Living Well in Low Carbon Homes Project Report

Active Building Centre Research Programme

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1. Introduction

For UK decarbonisation and climate change targets to be met, significant changes to existing and future housing stock are required. In particular, a reduction of residential energy consumption is urgently needed (Mechlenborg and Gram-Hanssen, 2020). In the UK, buildings account for 20% of UK carbon emissions, and of the overall emissions from buildings, the majority (nearly 80%) is from residential buildings (CCC, 2022). UK and devolved Government policy commitments necessitate substantial changes in the heat and power of buildings, with increasing focus on utilising low carbon and renewable energy sources (Welsh Government, 2020). These commitments, along with growing societal demand for further decarbonisation, directly implicate the potentially transformative role that buildings play within the energy system and society (O'Sullivan et al. 2020).

Being sustainable, energy efficient and digitally intelligent, Active Buildings are envisaged as making a significant contribution to UK decarbonisation. As social scientists, we have an interest in Active Homes as a particular type of Active Building as they represent a potentially transformational innovation, altering how energy is produced, distributed and consumed, in addition to how homes are designed, constructed and then lived in. Until recently homes were considered as places of energy demand and consumption, but increasingly are also places of energy production, with potential to be places of energy flexibility, through energy storage capacity as well as intelligent energy import and export to national grids (Thomas et al. 2020). As many pathways towards decarbonisation in the UK predict significant electrification across buildings, transport and energy sectors, new patterns of electricity demand will form, and existing patterns may change (CCC, 2019; Ofgem, 2020; Regen, 2020). In addition, the integration of renewables presents challenges for national energy grids and energy regulators in balancing energy production with existing and new patterns of consumer energy demand. Without management, such decarbonisation pathways could mean that existing grid capacities are exceeded. The integration of Active Homes into the UK energy infrastructure offers a potential means for addressing this issue.

While holding an important role in UK decarbonisation, Active Homes are depicted as offering multiple benefits for residents, such as 'self-sufficiency, improved quality of life and a tangible

economic payback' and have been described as 'houses of the future' (ABC website). It is important to recognise Active Homes as more than a material building, or an extension of energy infrastructure, they are also homes. This means they are laden with subjective intrinsic meaning and value, representing to some, security or safe haven; privacy; control; reflection of values (Roberts & Henwood 2019); and are places of personal relationships and emotional experience (Després 1991). Active Homes will likely alter these meanings, through changing existing materialities, by altering traditionally individualised and private spheres of energy demand and production towards ones where data and energy resources are shared, subsequently affecting communication and contestations between both new and existing actors.

Further complicating this transformation is that it holds effects for and will also be affected by the way people live in their homes, including their energy related practices. Everyday and often taken for granted routines are influenced by a variety of complex and interconnected dimensions, which include the aforementioned material, technological and intrinsic values, but which also span the social, cultural, societal and subjective. Research has already demonstrated that how and why energy is used by households is related to where they are in their life course and the lives linked to the household at different points in time (Groves et al. 2016; Shirani et al. 2017; Hargreaves & Middlemiss 2020). These personal contexts and linkages within a household also interplay with linked lives or relationships with others outside of the household (Hargreaves & Middlemiss 2020; Shirani et al. 2020), as well as place-specific contexts and energy geographies (Golubchikov & O'Sullivan 2020; Roberts, 2020), which are changeable through time. Together, these multiple links shape how and why people live in certain ways within their home, how tangible energy and other daily practices fulfil multiple other intangible or invisible functions, including psychosocial effects (Henwood et al. 2016). Without understanding fully the interplay between these interwoven elements, Active Homes may not fulfil their multiple performance goals including that of being sustainable and liveable homes.

Living Well in Low Carbon Homes is a research strand of the Active Building Centre Research Programme, Work Package 9 taken forward by Cardiff University. The Active Building Centre's vision is to transform the UK construction and energy sectors through the deployment and

demonstration of innovative buildings that are sustainable and low or zero carbon, potentially significantly contributing to UK decarbonisation. Our Living Well in Low Carbon Homes (hereafter LWLCH) research is producing insights into the lived experience of residents in Active Homes, elucidating the interplay between people, homes, and energy, as the anticipated new dynamic role of buildings in energy infrastructure is realised. Using a combination of interviews and multimodal activities, we are exploring the impact of living within these homes on residents' everyday lives and anticipated futures at different points in time (including prior to occupation). In addition, we consider how these contexts impact upon individual households' direct and indirect energy practices and internal relationships, as well as wider community relationships. To gain a nuanced and contextual understanding, we also explore developer motivations, the ethos underpinning different designs, and subsequent lived experience of the homes. This, along with multi-scalar and interconnected social and political contexts, influence the developments' materiality and technical specifications. Finally, emergent changes in regulatory regimes and decarbonisation of whole energy systems in the medium and longer term have been considered, as they may differently alter the role of buildings and homes within the energy system over time.

This report brings together insights from interviews with expert stakeholders, prospective and current residents of Active Homes, and focus groups with local communities, to present some of the main themes arising from our research. In detailing these themes, we highlight insights of relevance for policy makers and practitioners. Whilst the focus of our research has been on newly built homes, our research also has relevance for domestic retrofit endeavours, and we elucidate these insights in the report.

2. Case Sites

We selected five case sites across South Wales, varying in their specific locations, compositions of stakeholders, and their primary ambitions. Consequently, each varies in their built design (fabrics, layout, aesthetics), their impact on existing environments and communities and combination of energy sources and technologies. Wales is an appropriate study location as a particular locus of innovation for Active Home development, partly due to financial investment from the Welsh Government's Innovative Housing Programme (IHP). An emphasis on sustainable development is also enshrined in the Wellbeing of Future Generations (Wales) Act (2015), with the Future Generations Commissioner for Wales identifying a need in Wales to develop new, high quality and low carbon homes.

Table 1 below outlines the key features of the case sites, with more narrative detail about each development provided below.

Case Site No.	Defining Characteristics	Energy Specifics	Expected Resident Behaviour	Rural-Urban Classification	Development size	Tenure
1	- 3 phase power supply - Grid flexibility - Energy service	- Highly insulated - Electric vehicle charge point - Ground source heat pump (GSHP) - Solar Photovoltaic (PV) - Battery storage - Smart hot water cylinder - Underfloor heating - Wall mounted radiant heating - Smart appliances (optional) - Energy service	- Resident management of energy demand (space heating and hot water) via in-home thermostatic controls and bespoke energy service App - High insulation levels and slow rates of space heating and cooling may alter heating and cooling routines - Small number of wall mounted radiant heaters may lead to modification to laundry routines for some residents	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 - Battery storage - Solar Photovoltaic (PV) - Space heating & air circulation enhanced via building layout - Wall mounted radiant heating - Smart hot water cylinder - Indoor air quality sensors	- Resident management of energy use via programmable controls on individual radiators and a manufacturer developed battery App - To financially benefit from solar PV and battery stored energy, some modification of resident routines may be required - Small size of wall mounted radiant heaters may lead to modification to laundry routines for some residents	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 - Battery storage - Transpired solar collector - Solar PV film roofs - Smart hot water cylinder - Mechanical Ventilation with Heat Recovery (MVHR) - Wall mounted radiant heating	- Resident management of energy use via programmable in-home controls - To financially benefit from solar PV and battery stored energy, some modification of resident routines may be required - Small size of wall mounted radiant heaters may lead to modification to laundry routines for some residents	Urban city and town	16 homes ranging from 1 bed flats to 3 bed houses	Social rent. First residents moved in late 2020.
4	- Active travel links - Ecologically conscious / sustainable features - Energy aggregation and energy service	- Highly insulated - Electric vehicle charge point - Battery storage - Solar Photovoltaic (PV) - Smart hot water cylinder	- Resident management of energy demand (space heating and hot water) via in-home thermostatic controls and bespoke energy service App	Urban city and town	34 homes ranging from 2 to 4 bed houses	Private rent. First residents expected to

	- Low embodied carbon - Encouragement of further sustainable lifestyle choices	- Mechanical Ventilation with Heat Recovery (MVHR) - Ground Source Heat Pump (GSHP) - Smart appliances	- High insulation levels and slow rates of space heating and cooling may alter heating and cooling routines - Small number of wall mounted radiant heaters may lead to modification to laundry routines for some residents - Ethos and design of development to encourage further sustainable living			move in autumn 2023
5	- Ambient heat loop network - Water to water heat pumps - Mixed use - Building with Nature certification - Urban Farm & Community Interest Company - Natural & biologically flowing interior & exterior design - Place-making	- Highly insulated - Ambient heat loop network (recycling waste heat to space and water heating) - Shared energy production and possible export - Shared battery storage - Solar Photovoltaic (PV) - Individual Air Source Heat Pump (ASHP) - Individual Smart hot water cylinder - Individual Mechanical Ventilation with Heat Recovery (MVHR) - Individual 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

1. Case site 1

Case site 1 is a 15-acre site in the South Wales Valleys that, when completed, is planned to include over 200 low carbon homes. While the homes at Case site 1 will not initially be zero carbon, this is a target that should be met within ten years, as the grid decarbonises.

The focus of our research is phases 1 and 2 of the development, which comprises 80 houses (of varying styles, from two-four bedroom) and four two-bedroom apartments. Residents began moving into these initial properties in late 2020. The homes benefit from an energy efficient thermal building envelope, a mix of low carbon energy technologies including ground source heat pump (GSHP), solar PV (on most), intelligent battery storage, intelligent water cylinders, optional smart appliances (that can be automated), electric vehicle charging points and the option of choosing an on-site energy service provider.

One innovative element of Case site 1 is its three-phase connection to the national grid. This allows the site to generate its own energy for consumption on site and export to the grid, import from the grid and EV charging. The energy service manages the energy production, demand, and storage for each home, with households able to adjust heating and hot water demands using in-home controls and a bespoke app. The energy service is also responsive to wider climatic forecasts and price and carbon intensity signals from the national grid. This is a grid-flexibility service where import from the grid can be maximised to times when it is either lower cost or low carbon, and used for example to charge batteries, or heat water. This reduces strain on the national grid while reducing residents' energy costs and carbon emissions. Beyond technology in individual properties, at case site 1, shared green spaces are seen as an important element of the community development, which includes a central green space.

2. Case site 2

Case site 2 is a small development (fewer than 20 homes) in a rural location. Five four-bedroom detached houses have been sold privately, while the other ten homes (four two-bedroom houses and six one-bedroom flats) are socially rented through a Registered Social Landlord (RSL). Case site 2 is described as a garden village development, with biodiversity an important

consideration and plans for a shared allotment area. The first residents moved in during Spring 2021.

The highly insulated homes benefit from South facing aspects designed with Passive Solar principles in mind, giving natural light and space heating. Each home has solar PV, intelligent battery storage, and EV charging points installed. This arrangement allows each home to generate and store its own energy for household consumption, EV charging and export to the grid. Case site 2 homes use locally sourced timber for their structure and cladding and are manufactured locally.

