way, so it's all of that that's only going to come over time ... You know, what's the point of developing fantastic low carbon homes or zero carbon homes but they're costing people on low incomes a level that they cannot afford to run? You know, you're

absolutely defeating the object then, aren't you, in terms of what you're trying to do?"

(Expert 15 – resident liaison)

Whilst it is evident from this extract that some resident adaptation is expected, particularly in terms of changing appliance use to maximise efficiency, there is an underlying concern that this will not be enough to reduce energy costs and that the innovative buildings may not live up to the expectation of providing significant financial savings. For some residents, concern about energy use within their Active Homes, because of cost implications, appeared to be particularly acute [66]. For example, one expert gave an account of a house that was performing well according to monitoring criteria, but the residents were “wearing a hat and coat” to avoid using the heating, as well as checking and adjusting equipment within the home several times a day, because of concerns about affordability. Technical monitoring had demonstrated low energy use for this household but does not provide the full picture of the lengths the residents in question went to in order to monitor and reduce energy use. Instances such as this illustrate the limits of relying solely on technical solutions, indicating the need for “personal connection”:

“I think there will always need to be a human element to be honest with you. There's a lot of stuff they can do automated ... So there will be part of that which will need to be automated around it, but I do think there will... you know, my team I want to build to connect with people, because I almost... not as a customer service, just almost as a coach of this is how to get the best of your system .. and tailor it around that, and that will need having a personal connection with people because you have to build that relationship before you can answer their real questions... I'm supporting them to find their best solution because some of the things that they will do instinctively, from using a gas boiler, will actually create reverse results in their home.”

(Expert 12 – resident liaison)

Such accounts highlight the importance of continued engagement between Active Home developers and residents for the promises of these “homes of the future” to be fully realised, given the limits of automation.

5. Discussion

In this paper we have highlighted apparent contradictions in the way that Active Home residents are imagined, with divergent visions evident within the same expert accounts. Experts expressed mixed views on the level of information that it was desirable to provide to residents about their energy use and generation, with some suggesting that this formed part of the necessary “education” of residents about the operation of new technology, whilst others felt that information was uninteresting or irrelevant to residents. The perceived need for information provision was influenced by whether resident “behaviour change” was considered necessary or desirable, which again gave rise to mixed views. The presence of these diverging perspectives suggests ambiguity about how residents are expected to interact with the technology, which has implications for the homes' performance and the experience of living within them. Early insights from our resident interviews indicate that occupants would like more information about their homes in order to make efforts to use energy efficiently [67], indicating a willingness to make changes. However, without sufficient information, such changes may be based on erroneous assumptions. This supports existing research that highlights lack of information as potentially problematic for residents [53].

In the expert interviews discussed here, the need for information provision was also impacted by where control would be located; with the householder, with an energy service provider, or elsewhere (such as with an RSL). Evident in many expert accounts was the notion that it was preferable to minimise the level of occupant control over the domestic

energy system, in the belief that doing so was removing from the resident the burden of trying to understand and control a complex system and ensuring greater efficiencies. Some of the expert interviews indicated the value of information, in the form of “data”, to developers and as of little interest to residents. However, without information about how their Active Home and energy system operates – particularly how the different technologies interrelate – and without the ability to exercise direct control over it, this can potentially result in concern for some residents regarding their energy costs, which has implications for health and wellbeing [20]. Issues of access to data also raise important questions about control [8], which will be pertinent for future research into innovative home developments.

As alluded to by Expert 15, resident understanding of Active Homes and the technology they encompass is ‘*only going to come over time*’. Adjusting to a new heating system is likely to require time for residents to develop new “know-how” [15] to assess their comfort and heating system functionality, which will of course be influenced by seasonal changes in weather. Changes to heating regimes also have implications for other areas of everyday life – such as drying washing – where new practices may take time to emerge. Initial challenges with technology may be easily resolved or could lead to residents adopting “work-arounds” [11], which have longer-term implications for the sustainability of Active Homes. This recognition of temporal change and development highlights the necessity of continuing to engage with residents across the course of their move to Active Home living and beyond – and this kind of inquiry is particularly well supported by the QLL research approach used in our study [68]. Some Active Home site designs provide greater scope for ongoing relationships between residents and developers; for example, where energy service provision is included, developers have an ongoing commitment to ensuring resident comfort and reducing bills. In other sites, ongoing relationships are between RSLs and residents, which may give rise to challenges if RSLs lack the technological expertise to address issues with the homes and energy systems. As we have highlighted previously [67], ongoing personal communication is important in understanding the decisions that residents make in relation to their energy use and supporting them to get the best out of their smart home technologies.

6. Conclusion

Expert interviews reflected a view that developers are important instigators of change through design decisions. Less evident were notions of residents as active energy citizens, engaged because of broader concerns about climate change and energy beyond their own household. It appeared that whilst the homes may be active, residents were largely regarded as desiring a more passive engagement with their homes and encompassing technologies, which runs the risk of misinforming prospective residents [53] about the experience of life in an Active Home.

Assumptions that consumers are passive, indifferent and disengaged may also mask issues with the usability of technology. The success or failure of domestic smart technologies depends fundamentally on whether and how they are used by residents [63], as they will not always be understood and used as designed [11]. Providing information about how Active Homes operate and how residents can live well within them is important in facilitating residents' active engagement [59] with their homes and technologies they encompass, which may otherwise be only lightly incorporated into everyday life [53]. Moving beyond binary assumptions of residents is therefore an important step in more adequately tailoring information to individual needs.

For Active Homes to offer an opportunity for truly transformational change, they will need to be accepted by residents and address their needs and expectations. However, if residents feel that they have little understanding or control over their home, the prospect for change is limited. We suggest that it is crucial for developers to critically consider their assumptions about prospective residents and acknowledge that residents are likely to have varying levels of skill and interest, as well as

different motivations for moving to the homes. There is a risk that without critically considering expert assumptions, contemporary and evolving smart energy systems and smart building design will perpetuate and embody simplistic consumer archetypes. It is therefore possible that homes will not perform as expected, both in terms of their energy, carbon and cost savings and also in the achievement of residents' well-being [67], which has implications for the wider application of low carbon housing in the UK [54].

Without ongoing dialogue with residents, it is difficult to draw conclusions about the performance of Active Homes. Technical monitoring alone can provide an incomplete picture that does not consider how residents experience everyday life in an Active Home, whether they can meet their everyday needs and live well without concerns about cost. Given the emphasis that expert interviewees placed on customer satisfaction, this longer-term resident perspective is crucial in considering what makes a successful Active Home. Our ongoing research aims to address this by continuing to engage with residents over their first year of life in an Active Home to explore both initial experiences and those over a slightly longer term as they have had chance to settle into life in their homes. By continuing to engage with expert stakeholders across this period, we are able to feed back insights from residents to them, which can be drawn on to inform future Active Home developments. This ongoing dialogue also provides a potential opportunity to change developers' perceptions of residents, which could have implications for future home designs.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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