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From Active Houses to Active Homes: Understanding Resident Experiences of Transformational Design and Social Innovation

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Abstract: Active Buildings can contribute to efforts to address decarbonisation and climate change targets, and have the potential to support social aspirations for technical and infrastructural change. Yet achieving such goals is challenging. Active Homes as a type of Active Building represent a particularly interesting prospect; altering how energy is produced, distributed, and consumed, but also how homes are designed, constructed, and lived in are studied. Active Homes are designed with expectations of how residents will engage with them, but residents do not always live in the homes in ways envisaged by developers. Hence, there is a risk that the homes will not be experienced as comfortable living environments, or otherwise perform as anticipated. Thus, understanding resident perspectives is crucial to the successful wider rollout of Active Homes. We draw on social science research with designers, developers, and residents to explore expectations of life in an Active Home. Our longitudinal research design enables us to contrast early expectations with post-occupancy experiences, elucidating what residents consider to be successful aspects of Active Home developments. Our research reveals instances where expectations remain unfulfilled, or where living in the homes has been experienced as challenging or disruptive. In highlighting such insights, we offer recommendations relevant for future developments.

Keywords: active homes; low carbon; heating; qualitative research

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1. Introduction

It is recognised that decarbonisation of all sectors of society, including the built environment, is required to meet the UK Net Zero carbon emissions target [1]. While specific 'pathways' to net zero are evolving, most propose significant electrification of energy, transport, and buildings [2,3]. Decarbonisation via electrification poses challenges for national energy grids for balancing increasing levels of distributed and renewable (and therefore variable) energy production with consumer demand. Further complicating this, new patterns of less predictable energy demand are expected to develop as domestic electricity storage and transport innovations become more commonplace [3]. Such changes mean that without intervention, grid capacity could be exceeded at certain times, presenting challenges for energy management [4]. Subsequently, increasing focus is placed on transforming the role of buildings and consumers within the energy system.

While early efforts towards reducing energy consumption in buildings focused on increased energy efficiency and demand reduction, attention is now turning to integrate buildings more fully within the energy system as distributed or aggregated energy producers and energy storage sites, thereby creating additional system flexibility for national grids [5–7]. The characterisation of an Active Building has been used to differentiate buildings with 'active' technology that produces, uses, and exports renewable energy from 'passive' buildings such as Passivhaus, which reduce energy consumption and emissions due to 'in-situ' energy efficiency properties such as thermal insulation and natural ventilation [8]. However, current definitions of Active Buildings go beyond this, including the

ability to '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 [9]. Active Homes do not necessarily include smart controls for residents in the way that smart homes do, however, there are relevant synergies between these different designs, in light of accelerating household interest in battery storage, electricity sharing and trading, and demand response opportunities to better utilise the electricity they generate [10]. Being more sustainable, energy efficient, and digitally intelligent, such low and zero carbon buildings are seen as making a significant contribution to UK decarbonisation [2,3,11].

Active Buildings are not just transforming the energy-technological configurations and capabilities of buildings, but also the role of their occupants. Over recent years, previously termed 'passive' energy consumers or end-users have assumed more 'active' roles within the energy system, as prosumers [12] or energy citizens [13,14], with even 'passive' homes requiring a high level of occupant interaction in order to achieve both comfort and energy efficiency [15]. This shift is attributed in large part to the take-up of domestic renewable energy production alongside advancements in information and communication technologies, such as SMART meters [16] or Home Energy Management systems (HEMs) [12]. The integration of variable and complex configurations of low carbon energy technologies along with intelligent digital systems to enable communication with national energy grids, and potentially other Active Buildings [17], implies further transformation of demand side energy management, and the role of end-users.

As social scientists, we are particularly interested in Active Homes as a type of Active Building, given that they represent a potentially radical transformation of the home environment. Beyond decarbonisation, Active Homes have the potential to address a number of pressing social issues and policy priorities; for example, through offering residents a 'tangible economic payback' [9], they could contribute to addressing fuel poverty. In addition to lower energy costs, Active Homes are expected to provide residents with high quality and comfortable living environments [18,19] that enable residents to live healthily and well. Such ambitions are variously embedded within the design of Active Homes and influence both developer and resident expectations of Active Home living. Indeed, connections between homes or housing and resident health and wellbeing are well recognised within global policy and research literature [20–22].

Quality of the built environment has been identified as holding impacts for residents' health and wellbeing, whereby poor-quality housing can increase healthcare admissions, morbidity [21], and socio-economic inequality, limiting household life chances [22]. Similar household outcomes have been found relating to indoor temperatures, whereby inability to keep warm, or overheating, can adversely affect household health and increase risk of morbidity [23,24]. Moreover, established research on fuel poverty and energy vulnerability highlights the importance of household social-spatial-temporal contexts in addition to materially related energy efficiencies on both energy affordability and household health and wellbeing [23,25].

Active Homes may offer multiple potential benefits; as an innovative development they may also present risks to residents, not just in terms of underachievement of technical performance (as recognised in work concerning the 'energy performance gap' e.g., [26,27], but risk of economic loss [12], and disruption to everyday lives [28], which has implications for experience of life in the homes. Further, if residents do not engage with their homes and technologies in ways that correspond with designers and engineers' visions, there is a risk that these technologies will not contribute to network flexibility [29] or otherwise perform as expected [30–32]. This includes performing as a home in which residents want to live and can live well [18].