Due to the combination of low carbon and locally sourced building materials and energy technologies, the development has been found to be carbon negative by Woodknowledge Wales. Indoor air quality is also an important consideration at Case site 2 and has influenced the materials used and floorplan of the homes.

3. Case site 3

Case site 3 is a small development (fewer than 20 properties) for social rent, across 1 bed flats, 2 and 3 bed houses in a central town location. The building design is based upon the SOLCER House, Wales's first 'energy positive' house (built in 2015), which is an output of the SOLCER (Smart Operation for a Low Carbon Energy Region) research project. SOLCER House was built to demonstrate how renewable energy systems can be integrated into highly insulated and air-tight modular build structures, becoming an integral element of future home building. Additionally, in line with a 'Homes as Power Stations' concept, the buildings are potentially capable of producing more energy than they use at certain times of the year.

Electricity for the homes is generated from photovoltaic films fixed to the roof covering and can be used, exported to the grid or stored in batteries at each home. Hot water is generated by an Air Source Heat Pump in each home, linked to transpired solar collectors located on the cladded walls, which boost the incoming air temperature. Some residents were able to move in at the end of 2020, with the final residents moving in in early 2021.

4. Case site 4

Case site 4 is a planned development of 35 homes, ranging from 2 to 4 bedroom, alongside a large communal garden and a community building. The developers plan for the homes to be available via long-term tenure. Construction was due to begin in 2022, with the first residents moving in 2023, but there have been delays to this timetable.

The homes will be built according to passive design principles and be low in embodied carbon, clad in a mix of locally sourced and low-embodied-energy materials that include timber, local stone and reclaimed brick. Low carbon energy technologies such as solar PV and ground source heat pumps (GSHP), alongside mechanical ventilation heat recovery, battery storage and intelligent water cylinders are managed by the energy service provider (as per case site 1).

Biodiversity is an important consideration, and the site will incorporate three central ponds as part of a sustainable drainage strategy. Homes are designed with large windows to encourage connection to the natural environment. Case site 4 has also been designed to encourage sustainable travel, with electric vehicle charging points and bicycle storage for each home.

5. Case site 5

Case site 5 is a mixed-use living building planned for Swansea City Centre. The building will incorporate 50 residential apartments, retail and commercial space across a new 13-storey tower atop a renovated existing retail space. The residential units will be managed by an RSL.

Biophilic principles emphasise a connection to nature, which will be central to this urban regeneration project. Community cohesion is also a fundamental concern, with plans for residents to be involved in running an on-site urban farm as a social enterprise. The site will use an aquaponics system and have shared outdoor space (such as allotments, courtyards and a bee keeping area), as well as private balconies and gardens. Making links between its biophilic design and resident health and wellbeing, the development aims to achieve a building certification that recognises the impact of the building on resident wellbeing.

The building will have rooftop solar PV, a novel ambient heat loop system to utilise waste heat for space and water heating and energy efficient structure and fabric, while each apartment will have shower heat recovery units, mechanical ventilation heat recovery (MVHR) and air source heat pumps (ASHP). The building will integrate a central battery and thermal storage system managed by the building operator that will further increase efficiencies in energy production, use and export for all building users. The building will be designed to facilitate sustainable transport, with no on-site car parking, but provision for bicycle storage and maintenance.

3. Methodological Approach

LWLCH adopts four primary methods towards the elucidation of lived experiences of Active Homes over time. These include qualitative longitudinal (QL) interviews with Active Home residents, multi-modal activity packs (completed by resident and focus group participants), focus groups and expert interviews. We outline each method below:

3.1 Expert Interviews

At all our case sites we have interviewed key stakeholders – including architects, registered social landlords (RSLs), property developers and engineers, as well as those dealing directly with residents such as housing officers and sales advisors. This element of the research explores the context, underpinning ideology and ambitions for each development as these broader and foundational elements inform multiple aspects of the built design. This includes practical and material concerns for infrastructure and utility provision, design of the overall neighbourhood, design of residential areas (floorplans, energy technologies and services, expectations of residents and issues of autonomy and control over their spaces and energy-related services), and communal spaces, (purpose, layout and access). Embedded within the aims and ambitions for each development and also informing elements of the design, are expert imaginaries around who is likely to occupy the homes, how they may live, and what they may need to live well. As such, gaining insight into expert perspectives enables a deeper understanding of decision-making processes, of the overarching hopes held for the development and how this may come to interplay with future residents' experiences. Whilst some experts provide a general perspective on the development of Active Homes, others are focused on specific case site developments.

Expert interviews provide opportunity to:

- Explore motivations behind the developments (including low carbon aims)
- Consider how these stakeholders imagine future residents and how this influences the design of low carbon homes
- Understand how and why certain design decisions have been taken, including those regarding specific energy system configurations, in addition to the imagined behavioural changes that occupants are expected to make

3.2 Qualitative Longitudinal (QL) Resident Interviews

Informed by knowledge and practice of QL study design (Henwood & Shirani, 2022), the LWLCH research team have taken an original approach to understanding the views and experiences of low carbon home residents by speaking to them on multiple occasions over time. In case sites 1-3, initial interviews with people before they moved into their new homes enable us to explore their expectations of the developments and plans for life there. Later interviews allow us to consider how their experiences compare to their earlier expectations and how this changes over a year of life in the home.

Speaking to low carbon home residents at different time points (a qualitative longitudinal (QL) design) has several key benefits:

- We can consider how views change over time in relation to lived experiences, offering a more dynamic perspective
- We can explore residents' experience of seasonal variations in their homes, particularly heating, energy generation and comfort, providing a more comprehensive picture than a one-off interview could enable
- We can investigate if and how resident perspectives change in relation to broader social changes (such as energy price rises and cost of living crisis)
- We can have ongoing dialogue with developers as we feedback insights from different stages of resident interviews, which can be used to inform future building design and rollout

3.3 Focus Groups

Case site 5 is currently under construction, and as such our data collection comprised expert interviews (as 3.1 above) and three community-based focus groups. The decision to hold focus groups was informed by the proposed mixed-use of the development, which encompasses residential apartments; community and communal spaces (including an urban farm); and commercial and retail units. This indicates that the building may be used by multiple end-users and hold impacts for existing residents, community groups and businesses in the area, potentially having a much wider impact than a residential only development.

The focus groups aimed to encourage discussion between participants based upon on their own individual knowledge, beliefs and experiences. Discussions covered a broad range of areas including topics familiar to the participants (i.e., climate change concerns, the city they or their related activities were based in) as well as those less familiar or unknown (such as ideological concepts underpinning development design). To enable participants to hold informed discussions, we provided technical information and images about the building in addition to policy context relating to climate change and the local area, enabling participant perspectives to emerge, that, while technically informed, were based upon their own understanding and interpretation of the information in relation to the group as a whole (Thomas et al. 2020; Pidgeon, 2021). To facilitate this, we used a mix of text, photographs, architect impressions and videos via researcher presentations to introduce core topics and technical information. Immediately after each presentation we opened and maintained a deliberative space for participant discussion.

Focus groups provide the opportunity to explore:

1. The implications of the development for residents, green initiative community groups and locally owned businesses, including:
    - Future visions of life within the building for residents (routines, relationships, energy demand, travel/transport, health and wellbeing, security and safety)
    - Future visions for the wider city community (heritage and architecture, climate change mitigation/environmental protection, local economies, connections to nature, health and wellbeing)
    - Other potential impacts for the community (changes to the socio-economic and nature-built composition of the city centre including the temporality of human-activity; alteration of how space within and outside the building is socially, economically and symbolically valued; alteration of how space within and outside the building is used; opportunities for city centre regeneration and financial investment instigated by the ideology and high standard of the building)

2. Whether the future visions influenced by the development aligned with or diverged from the wants, needs and aspirations held by the community for the place now and into the future

3. Whether the development of further low carbon buildings was perceived as a solution towards climate change mitigation AND the achievement of multiple other place-based aspirations

3.4 Activity Packs

At four of our case sites we developed multi-modal activity packs to be completed at different points in time by our resident-participants (case sites 1-3) and community focus group participants (case site 5). Multi-modal activity packs provide an opportunity to:

- Encourage participants to think differently and in advance about elements of their life/other activities that they may take for granted or find hard to put into words (for example energy use and energy services, or daily routines)
- Encourage participants to consider their homes, decision-making and daily life within wider contexts of place and community, change through time, and climate change
- Function as discussion prompts
- Situate participants, within their home, community or neighbourhood/city
- Provide further depth to data collected
- Be inclusive - providing opportunity for different modes of expression

The activity packs were completed in participants' own time, and each completed activity was then discussed with the participants in subsequent interviews/focus groups.

The resident-participants (case sites 1-3) were asked to complete two activity packs; one before they moved into their new homes, and then a second around 9 months after they had moved in. Whilst all households were offered an activity pack, some have chosen not to complete them. Thus far, we have received 18 complete or partially completed post-occupancy activity packs.

Focus group participants were also asked to complete one activity pack prior to attending the focus group discussions. As we organised the focus groups according to the proximal interests of the participants, activity packs were tailored to reflect the interests of the group. Completed

activities were analysed prior to each focus group, allowing researchers to draw on all participants responses in order to prompt group discussion but in ways that maintained confidentiality. Table 2 below illustrates which methodological approaches were used in each of our five case sites.

Table 2: Methodological approach per case site

Case site	Expert interviews	Resident interviews	Focus groups	Activity packs
1	✓	✓		✓
2	✓	✓		✓
3	✓	✓		✓
4	✓			
5	✓		✓	✓

4. Sample

The research involves three sample groups, described in the subsequent sections below.

4.1 Experts

Qualitative interviews with relevant stakeholders or experts aim to understand their motivations for developing Active Homes, the processes of design and construction, as well as expectations of future residents. Experts were identified from initial contact with case site representatives and invited to participate, with the sample snowballing as further relevant experts were identified. Below we indicate the areas of primary expert specialism of the 29 expert interviewees, however, some experts crossed multiple areas and case sites.

Table 3: 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

4.2 Residents

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. 37 residents from across case sites 1-3 have participated 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

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

4.3 Focus groups

Our sampling strategy for the focus groups was informed by the proposed mixed-use of case site 5 as described in section 2, encompassing residential apartments, community and communal spaces, and commercial and retail units. This indicates that the building may be used by multiple end-users and hold impacts for already present residents, community groups and businesses in the area. 22 individuals took part in online focus groups related to case site 5. This involved:

- 9 local residents
- 5 local business owners
- 8 representatives of local community organisations

Local residents and business owners were recruited via a recruitment agency, whilst representatives of community organisations were contacted directly by the research team and invited to participate.

5. Findings

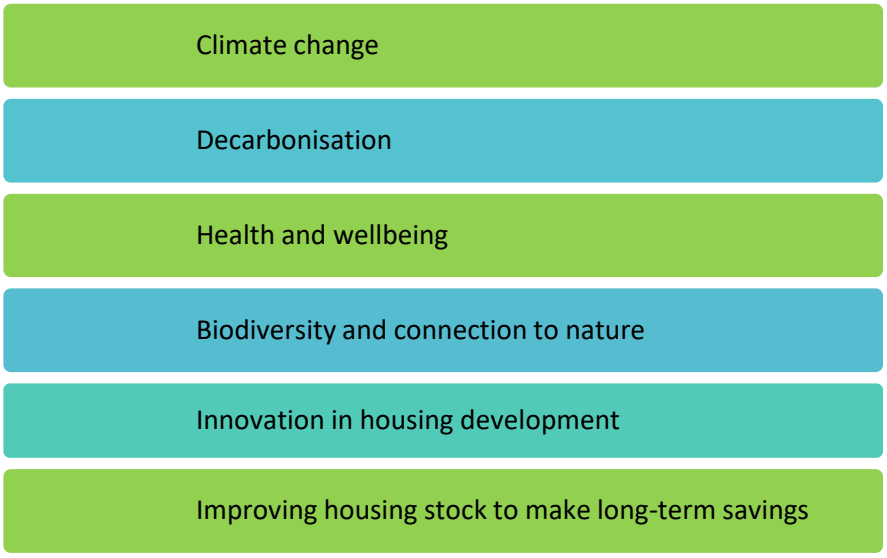
In this section of the report, we highlight the main themes arising from our research. We consider expert interviews, resident interviews and focus groups in turn, and incorporate insights from participant activity packs into relevant sections. To preserve anonymity, all participants are referred to numerically.

5.1 Expert Interviews

5.1.1 Motivations for Active Home developments

Active Buildings can be realised in different ways, for example with the use of different energy sources, technologies and services, the use of different building materials, designs and layouts, and the building orientation and location. By considering a variety of innovative case sites, we elucidate a range of motivations for Active Home development, which are outlined in figure 1, and which we discuss in detail in O'Sullivan et al. (2022).

Figure 1: Developer motivations



Some developers suggested that Active Homes would play a key role in addressing climate change and decarbonisation targets.

> "If we're going to hit those targets and make a difference, if you want to tackle climate change, it's the only option." (Expert 9)

However, for some Active Home developments, reduced CO2 emissions, renewable energy production, or smart intra-building and national grid communication singularly or combined was not reported to be a key objective, or primary motivation. For example, for some Active Home developers, a primary concern given is the alleviation of energy vulnerability and fuel poverty, while for others their key reported concern is occupant health and wellbeing. Being near or zero carbon, producing renewable energy or providing national grid flexibility in such instances is a secondary beneficial outcome in the achievement of this initial ambition, as Expert 8 describes.

> "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." (Expert 8)

All case sites had received funding from the Welsh Government's Innovative Housing Programme (IHP), which was crucial to enabling these innovative developments, as they were more costly than standard housebuilding. Broader political support in terms of legislation such as the Wellbeing of Future Generations (Wales) Act (2015) was also reported to be conducive to low carbon development. Because of this supportive context, Wales was described by several expert participants as a particular locus of innovation in housing.

> "I think that's, Wales is leading the way in this IHP exercise. And I think it's brilliant in the way that has really opened people's eyes now, you know, I'm getting asked to look into schemes with other, other developers, other housing associations in Wales … It's generally, yes, a lot more innovative … on the whole, it's been Wales, but there's interest from England that is definitely, definitely increasing." (Expert 22)

Whilst Active Homes may offer many potential benefits, the risk of such innovative housing is that the buildings may not deliver on these multiple aspirations. As many of the Active Home developments being taken forward are in social housing, this raises important questions about the position of potentially vulnerable residents, as Expert 3 recognised: "*So there is some kind of… issues around social housing … some of these innovations might fail, and we've got people living in houses which are not going to be the houses of the future*." Our previous work has

highlighted the potential challenges of innovation for vulnerable residents (Shirani et al. 2021), and consideration must be given to how residents can be supported if innovations fail to deliver on expected benefits.

Experts also questioned the ethics of mainstream housebuilding, where housing estates currently under construction will need to be retrofitted in the medium term to comply with changing policy requirements (e.g. removal of gas boilers). Several experts expressed a view that more Active Homes needed to be built to meet anticipated increasing demand for low carbon homes from prospective residents. However, experts described how central to the process of mainstreaming these homes would be changing the way in which such homes are valued. Without recognition of the benefits that low carbon energy technologies and thermally efficient fabrics can provide, it was proposed that Active Homes would continue to be valued on the basis of size and location, making it difficult for low carbon housing developers to compete with mainstream construction. Whether installation of renewable energy technologies or efficiency measures would increase the value of a home is also an important consideration in terms of retrofit expenditure.

Whilst experts generally refrained from providing specific information about likely energy bills to future residents, there was an expectation expressed – also shared by residents, as we consider below – that these would be lower than in conventional housing. Recent significant increases in energy prices were expected to change the context for Active Home developments, making energy generation technologies more appealing to future home buyers and tenants.

> "Definitely more demand for [low carbon 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 those technologies, especially with energy crisis now." (Expert 27)

Our research has encompassed early stages of the current energy crisis, however, further research over a longer-term period will be required to more comprehensively consider the impact of energy price rises on Active Homes.

5.1.2 Active Home and community design

Across the developer interviews, the importance of designing homes and neighbourhoods that people would want to live in long-term was highlighted as a key consideration. Developers described how it was essential that residents develop an emotional connection with the neighbourhood, both in terms of the designed environment, and socially through a sense of community. Including public green spaces within the neighbourhood design was suggested to offer an opportunity for residents to develop long-term connections to the neighbourhood.

> "I think it's about creating for community... you know, what we want to try and do is build schemes which encourage places for people to bump into each other, for people to be able to recognise their neighbours. It's an inbuilt way of generating a degree of security because you recognise people that should be there and someone that doesn't fit, you notice. But it also... it also just means that you feel at home, and that's important." (Expert 5)

Public green spaces were viewed by developers as providing opportunities for residents to connect with nature, which would hold benefits to their health and wellbeing. This was particularly evident in discussions of case site 5, which foregrounded both connection to nature and community. Despite developers emphasising the importance of including public green spaces in order to support both community cohesion and resident health and wellbeing, these were often the last area of the developments to be completed or were scaled back. In addition, where some green spaces had been completed, they did not resemble what had been envisaged or could not be maintained. The two case sites under construction (and therefore unoccupied) had the most radical plans for communal spaces, with both sites 4 and 5 planning on having spaces that were accessible to the wider community and not just residents.

One challenge for developers in creating a communal space was restrictions on available land for housebuilding and expectations of how the space should be used.

> "So it does vary depending on the site, but a lot of our sites are really restrictive to enable us to do that because you do – we're under pressure to get as many properties as we can onto the site to meet the housing need. So we're often restricted in terms of how much we can do." (Expert 15)

Whilst developers emphasised the benefits of communal space and facilities, there was recognition that this brings an additional workload of managing the space, which developers

or RSLs may be unable to take on. Where there were plans for developers to remain involved with the sites longer-term, for example due to tenure (site 4) or the number of facilities that required ongoing management (site 5), there was greater scope for what could be included in the development as part of efforts to *"develop long term sustainable places"* (Expert 4).

The value of having longer-term relationships between developers, RSLs and residents was recognised by some experts.

> "Okay, again early doors with this project realised that to make this successful it required a fundamental shift in approach by the developer, from one… I think I mentioned it before, this is not about coming in, putting something in, selling it and moving on. This is actually about a long-term strategy. As soon as you start taking a long-term… Is also one of the reasons why there needed to be a partner like [RSL], who aren't going anywhere, and have got a long-term view on, you know, on housing in Wales and we can actually then work together, to get the right solution." (Expert 23)

The need for long-term relationships between residents and developers partly relates to the extent to which experts saw resident behaviour change and 'education' as necessary or desirable, which have been important aspects of our research investigations.

5.1.3 Expectations of residents

In the context of existing research, which has highlighted how experts' expectations of residents can influence design decisions and, in turn, 'script' resident behaviour (Cherry et al. 2017; Hansen & Hauge, 2017), an important aspect of our LWLCH research was to explore these issues, which we discuss extensively in Shirani et al. (2022). The expert interviews indicated that contradictory views of residents were held, often within the same accounts, which centred around three main issues:

- Interest and information provision
- Control and automation
- Behaviour change

Across the expert interviews, we identified a view that residents were uninterested in energy use or technical information and therefore there was little point in providing them with information.

> "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)

Conversely, some experts emphasised the importance of 'education' through information provision, in order to ensure that individuals understand and correctly operate their new home technologies.

> "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's behaviour of individuals in those homes, rather than the actual technology. In other words, they're not using their electric wisely." (Expert 15)

Furthermore, some expert interviews indicated that housing professionals were not only giving residents information about how to use Active Home technology, but also proposing how residents should live, or how not to live, in Active Homes (Hale et al. under submission). Such divergent views of residents led to a range of approaches to information provision across our case sites; from extensive handbooks and manuals, and walkthrough demonstrations with residents, to reports of no information provision at all. We explore the residents' views of this in section 5.2.

Across the case sites, most experts suggested that it was preferable for control over home energy systems to be located with experts, rather than with residents. This was reported to be beneficial in terms of ensuring the homes would perform as expected, but also for residents; through removing the burden of having to worry about their energy use or understand complex systems. However, this perceived ease for residents assumes technology working correctly, which is not always the case, and, without a sufficient understanding of the technology, it could be difficult for residents to identify faults.

At case site 1 where an energy service operates, the need to learn from resident experiences and feedback was emphasised by some experts. While overall expert control of household energy was depicted as preferable (as above), adapting the service in line with resident

feedback based on their experience was important. For example, this was discussed in relation to the timing and temperature of heating, and also in relation to usability of a bespoke App used by residents to manage their heating and hot water.

Property tenure also appeared relevant to these discussions, with some experts describing how it was preferable for technology in rented properties to be externally located in secure units for maintenance and security. Where homes were designed from the start to be 'Active,' provision could be made for technology to be 'hidden'.

> "I think we, we don't, we're not averse to seeing [energy technology] in homes. We're probably on that side of actually, it's nice to see them, it shows off, if you like, the, the kind of green credentials of the home and it is a, a kind of a talking piece and a reminder of, you know, kind of what it is this home is capable of doing. But obviously, if you know, if space allows and you've got the time and the design allowance to do it, then yeah, sticking it in a store is probably the best place. You know, the home's for living in and, and enjoying, you don't necessarily want to, if you could, you'd put your washing machine in an external store or somewhere out of the living space as well. You'd have everything hidden away as possible, I think's probably the general approach. So yeah, we. Whilst we don't think they're, they're a major hindrance, I think if it's feasible, then we, we'd try and hide them away as best we can." (Expert 27)

However, for case site 1 where the homes had a traditional design with technology added at a later stage in the design and development process, there were space restrictions, which meant that, in some homes, batteries were located in a prominent position. Some experts suggested that this could have a positive impact.