Below, we explore findings from our Living Well in Low Carbon Homes research, demonstrating how ambitions embedded within Active Homes, along with expectations for how residents will live, influence the energy-technological-built design of the homes and subsequent experiences of residents post-occupancy. This multi-perspective approach

allows us to elucidate instances where expectations are met, remain unfulfilled, or where living in the homes has been experienced as challenging or disruptive. Our approach also enables us to identify unexpected challenges faced by residents post-occupancy. As with our previous work on energy and everyday life [33], our methodological approach has potential value for participatory approaches to technology assessment such as those promoted under the rubric of 'responsible innovation'. We also follow Strengers (2013) [34] in proposing that an important site for such qualitative social science work is the thick contexts of people's practical engagement with technologies [35]. As developers recognise that resident satisfaction is crucial to the successful wider rollout of Active Homes [14], research exploring resident perspectives can play an important role in informing these innovative developments.

The paper proceeds with an explanation of the research methods, case sites, and samples. We then turn to the discussion of interview data, beginning this section with a brief overview of expert interviews in order to situate the more extensive subsequent discussion of resident expectations and experiences pre- and post-occupancy. Following this is a discussion of relevant insights, highlighting the original contribution of our approach in the context of existing literature. Finally, drawing on these findings, we conclude by identifying opportunities and recommendations for policy and practice.

2. Materials and Methods

The data presented in this paper come from the Living Well in Low Carbon Homes project, a social science study that forms part of the interdisciplinary Active Building Centre Research Programme (ABC-RP). ABC-RP involves a collaborative research framework to deliver insights on a range of aspects of building innovation with a view to enabling the construction industry to transform into a net zero emissions building sector within the next 30 years. An important aspect of this is understanding how these low carbon innovations are experienced by the people who occupy them, as their satisfaction is crucial to the wider success of such developments. Our Living Well in Low Carbon Homes (hereafter LWLCH) project involves a combination of in-depth interviews with developers and residents across five case sites of innovative Active Home developments in South Wales, UK (outlined in Table 1 below).

Qualitative interviews can give insight into the meanings that people attach to experiences, social processes, practices and events, and as such can yield valuable insights for policy decision-making [36]. Conducting interviews with experts allowed us to gain in-depth understanding of their views and experiences in light of their 'specific knowledge' [37]. In addition, taking a longitudinal approach with residents, where the same individuals were interviewed on multiple occasions at different time points, meant that participant accounts could be collected as biographically transformative experiences (such as moving house) were lived through [38], enabling exploration of change over time [39]. Bringing together these expert and resident perspectives enables us to explore how developers' decisions impact on resident experiences, highlighting practical insights relevant for future Active Home developments. Whilst expert interviews cover all five case sites, two sites were under construction, so resident interviews took place at sites 1–3 only.

In total, 29 experts took part in one-off interviews, which explored the motivations and context for Active Home developments, their expectations of future residents, and thoughts about future developments in low carbon home innovations. Relevant experts were identified from initial contact with case site representatives based on their knowledge of and involvement in Active Home developments, and were invited to participate, with the sample snowballing as further relevant experts were identified. In Table 2 below, we indicate the areas of primary specialism of the experts, however, some crossed multiple areas and case sites.

Table 1. Case sites.

Case Site No.	Defining Characteristics	Energy Specifics	Expected Resident Behaviour	Rural–Urban Classification	Development Size	Tenure
1	- Three-phase power supply - Grid flexibility - Aggregated energy & energy service	- Highly insulated - Electric vehicle charge point - Ground source heat pump (GSHP) - Solar Photovoltaic (PV) - Intelligent battery storage - Smart hot water cylinder - Underfloor heating - Wall mounted radiant heating - Smart appliances (optional) - Energy service - Aggregated energy demand, storage, and export	- Energy service to manage resident comfort requires communication between occupant and service technology - Resident management of energy use via in-home thermostatic controls and bespoke energy service App - No modification to resident routines is expected	Rural town and fringe	225 homes ranging from 2 bed flats to 4 bed houses	Owner-occupied. First residents moved in late 2020.
2	- Modular wood construction - Non-Volatile Organic Compound (VOC) paints - Air quality sensors - Local supply chain - Community allotment	- Highly insulated - Electric vehicle charge point - Intelligent battery storage - Solar Photovoltaic (PV) - Space heating & air circulation enabled via building layout - Wall mounted radiant heating - Smart hot water cylinder - Indoor air quality sensors	- To benefit from competitive tariffs, some modification of resident routines may be required - Resident management of energy use via programmable controls on individual radiators and separate battery App	Rural village in a sparse setting	15 homes ranging from 1 bed flats to 4 bed houses	Social rent and owner-occupied. First residents moved in Spring 2021.
3	- Transpired solar collector - Solar PV film roofs	- Highly insulated - Electric vehicle charge point - Intelligent battery storage - Transpired solar collector - Solar PV film roofs - Smart hot water cylinder - Manual Ventilation Heat Recovery (MVHR) - Wall mounted radiant heating	- To benefit from competitive tariffs, some modification of resident routines may be required - Resident management of energy use via programmable in-home controls	Urban city and town	16 homes ranging from 1 bed flats to 3 bed houses	Social rent. First residents moved in late 2020.