> "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 visual indicator and almost like a little surreptitious reminder to save energy." (Expert 22)

In this way, through a 'surreptitious reminder,' residents could be prompted to do things differently. Some experts spoke about how residents would need to make more extensive changes; for example, where low temperature heating systems required planning heating regimes much further in advance. Conversely, other experts indicated that "*anyone could live in the homes, there's no two ways about that*" (Expert 26). From this perspective, the homes' efficient design and energy technology was working in a "*behind the scenes*" way, with

developers "*not assuming that they have to live any differently*" (Expert 4), which meant that residents were not expected to make significant lifestyle changes.

5.1.4. Section Summary

The expert interviews have illuminated a number of important points of consideration that have relevance for other Active Home developments and for resident experiences:

- Decarbonisation is just one element of the rationale for Active Homes, which have the potential to address other pressing social issues. A longer-term perspective is required to fully consider their ability to live up to ambitions of being 'houses of the future'
- The supportive funding context in Wales has been crucial to facilitating these innovative developments
- Consideration must be given to the risks of innovation for vulnerable residents and how they can be supported by developers if developments do not achieve expected comfort, economic, low carbon and technical performance outcomes
- Communal spaces are described as important by developers for fostering connection to nature, sense of community and place, but these can be challenging to design and manage and do not always materialise as anticipated
- Experts hold conflicting views of residents in relation to the necessity of behaviour change, which has implications for information provision, design and intended use of user-interfaces (Apps and manual controls) and the siting of technology
- Designing homes as Active from the outset gives developers greater choice about siting technology. Whilst having equipment visible in the home is less desirable, some potential benefits, in terms of encouraging residents to think more about their energy use, were envisaged

5.2 Resident Interviews

In this section, we present an overview of findings from the resident interviews across the three occupied case sites.

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, the Active characteristics of the home were reported to be an important element of their decision to move. For a small number, the development's low carbon credentials were said to be the primary motivation for moving, and some participants had relocated a considerable distance in order to live in an Active Home. 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. Some spoke of how they saw buying an Active Home as more convenient, economical and less risky than attempting to organise retrofit work themselves, when they would be unsure of technologies and reliability of contractors, and were concerned about being 'ripped off'.

Participants expressed pride in being among the first residents of Active Homes in the UK, with many expecting that this was an inevitable direction for future housing.

> "Proud. I would say. I like that idea. We had the same with the electric car, we had one of the first, we were among the first people in the UK to have an electric car and … that was not, not very widespread to put it mildly. Yeah, we're doing this again. So being a bit of a trailblazer there sounds like a nice idea to me." (Participant 14)

Whilst several participants spoke of valuing the homes' low carbon credentials in terms of concerns about sustainability and climate change, most described expectations that these characteristics could also reduce energy bills. As the majority of participants reported ambitions to remain living in their Active Home long-term, a motivation for many in moving there were expectations of the homes being low maintenance and low cost now and into the future.

5.2.1 Design, layout and aesthetic

Participants across all three case sites expressed positivity about the design, layout and finish of the 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 at case site 3 describing their life as "500% better". Whilst some participants from case sites 2 and 3 spoke of negative comments that they had received from people outside the development about the unconventional appearance of the homes, participants themselves described their own positive views of the external aesthetic, across the three very different sites.

Post-occupancy, a number of participants expressed surprise about how spacious and well thought-out their homes were. However, many said that they would have appreciated more storage space as most built-in cupboards had been used to house energy equipment (i.e. water tanks or heat pumps) and access to loft space was restricted. Some participants expressed surprise and frustration that what they had assumed from floorplans was storage space was actually used to house energy equipment and therefore that the space was not usable as they had envisaged. Some had built, or were planning to build, external storage areas such as sheds and garages. Where elements of energy technology were visible and accessible, participants noted that it reminded them of their energy use, prompting them to think further about when they should use energy and for what purpose. This suggests in some cases it did appear to act as a 'surreptitious reminder' as Expert 22 described (see section 5.1.3).

> "when I do see [battery], I do think… I wonder, like, how much energy's in there, whether we're, like, running off that or whether we're running off the grid. So it does make me think, yeah, and I think I just wish I had some more information about it because we don't really know a lot about it or what it's doing." (Participant 2)

Where equipment was accessible to residents, some participants described how they had managed simple fixes themselves (e.g. releasing pressure in GSHP under direction of the developer) and how they had been able to share this knowledge with other residents. Where energy equipment was locked away, participants spoke of having little connection to or ownership over the workings of their home, which they indicated made them dependent on

landlords, developers or engineers to identify and fix faults. This meant that some participants described having little understanding of the effectiveness of their home's energy system:

> "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)

For several participants, having their own garden was highlighted as a key draw to their Active Home, as some had been living without private outdoor space. The attention that the developers had given to the design of the outdoor space, particularly at case site 2, was praised by future residents, many of whom appeared to share the developers' views (as discussed in section 5.1.1) that such spaces would be conducive to fostering a sense of community. However, post-occupancy, outdoor space was one of the areas that participants expressed most disappointment about. Several participants across the case sites described their gardens as boggy, which they spoke of as presenting difficulties with usability. This led some to consider making substantial changes (such as paving or astroturfing lawned areas) in order to make the garden space more accessible, which has implications for development aims in relation to biodiversity. Some participants expressed disappointment with how the gardens were finished and of challenges with maintaining outdoor space, which they suggested contradicted the ethos of the developments.

> "the whole point of this was that it's a shared community garden space, and also individual gardens. None of us have got outside taps. So, we're all really struggling to keep the gardens going. And that's one of the things I mentioned that we're all a bit disappointed by." (Participant 22)

Post-occupancy, several participants from different case sites commented on the absence of water collection and recycling in the design of the homes. Most often, participants said that they would have liked water butts for rainwater harvesting in order to use this water for gardening. Some had installed these themselves, but others suggested that they had difficulty in identifying a suitable model for their homes and had not yet been able to organise this. A small number of participants also raised the possibility of grey water recycling and would have liked to have seen this in homes. Discussions of water use were raised by several participants during the later interviews, many of which took place during or shortly after the extreme

heatwaves and water shortages of summer 2022, which may have prompted thinking about these issues.

Across the case sites, there was a mixed picture of sound insulation. Generally, participants in houses indicated that their homes were well-insulated and external noise was not intrusive, although internal noise was reported to be a minor issue for some participants in homes with an open-plan design. Participants living in flats expressed most concern about noise intrusion from adjoining flats, which, for some, was reported as having a significant impact on their everyday lives including their health and wellbeing. At case sites 1 and 2, participants spoke of hearing new noises emitted from various technologies, such as the GSHP or battery (case site 1), or from water tanks (case site 1 and 2). For a minority of participants, these noises were reported to be intrusive and to be negatively affecting their comfort and wellbeing, and some reported that they had taken additional sound-proofing measures. Others described becoming used to these noises over time.

Pre-occupancy, some participants anticipated that the design and layout of the properties would have an impact on certain aspects of everyday lives. For example, if there was no space for a tumble dryer, no radiators due to underfloor heating, or advice not to cover electric radiators, some participants spoke of uncertainty about how they would be able to dry washing. Post-occupancy experiences were mixed across the case sites. Some participants expressed surprise at how quickly they were able to dry washing on an airer in a spare bedroom, and some spoke of purchasing dehumidifiers to both assist with this process and to avoid relying on a tumble dryer. Others spoke of greater use of the tumble dryer since moving to their Active Home (particularly at case site 3 where washer/dryers had been provided for residents). This was variously attributed (by participants across all three sites) to; lack of space for an airer, being unable to use airing cupboard space (because hot water tanks took up the entire space or were too well-insulated to emit heat), being unable to dry on radiators, not wanting to create moisture in airtight homes, and the energy being generated by the home as negating the high energy demands of the tumble dryer. The question of how best to dry washing remained unresolved for some who were reluctant to invest in tumble dryers because they perceived it as against the ethos of the home.

> “The other thing I'm finding difficult still is drying clothes because I don't want to use the tumble dryer … there's nowhere indoors to really put an airer … it doesn't seem right in an eco house to have a tumble dryer, somehow.” (Participant 25)

This highlights the importance of considering how everyday tasks will be accomplished in Active Homes and ensuring that the building design can facilitate this (Shirani et al. 2022).

In post-occupancy activity packs, participants were given an example floorplan and asked to annotate these with coloured stickers representing five criteria:

- things that annoy me (red)
- where I notice energy (orange)
- my favourite places (yellow)
- where I enjoy the environment (green)
- where I connect with other people (blue).

Many participants also provided additional annotated comments. In this activity, participants noted appreciation of aspects of the layout, light and space of their home. The incomplete communal space was highlighted as an annoyance by participants at case sites 1 and 2, and issues with EV charging were raised across all sites (being incomplete at case sites 1 and 2, and perceived as unnecessary by some at case site 3). Hallways as cold or draughty spaces were indicated by participants from case sites 1 and 3, with storage highlighted as an issue at the same sites. Below we include images of the combined floor plans of participants from each development to indicate some of the points raised.

Figure 2. Case site 1 combined floorplan

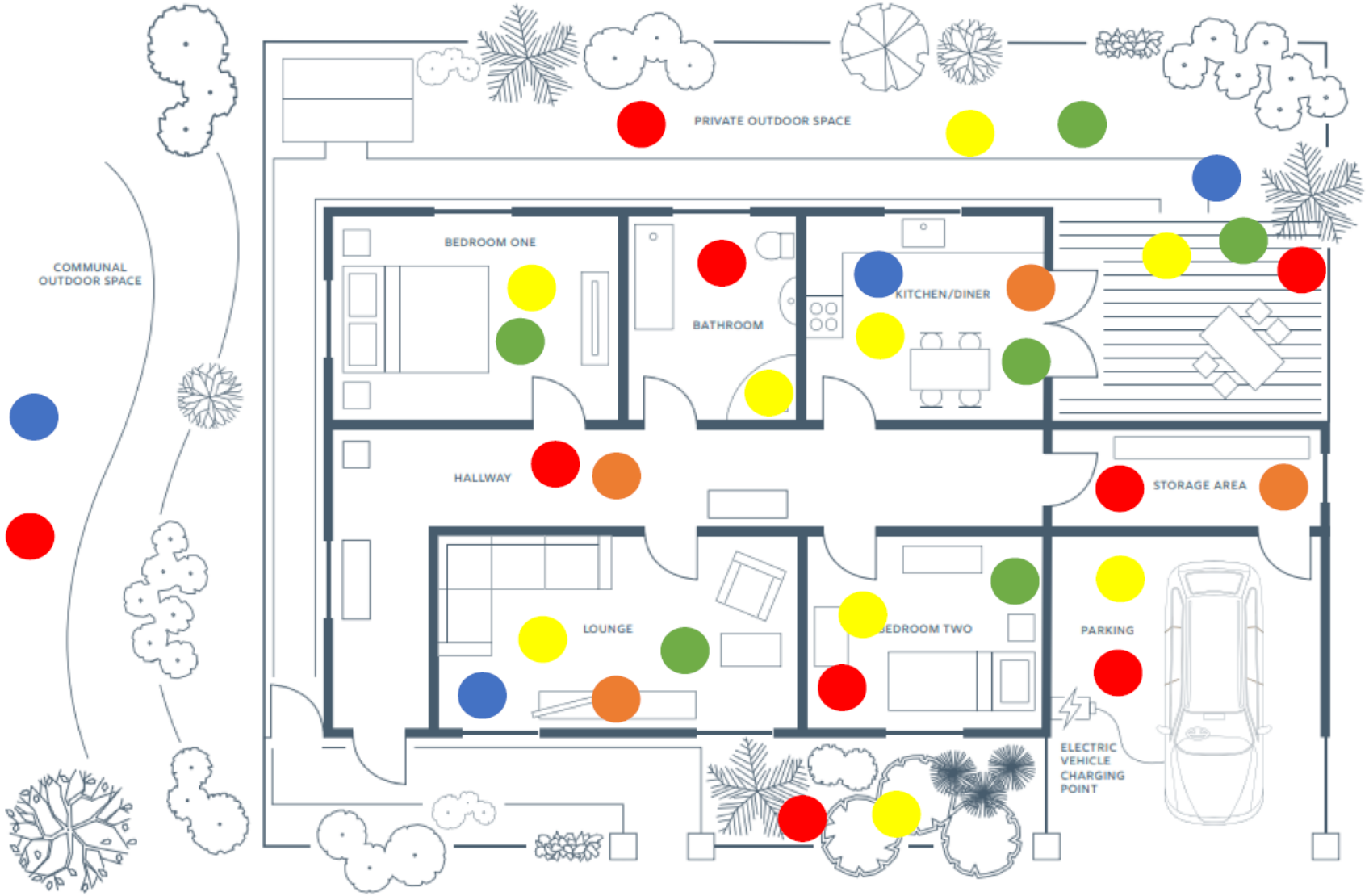


Figure 3. Case site 2 combined floorplan

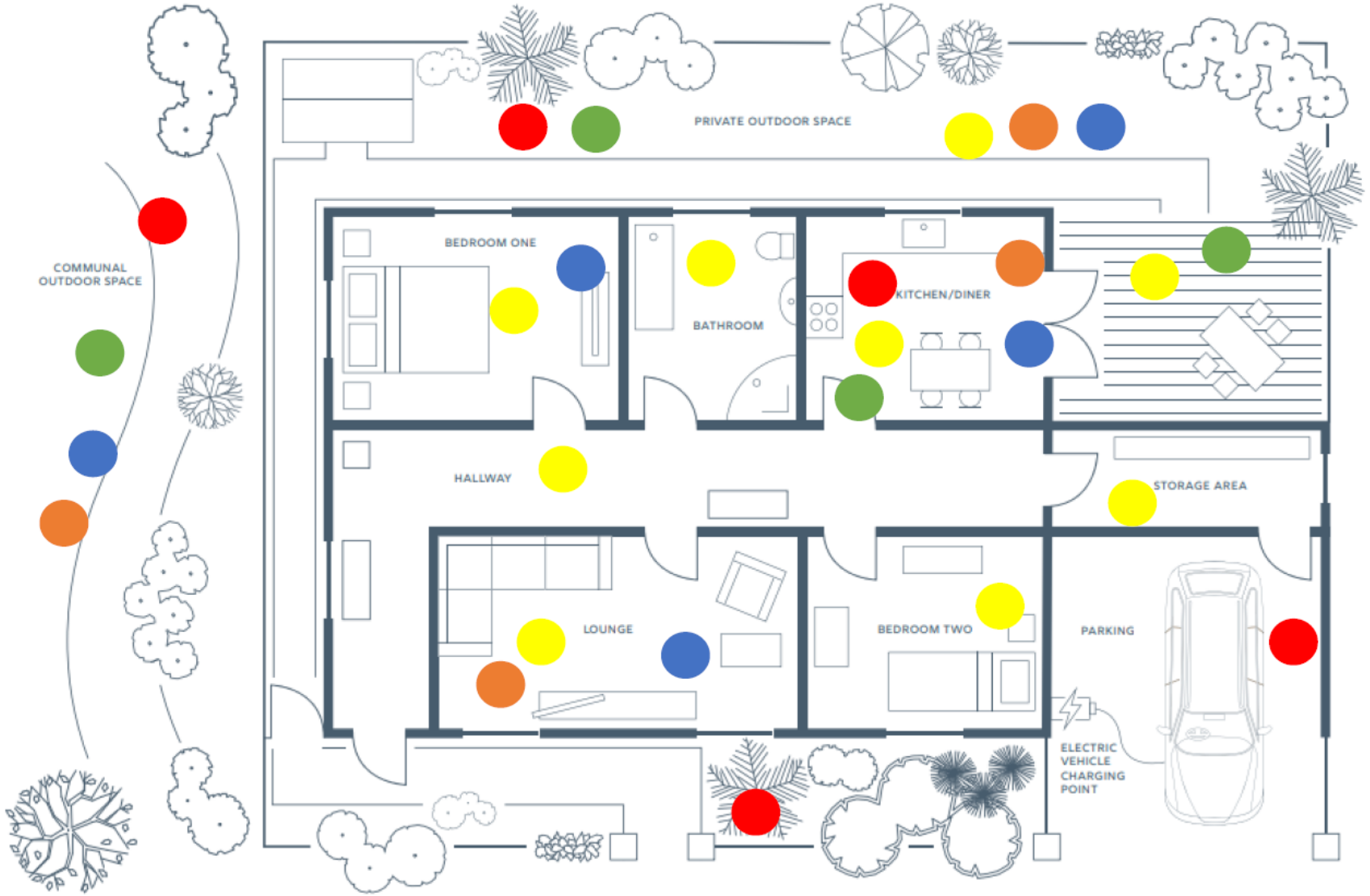
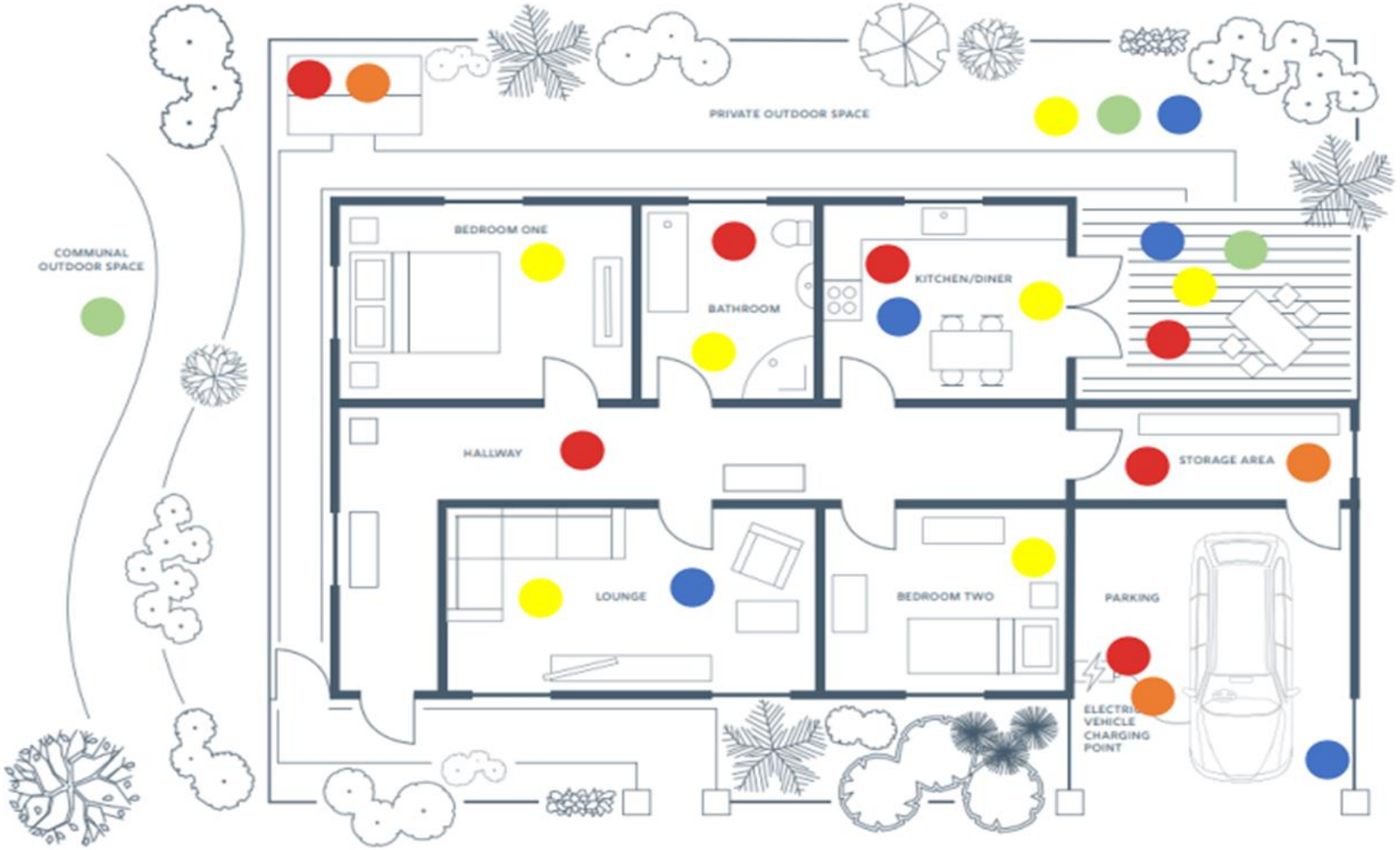


Figure 4. Case site 3 combined floorplan



Cross case site highlights: Design, layout and aesthetic

- Participants expressed positivity about the design, layout and finish of their homes, including the external aesthetic
- The accessible layouts (indoor and outdoor) of some developments were described as making a significant improvement to the lives of people with mobility difficulties, and their households
- The location of technology appeared to have an impact on how participants related to their homes and how they were able to use the space
- Noise intrusion was reported to be a significant issue for those living in flats, whilst noise from energy technology was expressed as a concern by several participants. Participants in houses were largely positive about their homes' soundproofing
- Participants were conscious of aspects of their home designs that appeared to contradict the 'Active' or 'eco' nature of the developments and commented on where they felt designs could have been more sustainable (e.g. inclusion of water collection and re-use)

5.2.2 Thermal comfort and hot water

The majority of participants were moving from dual fuel homes and, whilst not generally expressing concern about living in an all-electric home, some held reservations about electric cooking. Post-occupancy, all participants moving to homes with induction hobs reported that they were happy with the cooking performance and that they were responsive and easy to clean. Some participants expressed reassurance at no longer having a gas supply – particularly those from case site 2, who had often relied on bottled gas in previous homes – and for several, an all-electric home was considered safer. Participants also indicated that features such as battery storage and energy production counteracted any concerns that they may have held around security of energy supply associated with living in a single fuel home. However, some expressed frustration at the prospect of having a single fuel home in the event of power cuts, where there was no alternative means of heating and cooking.