Table 1. *Cont.*

Case Site No.	Defining Characteristics	Energy Specifics	Expected Resident Behaviour	Rural–Urban Classification	Development Size	Tenure
4	- Active travel links - Ecologically conscious/sustainable features - Energy aggregation and energy service - Low embodied carbon - Encouragement of further sustainable lifestyle choices	- Highly insulated - Electric vehicle charge point - Intelligent battery storage - Solar Photovoltaic (PV) - Smart hot water cylinder - Manual Ventilation Heat Recovery (MVHR) - Ground Source Heat Pump (GSHP) - Smart appliances	- Energy service to manage resident comfort requires communication between occupant and service technology - Resident management of energy use via in-home thermostatic controls and bespoke energy service App - No modification to resident routines is expected, however, ethos and design of development to encourage further sustainable living	Urban city and town	34 homes ranging from 2 to 4 bed houses	Private rent. First residents expected to move in autumn 2023
5	- Ambient heat loop network - Water to water heat pumps - Mixed use - WELL Certification - Urban Farm & Community Interest Company - Natural and biologically flowing interior and exterior design - Place-making	- Highly insulated - Ambient heat loop network (recycling waste heat to space and water heating) - Aggregated energy production and export - Intelligent battery storage - Solar Photovoltaic (PV) - Air Source Heat Pump (ASHP) - Smart hot water cylinder - Manual Ventilation Heat Recovery (MVHR) - Wall mounted radiant heating	- Exact energy management of building is under development - No modification to resident routines is expected - Ethos and design of development to encourage connections to nature and further sustainable living	Urban city and town	50 homes ranging from 1 to 3 bed flats	Owner-occupied and Social rent First residents expected to move in 2024

Table 2. Experts.

Areas of Expert Stakeholder Specialism:	Number of Experts
• Architecture and building design	3
• Technology/engineering	2
• Housing policy	2
• Housing development	8
• Sustainability	3
• Project management	4
• Resident liaison (including sales, customer service, and RSL housing officers)	7

Whilst experts have undertaken individual research interviews, residents were invited to take part in three interviews across their move to an Active Home: once before moving and twice within the first year post-occupancy. This qualitative longitudinal design enables us to explore changes in participant accounts over time, from pre-occupancy expectations to post-occupancy experiences, as participants move and settle into their new homes. Interviews across a year enable us to consider how they find the home across different seasons, weather conditions, and related energy demand.

Information about the research project was distributed to all future residents of our case sites, either by housing sales teams or by Registered Social Landlords (RSL), with individuals invited to contact the research team if they were interested in taking part. A total of 37 residents from across case sites 1-3 have taken part in the research, with the final phases of interviews ongoing. This has involved:

- 17 residents from case site 1
- 11 residents from case site 2
- 9 residents from case site 3

Residents range in age from their early 20s to late 70s and have a variety of living situations, including living alone, in couples, or family groups. Of the 37 residents, 13 are men and 24 are women.

Interviews are transcribed verbatim and coded thematically using NVivo software. Whilst our analysis of the expert interview data has largely focused on prominent themes arising, with the resident data we are also able to consider individual accounts at different points in time to explore changes in everyday life across participants' accounts [40]. Below we present data from expert interviews, and from residents both pre- and post-occupancy, to consider both expectations and experiences of Active Homes.

In previously published work from the Living Well in Low Carbon Homes project, we have explored expert imaginaries and how they influence decisions concerning the design of Active Homes [14], as well as implications this has for gendered experiences of everyday life in these homes [28]. We have also developed a detailed conceptual overview of the development of Active Buildings [17], which provides insights into the social science context for researching Active Homes and relevant methodological development in this area [18], including consideration of the role of Active Homes in smart energy imaginaries, for example, in the context of smart cities [19]. In this paper, we present original temporally situated research insights concerning resident expectations of the homes and how these are met, exceeded, or disappointed post-occupancy. Understanding resident experiences has been identified as an important research endeavour; for example, Berry et al. (2014) [41] argue that:

> "Vital to the success of low carbon 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"

Our work aims to address this issue and insights from our research have clear implications for practitioners and policymakers in this field, which we highlight in the conclusion.

3. Results

We begin this section with a brief discussion of relevant themes arising in expert interviews, in order to situate the more extensive discussion of resident experiences that follows.

3.1. Expert Perspectives

Experts identified a range of motivations for Active Home development beyond addressing climate change and decarbonisation, which are listed (in no particular order) in Figure 1 below and discussed in detail as part of a conceptual overview in [18].

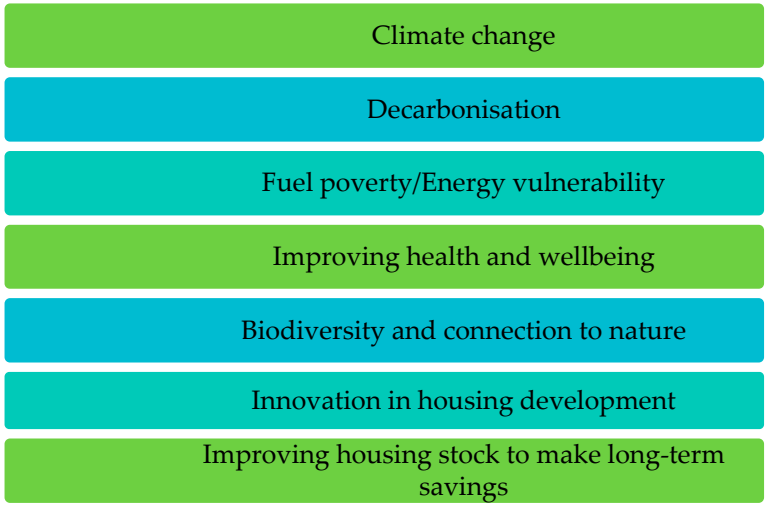

Figure 1. Developer motivations.