Participants gave a mixed picture regarding heating and insulation. The majority described the houses as warm and a sense that they were well-insulated and retained heat well. However, a significant minority reported that their homes felt colder than they had expected, which was perceived as resulting in greater use of heating than they had anticipated, or in purchasing freestanding electric heaters. For some, these additional appliances were used to supplement heating, whilst others reported using these in place of central heating because of concerns about cost or difficulty in controlling their heating. At case site 1 where homes had underfloor heating, most described experiencing reasonable levels of comfort, and the absence of radiators was referred to by some as beneficial from an aesthetic perspective. Others expressed less satisfaction with underfloor heating and spoke of experiencing comfortable temperatures in most rooms of the home, but that the underfloor heating did not emit enough warmth; for some, cold spots on the flooring had an impact on their overall comfort. Some also missed radiators as a sensorial indicator that the heating was working.

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 most participants 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)

Across the case sites, most participants reported operating their heating using manual controls (on individual radiators or wall mounted thermostats) as and when they required a change of temperature as opposed to setting up an energy regime using timers, although some spoke of an additional mental load associated with this practice. For example, where radiators were controlled individually, some participants spoke of this not being 'user friendly'. Whilst the rationale for this apparently lay in giving residents greater thermostatic control over individual rooms or zones of the house, some participants described feeling that it was easy for individual heaters to be left on unintentionally, potentially undermining the energy saving objective of the design.

Varying reasons were given by participants for relying on manual control; it was how they were used to operating heating, they were unable to programme digital systems, or found the systems inconvenient to programme or difficult to align with their lifestyles (i.e. shift working). Moving from gas central heating to GSHP and underfloor heating required participants at case site 1 to think differently about their heating by planning their schedules in advance. Whilst some said they were happy to pre-set their heating regimes, others expressed some frustration at trying to plan ahead and then altering their app settings as their routines changed. At this case site, participants spoke of the significant role that the customer experience team had played in assisting them in programming their app and in making changes to it at different stages post-occupancy (discussed in section 5.2.3). This process was reflected in stakeholder interviews, in which the role of the customer experience team was discussed. In addition to assisting residents, the team's role was described as also involving communicating resident experiences and preferences with other staff in their organisation (i.e. those involved in the technical and digital design and governance of the homes), and where changes could be made to improve this. Iterative adaptions in the app design and usability as a result may explain some participants' reported increased use of the app and reduced use of thermostatic control of their heating by the time of the 12-month post-occupancy interviews. However some participants at case site 1 said that they rarely used their app by 12 months as they had established a suitable routine and had little need to adjust this.

A significant concern mentioned by a number of participants at all sites related to overheating and uncomfortably warm temperatures, particularly during summer. The exception to this was the detached homes at case site 2, which were described by several participants as maintaining a reasonable temperature even in the two summer 2022 heatwaves. Some at case site 1 reported that heat being distributed to towel rails led to overly warm bedrooms throughout the year, impacting on sleep. Others across the three case sites said that the homes' insulation and glazing 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. Some participants suggested that developers needed to pay greater attention to overheating and potential measures for cooling in future Active Home designs. The positive experiences of participants in the detached homes at case site 2 during periods of extreme heat suggests there

is potential for design insights to be gleaned from these homes In relation to the avoidance of overheating.

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. 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, with some describing frustration that this seemed to be a step backwards. Others spoke of becoming used to the new system over time. 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)

Case site 3 was the only occupied site in our study to include mechanical ventilation and heat recovery (MVHR), although case sites 4 and 5 also plan to include this. Several participants from case site 3 suggested that they did not want to use the MVHR as they felt that adequate ventilation could be achieved through opening doors and windows. Many described how having limited control over the MVHR, in particular, being unable to turn it off, made it difficult to achieve thermal comfort. Some said they had attempted to counteract the cold air emissions from the MVHR by increasing their heating temperature and/or duration, which led to

concerns about energy use and cost. Several participants spoke of the MVHR as similar to air conditioning, but that they found the temperatures of the air were at odds with the seasonal heating/cooling needs. Whilst some said that they wanted their MVHR turned off completely, others expressed reluctance to do this because of perceived benefits associated with clean air in the homes (discussed further in section 5.2.7). For some, the air quality was reported to be evident through the absence of damp and mould that they had had to deal with in other homes. For others, the MVHR system was said to offer 'peace of mind,' as it was perceived as filtering out potentially harmful pathogens from the air. Whilst no mechanical ventilation systems were in place at case sites 1 and 2, most participants at those case sites spoke positively about their homes' air quality and indicated that they were happy with manual ventilation.

Cross case site highlights: Thermal comfort and hot water

- Participants expressed positivity about their experience of all-electric systems, despite some pre-occupancy reservations
- Adapting to new heating and hot water systems that operate over longer periods takes time
- Where heating controls were not experienced as user-friendly, they were sometimes bypassed in favour of manual control
- Most homes were described as warm in winter, but overheating during summer was reported to be a problem for some participants at all case sites
- Additional appliances, such as portable heaters, fans and air conditioning units, were reported to be used by a number of participants to regulate temperatures
- Sufficient hot water was reported as an ongoing issue for some, which could affect personal hygiene and comfort routines
- Participants expressed positivity about the air quality of their homes, but those with MVHR expressed mixed views as to its utility

5.2.3 Information and learning

Whether information was provided to residents, how it was provided, and when, was variable both within and across case sites. For example, whilst some participants said they were provided with extensive handbooks and user manuals, others described receiving no information at all about their homes or how to operate the technologies that they encompassed. The process of moving house was often described as a stressful period during which time it was difficult to take in information, therefore having something to refer to and the ability to raise questions at a later stage was depicted as valuable. The ongoing restrictions due to the Covid-19 pandemic also limited in-person handovers and information sessions for some residents. Some participants used terms that they associated with their previous heating systems (e.g. referring to the GSHP as a boiler) or with the technology's function (e.g. referring to MVHR as vents or fans), which could lead to challenges in finding relevant operational information. 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 holistic information about how the different elements of the homes worked together (rather than just individual technologies) and about how residents could use the home most efficiently.

> "I'd expect a handbook or some kind of handover process, because it's not a normal house, it's not a normal house at all … I think there should be some kind of manual, and more help than there has been, to get the most from your home, 'cos I think that's probably what most of us moved in for in the first place, it's because we are conscious of the environment and we want to see a difference. We want to–- we're quite prepared to change our lifestyles, the way that we do things, if we can see a gain for someone. You know, just simple things like when you put your washing machine on." (Participant 28)

> "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)

Across all the case sites participants spoke of instances when incorrect information had been passed on about particular technologies, or that there was confusion around certain aspects

of the home's technological configuration or governance arrangements. This became most apparent when participants began to investigate selecting energy suppliers and tariffs or set up their EV charging points. At these points, questions were raised around, for example, who owned the batteries and who was due to receive export tariffs. However, in case sites where equipment was locked away, participants reported more pronounced feelings of disconnection and lack of control over the functioning of the home. Some indicated that miscommunication and confusion caused frustration and anxiety for them, especially as this was perceived as directly impacting on their energy costs.

At case site 1, which operated an energy service, most participants had been offered in-person or virtual explanations and walkthroughs of their homes, including their energy technologies prior to moving in. This 'onboarding' process was said to also include assistance in downloading and setting up their energy regimes on a designated app. Furthermore, at this case site a dedicated customer experience manager (and later team) who participants knew by name was reported to be available and responsive to ongoing queries. Participants indicated that they valued this kind of personal contact and that this led to a generally positive view of the company.

> "Yeah, they're lovely, they always answer on the phone, they always answer emails, and they get back to you straight away and, you know, they have sorted out problems with regards to heating." (Participant 13)

At case sites 2 and 3 some participants had said they had received informal 'walkthroughs' regarding particular elements of their homes, often serendipitously (e.g. when a particular technology was being installed or repaired). Several indicated that having these in-person explanations and opportunities to ask questions was valuable, however, frequent visits, and equipment inspections where the motive and outcome were not explained to them were perceived as somewhat intrusive and disparaging.

Across the case sites, participants spoke of how they had gained knowledge regarding how to best operate their energy systems from other neighbours. This informal knowledge sharing was described as an important route to developing a sense of community and relationships with neighbours (as we consider in section 5.2.6).

All of our case sites have some form of ongoing technical energy-monitoring being carried out in at least some of the homes, generally by third party organisations, to ensure that the homes achieve their technical performance outputs. The participants that we spoke to indicated that they did not fully understand what monitoring was taking place and how this information was being used. For some this was reported to be a significant concern, described as making them feel 'uncomfortable' and giving rise to concerns about data protection. Others appeared less concerned about the monitoring and use of data but spoke of how they would like to receive feedback from this process about their home's performance; particularly any faults identified or improvements that could be made.

> "Well, even though we're happy with the monitoring, we're not getting any information back off them as to well is it working, is it not working, is it? Could it, could it be, could it be something we're doing? Or if they said… your emissions are more or less than somebody else in the thing, same sort of property. Then, I don't know, it'd be, it would be nice to know ... the more information we have, the better off we are able and the benefit in the house, to benefit us." (Participant 31)

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 an assumption of residents as disinterested and disengaged (as discussed in section 5.1.3) and raises important considerations about the type, timing and manner of information provision.

Cross case site highlights: Information and learning

- Understanding key principles underpinning the home design, energy technology configuration, and ownership (of technologies, energy generation and export tariffs), including how these work holistically is important to participants
- Information should be clear and relevant, in a format that residents can refer back to, with an opportunity to raise questions at a later date
- Different modes of information are most inclusive and helpful (text, images, online, in-person demonstrations) to cover different ways of learning about the homes
- Operation instructions should also highlight trouble shooting/fault identification

- Participants are willing to live in the homes in ways that maximise technical performance and make changes to their routines to do this. Without information about this, such changes may be based on erroneous assumptions
- It is important that residents are fully informed about data monitoring and receive feedback from this process

5.2.4 Energy demand and cost

In our pre-occupancy interviews we found that the low carbon and renewable energy features of the homes contributed to participants expressing an expectation of lower energy bills than in previous homes. Post-occupancy, this expectation was reported as being met for many participants, particularly at case sites 1 and 2, where several 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)

Some of the expected financial benefits of an Active Home include residents receiving income from exporting solar energy in the summer months to partly compensate for drawing energy from the grid during the winter. The process of finding energy companies and appropriate tariffs was described as difficult and often protracted for many participants at case sites 2 and 3 (as at case site 1 all our participants were signed up to the development's energy service and therefore did not have to search for a provider). 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 and the timings of export to the grid, in addition to entitlement to export tariffs and energy produced, were reported by some as making it difficult to gain access to appropriate energy tariffs, download independent energy monitoring apps and understand their own energy profiles.

Some participants described their bills as being higher than anticipated and, in a small number of cases, as unsustainably high, which was described as leading some participants to question whether they could live in the homes in the long-term. In these instances, several participants expressed negative impacts on their health and wellbeing due to self-rationing heating, ongoing anxiety and new situations of energy debt. In some cases, higher than anticipated bills appeared related to participants' unclear or inaccurate expectations pre-occupancy (such as the belief that energy would be free), whereas in others, homes were more expensive than anticipated to run, potentially related to technology not functioning as anticipated.

Several participants expressed frustration with the length of time it took for them to receive an accurate energy bill, with many saying that they needed to reflect over a 12-month period of bills to fully assess the extent of any financial savings afforded by their new homes, which could include income from solar energy exported to the grid during summer. At case site 1, where some participants who moved in during the winter months had initially been surprised by higher than anticipated bills, they spoke of seeking guidance from their energy service provider about changes that they could make to reduce these costs and subsequently adopted different ways of operating their heating system.

> "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)

In the final interviews, reflecting over 12 months of occupancy, this participant gave a more positive view of energy bills given significant savings over the summer months, as discussed in section 5.2.8.

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 most participants with some reassurances that despite the cost of living and energy crisis, they would remain able to afford their energy without compromising their comfort or lifestyles. At case site 1, early communication to households by the energy service provider about the impact of the energy price crisis was reported to have further reassured participants.

Cross case site highlights: Energy demand and cost

- All residents reported expecting lower energy bills in their Active Home than in a conventional home
- Where low bills have been achieved, participants expressed feelings of security, relief and comfort, particularly in the context of energy price rises
- In cases where bills were higher than anticipated, some participants have expressed feelings of anxiety and dread, and in some cases reported taking actions to self-ration their energy use
- Reflection over at least a 12-month period, in order to include seasonal variations in weather and solar exports, was proposed to be necessary in evaluating the extent of financial savings that Active Homes can afford
- The process of finding a suitable energy supplier and tariff was reported to have been confusing and protracted for many participants
- The 2022 energy crisis has changed the context in which Active Homes are being developed. Information about how this may impact Active Home residents has been reported as welcome by some participants

5.2.5 Environmental awareness

As discussed in 5.2, many participants spoke about how in moving into an Active Home, they were doing something different to the norm, being innovative and positively contributing to society through addressing climate change concerns. Several participants spoke with pride about being able to move into innovative homes that linked with their pre-existing environmental concerns, expressing how this represented a big step for them and society more generally towards a better way of building and living, not only for them but for future generations. Participants also indicated that they expected low carbon homes to become more

valued and commonplace over time, therefore by moving to an Active Home they were 'ahead of the curve,' which was proposed to be particularly fortuitous in light of increasing energy prices.

> "I mean it, it certainly has made it feel like it was the right decision to buy this place … it's really emphasised to other people who are maybe less conscious about the importance of the environmental factors, you know the insulation and the solar and all the rest of it. But I think people who maybe hadn't really given that much consideration previously are now very interested in the house and quite envious of what we've got here." (Participant 26)

The majority of participants suggested that they would like more homes to be built as low and zero carbon, with technologies or built designs that are considered relatively low cost and uncomplicated (i.e. solar panels or installing windows at aspects that capture thermal gains) installed in new-build homes as standard.

In post-occupancy activity packs, participants were asked to complete a ranking exercise in relation to potential and existing features of different Active Home developments (see appendix 1) and were asked to note which they did/not like and which they considered most and least important for future homes. The most important options indicated by participants from across the case sites included renewable energy generation, being highly insulated and energy efficient, and using sustainable materials. Some participants from case site 2 also highlighted what they saw as the importance of homes being built by local tradespeople using locally sourced materials, which had been an important aspect of that case site development (see section 5.2.6). In contrast some participants at other case sites noted this as unimportant.

Participants overwhelmingly indicated that automation and control by a third party (such as an energy services provider) was the point they liked least, or saw as the least important. Where reasons for this were given, participants stated they felt this was 'over-control' or did not like the idea of control being located outside of their household. Some at case site 3 highlighted MVHR as something unimportant, or that they disliked, related to issues they had experienced in their own homes. Conversely a participant from case site 1, where MVHR was not installed, highlighted it as a potential solution to dealing with the overheating some participants described experiencing in summer. Several participants (including those living in a rural location in case site 2) also expressed dislike of the idea of homes being increasingly located in

rural areas. They suggested that building more homes would detract from the reasons people wanted to live in rural areas, with surrounding land and space.

While most participants indicated varying degrees of environmental awareness prior to moving into their new homes, several reported that moving into their homes had prompted them to reflect further on various aspects of their everyday lives. For example, some participants explained how they had started to think more about sustainability outside of their home setting, in their social networks and workplaces, and that they planned to make changes to their consumption habits. One participant explained that they had initiated some low carbon changes in their workplace, while others said that they had decided to join existing workplace environmental/sustainability groups. In addition, some participants spoke of ambitions to make their lifestyles even more low carbon and sustainable, for example, through investing in electric vehicles (EV), something that they said they had not thought possible in previous homes due to the cost and lack of EV infrastructure. In this example, having EV charging provided was described as directly impacting the perceived feasibility of having an EV.

> "So [EV is] being delivered next week so that's cool. So I think it's, like, I'm definitely going in the right direction, but I feel like I've nailed the big things now with the house and the car. But I feel like the little things I need to, like, work on. I feel almost like I'm, kind of, like, under more pressure to, like, do better because I have this house. Does that make sense? That I feel like I need to earn the right to live here." (Participant 2)

However, the initial outlay cost of EVs meant that many participants saw having their own EV as prohibitively expensive. Whilst there was some interest in the idea of communal EV schemes, or being able to lease an EV from the site's developers, most participants suggested that they would want the convenience of their own vehicle.

Participants spoke of how living with low carbon technologies, particularly new and readily visible technologies (such as batteries in case site 1) had made them more aware of their energy use and more willing to try and alter or reduce this where possible. However, environmental and energy awareness also meant that many participants across the case sites indicated that they were sensitive to instances where the practical day to day experience of living in the homes worked against the perceived building ethos and low carbon aims.

Participants spoke of this in reference to increasing their use of tumble dryers, opening windows/using fans to cool homes while the heating was still on, the use of synthetic or plastic floor coverings or concern about Electro Magnetic Frequencies (EMFs). In the latter instance, digitalisation, technological configuration, additional wiring and Wi-Fi requirements were depicted by some as excessive and in contradiction with low carbon, sustainable homes. This was contrasted by some to perceived low-tech and low cost features that were not included in the homes (such as grey water recycling, noted in section 5.2.1).

Some participants spoke of their desire to make changes to the internal appearance of the property e.g. through installing a fireplace, to make it feel more homely, or to echo features that they had valued in previous properties, and some reported making these changes early in their occupancy. However, participants at case site 2 described how they had been advised against doing this by the developer because it would lead to overheating. At 12 months post-occupancy, some participants said that they were still undecided as to whether they would install fireplaces or wood burners because of the aesthetic and sensory pleasures that they would provide.

> "I'd still like one … you don't need it for heat at all, it's just, it's just that you come home on a wet – it rains a lot. Go off on a wet walk, and just having a real fire … Not necessarily for the heat, just for the, you know, the feel … really just to have a real fire was my desire." (Participant 24)

At case sites where choices over the interior had already been made by the developer (e.g. kitchen units, tiles or flooring), some participants spoke of frustration over having to alter these once moved in as the choices made did not suite their taste, were perceived as low quality or ineffective (particularly extractor fans) or were described as made from materials that could leach chemicals into the home and hold adverse effects on participants' health (i.e. vinyl flooring, or synthetic carpets). Participants identified the waste that such a process incurred and described feeling that this was in contradiction to their own environmental concerns and the ideology underpinning the home design. Some suggested that offering residents greater choice over the finish of homes (which they recognised would need to be reflected in different costs) during the construction process could help to avoid potential waste from refurbishment.

At case site 2, many participants indicated that the use of local wood for the frame and cladding of the buildings was a positive step towards addressing environmental concerns and also providing employment in the local economy (as noted in section 5.2.1). Several participants said they were familiar with the woods that the timber was sourced from and some even knew the loggers. This local connection was described by some as strengthening their positive emotions towards the home and also to have provided a means of counteracting criticism on the aesthetic of the homes from others.

Cross case site highlights: Environmental awareness

- Participants expressed pride in living in innovative Active Home developments, variously describing themselves as 'pioneers' or 'ahead of the curve'
- Some indicated that Active Homes reflected their personal values and social priorities relating to addressing climate change and living sustainably
- Following their move to an Active Home, several participants spoke of other changes they had made to make their lifestyles more sustainable, such as changing to an electric vehicle
- Participants were alert to aspects of the development that contradicted what they saw as the sustainable ethos of their homes, such as choice of materials
- In contrast, some reportedly unsustainable technologies (such as fires) were described as valued because of the sensory pleasures they provided, which could not be replicated with low carbon technology

5.2.6 Place and community

Across the case sites, participants described appreciating how the neighbourhood design retained existing natural features such as trees, or offered sightlines to nearby natural or green spaces, which some participants spoke of accessing. However, some participants at case site 2 expressed frustration at being in the countryside but being unable to access it on foot and spoke of their efforts to open up local walking routes to make this more feasible.

Participants at case sites 1 and 2 spoke of delays to or uncertainty over the completion of communal green spaces. At case site 1, construction was ongoing, and the communal green

space was finished after the completion of houses in the vicinity. However, after 12 months the communal space at case site 2 remained undeveloped and several participants expressed concern, disappointment and frustration that the anticipated communal allotment space appeared unlikely to materialise, although some remained hopeful that the space would be used by the site community in some way in future. Participants expressed disappointment about delays or changes to planned communal green spaces, and the anticipated impact that this had on the community; in light of expectations that the spaces would facilitate interaction with other neighbours, particularly during the summer period.

At case sites 1 and 3, the public green spaces did not have a set activity or purpose (as opposed to, for example, a play area or allotment), which some said meant that they were less likely to use the space. Despite being spaces for the whole community, some participants described how there was a sense that the houses directly adjacent to the green spaces had more right to access it, and some expressed concern that in accessing the spaces they would be overlooked or seen as disruptive.

> "But then even if you went on this green space, like the road that goes around it there have got houses, all these houses all look inwards. So the space, I can't really see people, you know, sitting there with their kids and the kids are running round. This is, there's a road around it for one, and every house, there's honestly, must be 10 or 15 houses all looking in at that space. You know people are gonna walk 30 seconds out of the site and go to like a park up the road or something, do you know what I mean?" (Participant 9)

Some participants also spoke of how children had been told off for playing in the communal spaces, making them reluctant to use them in future. Participants expressed appreciation of the clear demarcation of public and private spaces and clarity over usage. This included the demarcation of public and private parking spaces to prevent resident spaces being used or blocked by others. Although participants expressed mixed responses about the community green spaces, the design of the overall external elements of the neighbourhoods were praised by most. Sightlines across streets, cul-de-sac or crescents were proposed to enable neighbours to see each other and communicate more freely, encouraging social encounters, generating familiarity and a sense of security and safety.