These motivations were often interlinked, with multiple issues being addressed almost serendipitously, as Expert 8 described:

> "And although we started off initially with, you know, energy poverty and affordable housing, it was almost serendipity that led us into . . . you know, looking at things like local sourcing, using timber . . . you know, and sustainability. All those sort of things fell out as a natural outgrowth of that main aim was to try and tackle energy poverty."

As such, Active Homes were depicted as having the potential to simultaneously address multiple pressing social issues and policy priorities. Active Homes were also described as offering numerous potential benefits to residents through thermally efficient fabric and energy generation technology resulting in reduced energy use and costs, as well as a more comfortable living environment. In addition, connection to nature through the provision of green spaces was expected to improve health and wellbeing and create cohesive communities:

> "So now the houses are going to be virtually zero, well, they're certainly going to be free of any bills, because once you put a [battery] in, it means you can store energy and you can also export it with a reasonable energy provider like Octopus or Tesla themselves, people will be able to live in these houses hopefully without the need to virtually pay any bills."
>
> [Expert 8]

> "the upsides are obviously much greater in terms of the space we're creating is, you know, very unique . . . we really believe that that's going to improve people's health and wellbeing, their mental state being immersed sort of in nature . . .

> the main success will be does it help generate create community? Does it help people's wellbeing? You know, and that's what we're trying to prove."
>
> [Expert 18]

> "With the range of advantages that experts envisaged from Active Homes, they expected that residents would "benefit from it, but also do their bit towards the low-carbon living."
>
> [Expert 26]

Experts differed in the extent to which they felt Active Homes required resident "behaviour change" or whether "anyone could live in the homes." This appeared to be related to whether they saw residents as interested in and able to learn from information, or whether they viewed residents as disinterested and incapable of understanding the homes' complex systems, with external expert control viewed as preferable [14]. The archetype of consumers as 'indifferent' has been identified in expert visions across a range of technological developments, such as low carbon homes [42], smart grids [43], and demand side response [44]. These studies have highlighted the way that such archetypes can 'script' user behaviour, with potentially negative consequences [45]. The persistence of such archetypes is particularly relevant in the context of Active Homes, as energy generation technologies such as solar PV may require active administration [5]. There is also evidence of expectations embedded in industry visions that opportunities for consumers to access and participate in the energy market by using new energy technologies will give rise to the engaged consumer and prosumer [46]. Several experts anticipated this greater engagement from residents, expecting increasing demand for Active Homes, influenced by broader social issues, changes and debates, such as growing awareness of climate change and rising energy costs:

> "Definitely more demand for [energy generation technologies]. It's not the primary kind of driver for anybody but there's significant more demand. I think the higher up the house price ladder you go, the more the demand becomes evident. But yeah, definitely awareness of, of, of those technologies, especially with energy crisis now,"
>
> [Expert 27]

These multiple anticipated benefits, combined with a perception of societal demand for, and government commitment to achieve, UK-wide net zero targets [2], meant that many experts expected that Active Homes would become increasingly mainstream developments in future. However, broader success was recognised as contingent on residents being able to live well in the homes. Whilst technical monitoring can provide some insights into an Active Home's performance, this provides a limited picture of resident experience. By speaking to residents over time, we can explore in detail the day-to-day experiences of life in an Active Home, elucidating successes and challenges, and highlighting implications for future developments.

3.2. Resident Perspectives

For the remainder of this section we focus on insights from resident interviews, highlighting their pre-move expectations and considering how these were met, exceeded, or disappointed following Active Home occupancy. Topics we consider include energy bills, health and wellbeing, thermal comfort, obtaining information and learning about the homes, and the benefits and risks of innovative developments.

3.2.1. Pre-Move Expectations

Participants described a range of motivations for moving to an Active Home development, which varied according to their individual circumstances. For some, it was simply a case of finding a house in the right location and budget, with the 'Active' nature of the home a secondary consideration. However, for the majority of participants, the Active aspects

of the home were an important element in their decision to move. For a small number, the development's low carbon credentials were the primary motivation for moving, and some participants had relocated a considerable distance in order to live in an Active Home. Whilst several participants valued the homes' low carbon credentials in terms of concerns about sustainability and climate change, most perceived that these characteristics could also reduce energy bills. Although developers had generally not specified the level of energy bills that residents could expect, in our pre-occupancy interviews we found that all participants described expecting lower (or even non-existent) energy bills.

> "But what drew us in was all of the kind of eco, the low-carbon features, and the fact that a place like that did exist . . . the amount of, the amount of carbon saved, and the fact that, you know, the solar panels can generate, you know, 13, 14 kilowatts of energy, which can then be stored in a [brand] battery . . . So kind of zero energy costs. And being able to, you know, switch on a light and do whatever you wanted, and thinking, oh, this is all, this is all free."
>
> [Participant 28]

Buying a new home was expected to be low-maintenance and low-cost now and into the future, which was an important consideration for many participants, given that the majority saw their Active Home as a long-term residence. Several participants described their new build Active Home as a more convenient 'ready-made' solution to sustainable housing than attempting to retrofit an older property [28]. Whilst some low carbon developments such as self-build eco houses are often associated with hardship and compromise [47], participants expected Active Homes to offer comfort alongside energy savings:

> "I mean, one other thing about low-carbon design . . . Active houses—they're meant to be comfortable; you know, you're not meant to suffer in them for the sake of low energy use, you are actually meant to be enjoying being in them."
>
> [Participant 24]

Those who were living in older hard-to-heat properties often described experiencing damp and mould, which were sources of discomfort [48], and which participants perceived as contributing to health problems. In contemplating their imminent move, most participants spoke of expecting their Active Homes to be warm and comfortable. Poor quality existing housing was described by some participants as exacerbating existing health problems, particularly respiratory issues, which many expected to improve post-move with the better air quality and thermal efficiency of an Active Home. For some participants with mobility issues—or who lived with household members who had—the accessible layout of both indoor and outdoor space at their prospective home was expected to improve their ability to undertake everyday tasks and therefore enhance their quality of life.

> "it will be a lot better . . . it's right round the back of the cottage it is, and I go round there and pull the gas [bottle] sometimes, you know, just to see what . . . what's not empty, but it's a joke. So, yeah, I can't change the gas either because my hands don't work properly so I have to get [my son] to come all the way over here to change the gas for me."
>
> [Participant 18]

Participants were largely positive about the move to their prospective homes and the improvements that they felt this may bring to everyday lives; however, some expressed concerns. Most commonly, these related to new or unfamiliar aspects of the home's design that led to uncertainty over operation (such as moving from a gas central heating system to a ground source heat pump), or how this may impact day-to-day life (for example, how laundry could be dried without radiators). Several participants also indicated that with high levels of insulation and glazing, they expected overheating in summer to be a potential issue:

> "I wouldn't say this is a worry, but again, just curious—in the summer, because I know the insulation is very special, very specially insulated, so I'm wondering, is it gonna be like a sauna in the summer, our house? [Laughs] . . . So yeah, I think that's probably another little worry"
>
> [Participant 12]

Other concerns were expressed in relation to reliability and durability of technology, given it was perceived by some as innovative:

> "The only thing that would be a concern obviously because there's a lot of new technology maybe that hasn't been around for long, whether there's glitches or whether like there's faults and stuff with it. Because on the estate there's a lot of boxes of electrical stuff and whatever. And it does seem quite excessive to have stuff like that. So it's whether or not it all kind of lasts and whether it is safe for a long time. In the houses they've got water sprinklers as well, so that's something I never had in my other new house. But yeah, things like that. I would worry whether it is durable and will last a long time."
>
> [Participant 5]

The recognition that they were moving to innovative developments was evident in participants' expressions of pride in being some of the first UK residents to live in an Active Home, which many perceived meant that there were likely to be initial 'glitches' or 'teething troubles', which they generally expected the developers would be able to address relatively promptly. However, some acknowledged potential risks of innovation, highlighting underlying worries about what would happen if the homes failed to deliver anticipated benefits or if technical difficulties could not straightforwardly be resolved:

> "I'm happy to carry a little bit of responsibility there, not responsibility, a liability side of it. We are, we are choosing to move into a house like this. We are in a way choosing to be the guinea pigs a little bit . . . We're doing our bit for the environment and if that's the, if that's what the responsibility we have to carry with it that's fine, but at the same time I don't wanna be left, you know, in the lurch like. Either with, either with a large bill or no electric."
>
> [Participant 9]

These pre-occupancy responses illustrated participants' optimism that Active Homes would deliver expected benefits and lead to improvements in everyday lives, alongside concerns about some of the risks envisaged in moving to an innovative development. We turn now to consider post-occupancy experiences in light of these early expectations.

3.2.2. Post-Occupancy Experiences

After living in their Active Home for several months, the majority of participants reported being happy with their decision to move into an Active Home and expressed ambitions to remain living there long-term. Many still expressed pride at living in a home that they perceived as being trailblazing and contributing to societal goals, and several participants commented on how the significant increase in energy prices seen during 2022 had made their decision to move to an Active Home seem even more fortuitous. Living in an Active Home was reported to have provided many participants with some reassurance that despite the cost of living and energy crisis, they would remain able to afford their energy bills without compromising their comfort or lifestyles. Some participants spoke of how feelings of anxiety and dread that they had experienced in previous homes as winter approached had been alleviated:

> "I'm not worried about winter. Which I think every year previously, it was, sort of, a bit of a dread going into winter cos you knew it was gonna be really cold. And it's always that, sort of, battle of trying to manage how cold you wanna be versus how much you wanna spend on your energy bills"
>
> [Participant 20]

Our interviews over a 12-month period enabled us to explore residents' experiences of thermal comfort across a range of seasons and weather patterns. We found that whilst some participants described their Active Homes as colder than they had anticipated, most described their homes as warm, including during winter periods.

> "I just realised, sort of, maybe, like mid to end of December that I didn't actually need to put the heating on . . . it's been a very comfortable temperature . . . I seem to have been very lucky because obviously like I just said, you know, the house is so warm, it's so well insulated that it just doesn't feel cold at all in here,"
>
> [Participant 20]

However, several participants spoke of their bills as being higher than anticipated and, in a small number of cases, as unsustainably high, which was described as leading some residents to question whether they could live in the homes in the long-term. Whilst in some cases this may be related to inaccurate pre-occupancy expectations (e.g., that energy would be free), in others these unexpected costs related to the homes not performing technically as anticipated. In these instances, several participants expressed concerns regarding negative impacts on their health and wellbeing due to self-rationing heating, ongoing anxiety and new situations of energy debt. Case site 1 incorporated an energy service for residents (see Table 1). The service is a form of Energy Service Company (ESCO) or aggregator (c.f. [5,49]), which manages energy generation, storage, and demand of households across the development in an effort to reduce residents' energy costs and carbon emissions. At this case site, some participants explained that they had initially been surprised by higher than anticipated bills, and so sought guidance from the ESCO about changes that they could make to reduce these costs.

> "I contacted them and said, you know, "this is not what we expected at all, how do we save?" really. And he said, the main thing is, kind of keep it on a temperature that you're happy with, don't let it drop below 18 because then if you let it drop to like say 15 and you decide you're cold, it's going to take hours to heat up then, which you're spending more money . . . So we have been trying that now, and that's where we'd like to see if that's improved anything for us because we never let, we used to let it drop to about 15 and then, we'd keep the heating off though, that's what we weren't understanding is perhaps we didn't put the heating on for two days, but we weren't saving by doing that. So now we want to see if obviously, because we haven't let it drop below 18, are we saving by doing that?"
>
> [Participant 13]

The ability to raise queries with and seek advice from developers through this kind of personal contact was described as valuable by participants at this case site and led to a generally positive view of the company concerned.

An unexpected post-occupancy experience reported by many participants at case sites 2 and 3, was that the process of finding energy companies and appropriate tariffs was difficult and often protracted. This difficulty was attributed to the novelty of the technological configurations of the home, incomplete, or sometimes incorrect information about the system. These issues, along with confusion around ownership of batteries used to store solar energy generated by PV panels on the homes, and the timings of export to the grid, in addition to entitlement to export tariffs and energy produced, were reported as making it difficult for participants to gain access to appropriate energy tariffs, download independent energy monitoring apps and understand their own energy profiles.

Whether information was provided to residents, how it was provided, and when, was variable both within and across case sites, which could partly reflect differences in expert views and expectations of residents [14]. For example, whilst some participants said that they were provided with extensive handbooks and user manuals, other residents described receiving no information at all about their homes or how to operate the technologies that they encompassed. For some residents who described themselves as 'not technological', finding relevant information was a challenge, yet many spoke of the efforts that they had made to learn about the technology and better understand their home [28]. Even where extensive handbooks and manuals had been provided, this information was not always presented in a way that was easily comprehensible to residents. A lack of comprehensive understanding of their system was a cause for concern for some participants; particularly those who were experiencing high energy bills and had little idea of what they could do to reduce these:

> "outside my patio door now there's a shed there, it's locked, never been able to get into it, never been given the key for it, never been told anything about any of the concept or the amount of energy that is stored by the, the solar panels. So we have absolutely no, well I, we have no idea if it's effective or if it's not effective"
>
> [Participant 31]

Regardless of the level and type of information that they had received, participants from across the three case sites described how they would like more information about their homes. Without information, some participants made erroneous assumptions about their systems (e.g., when they believed batteries were full or empty). In particular, a need was identified for developers to provide holistic information about how the different elements of the homes worked together (rather than just individual technologies) and about how the residents could use the home most efficiently.

> "Definitely, if you had like, like notifications on the app, saying like, you should use your dishwasher now because this is the cheapest price of the day. Like stuff like that, I'd like that because that's useful, and it's making you think more effectively."
>
> [Participant 5]

The desire expressed by participants for more information suggests an interest in learning about their homes and the technologies that they encompass in order to benefit fully from them. This goes against some expert assumptions of residents as disinterested and disengaged (as discussed in Section 3.1, see also [14]) and raises important considerations about the type and manner of information provision. These findings also support existing research that highlights the potential willingness of residents to change the rhythm of everyday life to be in sync with their Active Home's self-generation of electricity, and the necessity of supporting residents to become active energy citizens more engaged with their own energy consumption [50,51].

Discussions with neighbours were often described as an important source of information about the operation of technology and performance of homes. For example, participants described sharing information with neighbours about tariffs and suppliers, and how to operate or adjust equipment in their home. In this way, the nature of the Active Homes and learning how to live in them, was reported to be a key part of how community relations were being established:

> "People with, with any kind of new technologies or anything like this, it's useful to be able to compare notes with our neighbours. And because we're on speaking terms with all of them, I mean that happens quite naturally . . . Whereas traditionally you might have gone out and talked about things, we're talking about energy, energy, energy production and how much they're getting."
>
> [Participant 28]

Discussion of differences between the homes' performance was reported to have also led some participants to investigate faults that may have otherwise gone unnoticed without this comparison with neighbours.

A significant concern mentioned by a number of participants at all sites related to overheating. The exception to this was the detached homes at case site 2, which were described by several residents as maintaining a reasonable temperature even in the two summer 2022 heatwaves. Others across the three case sites said that the homes' insulation, glazing and roof design meant that they became uncomfortably hot in summer and participants spoke of investing in fans or air conditioning to manage this, which had implications for energy use.

> "Yeah, I think because of the insulation, it gets so hot in here. So yeah, I find myself opening the windows all the time just to get a bit of air through. There's no, like, draughts or anything coming through the windows when they shut . . . 'It's a really well-built house, isn't it? It is. You know, it's, yeah, it's very good quality . . . but it's boiling our bedroom . . . I think we will have to get a fan . . . We even spoke about maybe next year potentially investing in some air conditioning. [laughs] Maybe it's just, yeah, it's very hot.
>
> [Participant 11]

In light of concerns about increasing temperatures, some participants highlighted measures to address overheating as an important design consideration for future developments.

Several participants across the case sites self-reported improvements in health and wellbeing since moving to an Active Home; often this was in relation to perceived improvement in respiratory conditions. Participants attributed this to living in high-quality homes without draughts, damp or mould, which several described having had to contend with in previous properties. In particular, for participants with mobility issues, or who acted as carers for household members, the accessible layout and convenience of their Active Home was praised, and they described significant improvements in their everyday lives, with one participant describing their life as "500% better".

Some participants described how the mix of energy technologies in their Active Home required a significant level of electrical wiring and additional Wi-Fi capacity compared to a conventional home. For some, concerns were raised about how this may negatively impact their health because of EMF emissions, which were thought to impact on sleep or general wellbeing. Others explained that there was now an additional mental load associated with managing the technologies, including remembering to turn them on and off, which could be seen as a form of 'digital housekeeping' [52]. However, these perceptions were not universal, with some participants reporting feeling impressed with how the different technologies could work together, helping them live in a way that was low carbon and low cost but also convenient and comfortable.

> [w]e're really looking forward to being able to have similar conversations with people to say, an eco-house doesn't have to be a compromise. It's not all, you know, happy, clappy hippy stuff. It's, it's a perfectly normal functioning house that doesn't require you to think about it differently or do anything different. You just live in it. And, and it looks after you sort of thing.
>
> [Participant 26]

As described above, most participants anticipated some initial technical glitches as the home designs were new and developers were learning as well as residents. Often initial challenges were evident in relation to heating, partly related to the different operation of low temperature heating systems, which required planning further in advance. Some participants at all case sites mentioned issues with the hot water—either not having as much as they had anticipated, or the water temperature not being as hot as they would have liked, which resulted in changes to their routines (e.g., having showers rather than baths). For households with greater numbers of people, managing the amount of hot water available was reported to have been a learning curve and resulted in compromises to

routines [28]. For those used to instant hot water from a combi-boiler, waiting for water to heat up was said to be a new experience that required a greater degree of planning and that took some time to get used to. Several participants from case site 1 had reported seeking assistance from their energy service provider on the best times to set the hot water readiness in-line with their bathing times, whilst others said they had had their system checked for faults.

> "It's just the, the water rather than the heating that took some getting used to, the water tank . . . that is a big frustrating, annoying thing about this house . . . within the very first few days of us living here [partner] had a shower and it was just, it was running cold water . . . So there's, there's a number, just like an emergency line . . . Explained the situation, he was like, "your tank must have just been empty." I was like, "well surely if the tank is empty, you've still got like an instant hot water function, you know, like all boilers do?" And he was like, "no, it's just, just the tank like." So that's when he suggested changing the time on it, I dunno what it was on, it was, it was set on a default time, whatever that was. And he asked me, just asked me a few questions like, when do you think you're gonna be using the most, and that's when he set it to the seven o'clock thing and he said at 10 o'clock it'd always be full, and it'd always be full of hot water. So, you know, after it, theoretically you can have two baths at night like."
>
> [Participant 9]

Whilst participants were somewhat tolerant of initial teething troubles, issues that continued over longer periods were a cause for concern and frustration, and could have an impact on everyday life. Participants described their hopes that lessons would be learned from these initial Active Home developments in order to avoid repeating things that had been unsuccessful at other sites. For example, one participant who remained concerned about high energy bills 12 months post-occupancy noted:

> "hopefully the next sort of phase of these homes from when they built, they will get whatever heating system working properly that they should have had working here, will, will be much more advantageous to everybody going forward . . . And if they have learned anything from our development, and taking it forward to the next one, and, and how to improve the lives of more people, then all better."
>
> [Participant 31]

Subsequently, by drawing on insights from the experiences of residents of these early developments, opportunities for improvements in practice can be identified.

4. Discussion

Active Homes, through their scale up and aggregation, could represent a crucial component of pathways towards net zero. However, their important role in mitigating climate change can only be realised if Active Homes can function as homes that residents can live well within. It is imperative that as Active Homes begin to be realised and occupied, the lived experiences of residents are understood, and insights are applied to future developments [18]. Bringing together insights from experts and residents as part of an original qualitative longitudinal study has enabled us to garner a holistic picture of Active Home developments with unique insights relevant to policy and practice.

Our research findings highlight that both developers of Active Homes, and the residents who occupy them, hold various expectations for how the homes may perform and be experienced as living environments. This includes technical expectations for low carbon technology and designs, and expectations for homes that are imbued with value and meaning, where daily life can be lived well. Once living in the homes, our research has illustrated that a number of both developer and resident expectations are achieved, and some are exceeded, whilst others are not met. Our temporal research approach has also enabled us to reveal challenges experienced by residents post-occupancy that they had

not expected pre-move, such as issues with the quantity and temperature of hot water, or the complexities of trying to organise an appropriate energy supplier and tariff. Where developers were able to provide assistance with these issues, this was highly valued by our participants. However, lack of assistance could compound feelings of frustration.

Pre-move, most participants anticipated a good quality home and an absence of structural-related problems such as damp, which was largely realised post-occupancy. For some participants who themselves had, or who lived with others with mobility issues, the accessibility of the homes and neighbourhood overall were expressed as contributing to increased autonomy and privacy, both important intrinsic values associated with the home [20,25,53]. For our participants, having a warm home was considered important, particularly for those who had lived in cold or hard-to heat-homes previously, which several participants described as leading to negative health outcomes. Post-occupancy, most experienced the homes as warm and comfortable, although for some, thermal comfort was still a concern. Similar to findings of quantitative research by Baba et al. (2022) [54] and Jang et al. (2022) [55], many of our participants explained how their homes had been excessively warm over summer months. However, unlike Jang et al. (2022) [55], our participants explained that they had experienced difficulty in reducing the temperature, and naturally ventilating the home did not suffice. This had reportedly caused discomfort and necessitated the purchase of cooling appliances at additional cost and energy consumption.

Pre-occupancy, the majority of participants expected that the low carbon characteristics of the home, combined with renewable energy generation and battery storage would mean that they would incur no, or extremely low, energy costs. Post-occupancy participant experiences of energy costs were mixed, with some having low energy costs, in line with their expectations, and others having higher energy costs than anticipated. Where energy costs were high, some participants spoke of feeling dread, anxiety, and depression, especially when bills were received. A small number of these participants spoke about self-rationing their energy to the point of discomfort, which, as research exploring fuel poverty and energy unaffordability coping strategies has found, can hold serious negative impacts to health [56,57]. However, some explained that even though their energy was costing more than expected, they could not reduce their energy consumption as it would adversely affect the health of others in the household or caring practices that were viewed as 'non-negotiable' [58]. For several participants, higher than expected energy costs led to questions about the long-term financial viability of the home.

Post-occupancy interviews reveal the way that learning how to live in an Active Home takes time as residents learn to live with and operate new technologies and heating systems alongside seasonal variation in weather and energy demand. In addition, developers are also learning about the homes over time, identifying and dealing with technological faults and operation. It can be difficult for residents to take in information during the process of moving, which is a busy and stressful time. Residents valued ongoing relationships with developers where they were able to raise queries and where these were responded to quickly. From ongoing dialogue with residents, developers can also learn about the homes and where improvements can be made, which can inform future Active Home developments.

5. Conclusions

With ambitions for increasing numbers of Active Home developments, and recognition that the satisfaction of residents is crucial to the success of this wider rollout, it is imperative that the expectations and lived experiences of residents in these early iterations of Active Homes are understood, and insights are applied to future developments [18]. Whilst technical monitoring plays an important role in assessing the performance of Active Homes, ongoing dialogue with residents over a longer-term period is also crucial. Without this, technical monitoring may 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. Furthermore, as highlighted by some stakeholders, the development, occupancy, and management of Active Homes is a learning

process for all involved including both experts (such as developers, landlords and energy service providers) and residents. Thus, it is equally important that as residents are expected to learn how to live in their new homes, stakeholders also learn from resident experiences. Our ongoing research aims to highlight these resident experiences, feeding back insights to developers in order to inform future Active Home developments.

Drawing on initial insights from across our case sites, we highlight some recommendations for developers. Firstly, it is important to provide information to residents about the appliances and technology within their homes that they can refer to. Without this information, residents may make erroneous assumptions (for example, using the coloured light on the battery to decide when to use energy instead of reporting a fault). Learning how to use new systems takes time and residents valued ongoing relationships with developers where they were able to raise queries and where these were responded to quickly. Our interviews with residents indicated their interest in learning about their homes and potential willingness to make changes to everyday routines in order to use the homes most efficiently, but many expressed the need for further information to base these changes on.

Whilst participants expressed enthusiasm about the prospect of being 'pioneers' as residents of early Active Home developments, consideration must be given to how residents will be supported by developers if technologies do not work as anticipated so they are not "left in the lurch" as one of our participants put it. Many participants expected initial technical glitches or "teething troubles", but often anticipated that developers would assist with resolving these promptly. However, if these difficulties were not resolved quickly, it could have a detrimental impact on residents' experience of the homes. While recognising that the development of Active Homes is a risky, learning process for all involved, clarity must be provided on ownership and governance of all aspects of the home energy system prior to resident occupation. This includes issues around entitlement to energy produced, entitlement to battery control (discharge or retain charge), and entitlement to export tariffs. These were issues that many participants had not anticipated pre-occupancy and were surprised at how complex it was to resolve some of these uncertainties.

Finally, overheating was a notable concern for participants, which some had anticipated pre-occupancy. In light of concerns about increasing temperatures, future Active Home developments must address this issue in the design of homes to avoid residents relying on potentially costly additional cooling devices.

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