Whilst some participants reported explicitly choosing their Active Home in order to live in a particular location, often close to family and friendship networks, for others, the low carbon nature of the development was reported to have taken precedence over the location in their choice of home. Participants at case sites 1 and 2 described it as necessary to have a personal vehicle due to distance from essential facilities, and often, for commuting to work. Participants at case site 1 described some changes to travel patterns (including reduction of journey times due to their proximity to the motorway), whilst some of those at case site 2 spoke of how their car use had increased since moving to a rural area, but alternative transport options were limited. In contrast, the central location of case site 3 was praised by participants for convenience; enabling several participants to reduce their car use (and make resultant savings on fuel) and undertake a greater number of journeys on foot.

Overall, participants at all three case sites expressed positivity about the sense of community developing and reported that residents were friendly to one another, and that most people have good relationships with their neighbours. This ranged from exchanging neighbourly greetings and Christmas cards, to establishing friendships. Several participants spoke of virtual communications (e.g. WhatsApp, Facebook), with some saying that they are active in these groups and others that they preferred to be less engaged. Several participants spoke about how getting to grips with their new homes and technologies was an important part of community connection. For example, participants described sharing information with neighbours about tariffs and suppliers, how to operate or adjust equipment in their home, and plans for communal spaces. 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. Thus the broader context of Active Homes being situated within Active Neighbourhoods was an important aspect of how residents experienced living there.

Cross case site highlights: Place and community

- Participants generally expressed positivity about their new Active Home communities
- Delays or changes to planned communal green spaces were reported to be a disappointment, as these spaces were expected to be important in fostering community relations
- Changes to car use were reported to be dependent on the site location and proximity to workplaces or local facilities. Where participants were able to access facilities and green spaces by walking this was viewed positively
- Sharing information about how the homes and technologies within worked was described as helping to give rise to a sense of community

5.3 Health and wellbeing

All the case sites have been designed to be accessible for a wide range of potential residents. We spoke to several participants who themselves, or members of their family, were reliant on wheelchairs or mobility scooters, and they spoke of the increased privacy, autonomy and freedom that resulted from their move to an Active Home. Many participants also spoke positively about how the design of the overall development made them feel safe. Others spoke of how the inclusion of nature in the designs, such as the preservation of existing trees and the inclusion of private gardens for all properties, meant that they were able to enjoy watching wildlife and experience feelings of calm and peace.

> "I just like how peaceful it is here. It's just, it is just peaceful … And you know just, life, life now is just sitting in my garden now and there's a little squirrel running across the fence. [Laughter]. You know it's, it is, it's great, and the house itself is, you know, like it's just so lovely. There's such a good feel about it." (Participant 33)

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 reported that they had had to contend with in previous properties. Air quality was a particular point of discussion at case site 3, which had MVHR. Some described how having filtered air was reassuring, giving 'peace of mind,' whilst one participant spoke of a family member describing her home as 'magic' because of these perceived respiratory improvements.

Whilst participants largely expressed positivity about improvements to their health and wellbeing since moving to their Active Homes, some described feelings of 'anxiety' and 'depression,' often in relation to energy bills. For some participants – particularly those at case site 3 in relation to the MVHR – sounds from energy technologies were reported to be a reminder of energy being used. Where participants felt that they had little understanding or connection to the technology in their home, including what they could do to reduce energy use, the bills were a 'worry' as they could not find ways to reduce them. This also related to households where energy use (particularly heating) was seen by participants as non-negotiable, due to caring responsibilities for young children, elderly relatives, or the needs of household members with a disability.

> "I know some tenants on the street have said turn the radiators off. But if I turn my radiators off and we're really cold, what am I going to do, 'cause obviously with a one-year-old who's just learning to walk, you can't sit still under a blanket and put loads of layers of clothes on." (Participant 34)

In other cases, low bills were reported to be reassuring, alleviating anxiety about being able to keep warm during the winter (as discussed in section 5.2.4).

Finally, 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. However, these perceptions were not universal, with some participants reporting feeling impressed with how

the differrent technologies could work together helping them live in a way that was low carbon and low cost but also convenient and comfortable. At case site 2, some participants spoke of how a three phase system had not been installed because of concerns raised by members of the existing local community about potential health impacts of this, and how not having a three-phase supply made EV charging more complex.

Cross case site highlights: Health and wellbeing

- Participants described self-reported improvements in health and wellbeing attributed to living in high quality accessible homes without concerns about damp and mould, improved air quality leading to perceived improvements in respiratory conditions, and having access to nature and green spaces
- Where participants described feelings of worry, anxiety or depression, this related to concerns about energy costs, lack of understanding and control over their energy system and use, inability to attain thermal comfort, and the potential health impacts of some technologies
- At case site 3 the MVHR was contentious for some, with participants reporting valuing the improved air quality but expressing concern about their inability to turn off the MVHR and how this was perceived to counteract the heating, impacting thermal comfort
- The majority of participants said that they want to stay living in their Active Homes long-term

5.4 Considering Active Homes through time – a 12-month perspective

By interviewing participants on three occasions over the course of approximately 15 months, our LWLCH study has been able to explore changes in experiences over time and occasions where participants' views change significantly. For example, pre-move, one participant spoke of how she had chosen her home based on the price and location, with the energy technology a secondary consideration, or even cause for concern as she was unsure as to how effective or reliable the innovative technology would be. This participant saw her Active Home as a relatively short-term prospect, with plans to move elsewhere to an older property in several years' time. However, at 12 months post-occupancy, her views had significantly changed.

> We love it here. We absolutely love it. We can't see ourselves moving, you know, within the next few years. If we were, we said we would just like to buy a four-bedroom on this site. Just because it's just amazing with regards to how much we find we're saving. Obviously, we have friends that live in normal houses, should you say, and they spend a lot more than we do. You know, it's expensive enough with a mortgage, and then you've got – they've got their gas and electric bills on top of that, whereas we find that we save so much more … I think it's just with the massive change, and everyone's realising their bills have gone up so much that we think, wow, this is actually, we are so much better off than everybody else at the moment with everything so cheap here. And, you know, it's… Everyone comes in here and says how warm it is as well. The insulation is amazing. We could put the heating on yesterday, and it will still be warm today, whereas some houses, you know, they last an hour once they're off". (Participant 13)

The 12 month perspective has also been important in providing a more comprehensive picture of energy bills, given the variation in energy use, generation and export across different seasons and weather conditions. Participants 9 and 10 moved into their Active Home during winter and were surprised and disappointed by a higher than anticipated first energy bill. Whilst seeking ways to reduce their electricity usage, they were somewhat resigned to the higher costs as 'it's for a good cause' if 'everyone's going greener'. However by 12 months their view of the energy costs had changed significantly, following low bills and income from exported solar energy over the summer period.

> Participant 9: I don't know how many people we spoke to, our battery done amazing this year. It's saved us so much money. Like, probably £500, £600 we sold back to the board over a few months. It was crazy. We didn't pay electric for about six months. We've only started paying electric in the last, what, two months, I think.
>
> Participant 10: Yeah. So as much as it might be a little bit of an eyesore, it can have its own bedroom if it wants [laughs]. It's staying.

This jovial exchange shows how their views on the technology had changed somewhat over time; from irritation at the size and appearance of the battery to appreciation of the financial savings that it enabled. Thus conducting interviews over a 12 month view was crucial for establishing a more comprehensive picture of Active Home living. Like participant 13, participants 9 and 10 had revised their longer-term goal to move and now envisaged staying in their Active Home long-term, saying they 'could be here forever'.

After 12 months, most participants described feeling settled in their new homes and had established routines that enabled them to live comfortably day to day. However, linked to the points about information and learning discussed in section 5.2.3, several residents at 12 months said that they were still learning about their homes.

> "I'd still say I'm learning. Like, I still don't know, for example, so yesterday, I was charging my car, and then I want, I put the washing machine on, and something else I used the electricity for, I can't remember. But I thought is, is it more advantageous to do those things separately? You know, I could have saved putting the washing machine on until the car had charged and then put the washing machine on later. Does it make any difference to how much export I get, if I do it all at the same time versus one after the other?" (Participant 25)

This highlights how, as recognised by some of the expert interviewees, fully understanding an Active Home is 'only going to come over time', reflecting a process rather than a single moment of change when participants move from a conventional home to an Active Home. Understanding this as a process therefore has implications for relationships between developers and residents; where there is ongoing contact then there is opportunity for the continued flow of information between parties, leading to a greater understanding of the homes.

5.2.9 Section Summary

Resident interviews have revealed a range of experiences of Active Home living, with different issues arising across the three case sites. Despite this, we have been able to identify a number of common themes that have relevance for future Active Home developments.

Across the case sites and tenures, many participants indicated existing knowledge of climate change, low carbon technologies, and that Active Homes offered a new type of low carbon home that could work towards decarbonisation. For many this resonated with their own expressed worldviews and ambitions to live more sustainable lifestyles. Such perspectives align well with the ideologies underpinning our Active Home case sites and the ambitions held by the various stakeholders. For some, living in their Active Home had encouraged further sustainable lifestyle choices, some of which had previously been seen as unobtainable, such as investing in an electric vehicle.

The extent to which participants expected their daily routines would alter once living in an Active Home was mixed, however, most suggested that they expected little to no difference in how they lived day to day. Once occupying their Active Homes however, most explained that heating and cooling was different to their previous homes, and required a different way of thinking. In particular, the way that the Active Homes take longer to warm and cool than conventional homes was not anticipated by most participants and has taken time to adjust to.

Living in an Active Home appeared to affect participants' perceptions of privacy, autonomy and control – intrinsic values of home – in different ways. For some, incomplete understanding of how their homes were designed to perform technically and how they could make changes to their everyday lives in order to benefit from this caused frustration and in some instances anxiety. In instances where participants explained they were unaware that their energy data was being monitored, feelings of unease and distrust were expressed. Furthermore, incomplete information was purported to have affected several participants' energy costs as it made more difficult an already complicated task of selecting appropriate energy suppliers and tariffs.

The overwhelming majority of participants expressed happiness with their Active Homes and the hope to stay living in them long-term. A number said that having lived in an Active Home, they would be reluctant to return to conventional housing. Several participants at case site 1 indicated that they would want a bigger home in a few years' time, with some saying that they hoped to move to a larger property within the same development. Many identified issues that could be improved upon but spoke of how these did not overly impinge on the enjoyment of their home. However, a significant minority raised concerns about the ability to live in their Active Home long-term because of concerns about energy costs. These participants highlighted how lessons must be learned from these initial developments in order to prevent future developments repeating the same mistakes whilst benefiting from incorporating elements that have worked well.

5.5 Focus groups

In this section we highlight some of the insights from the focus groups specific to case site 5 that have wider relevance for other Active Home developments. The three focus groups with existing residents, business owners and community group members explored plans for the building, including how it was perceived as a place to live, and how the development related to the wider context of the city, surrounding environments and existing communities.

Participants were largely positive about the planned building, seeing it as an important opportunity to improve the reputation of the city and establish its standing as a locus of innovation in sustainable development. When shown an example apartment floor plan, participants expressed positivity about the layout, storage space and inclusion of private outdoor space. However, they also indicated an assumption that these high-quality homes would be unaffordable for local residents and suggested they may be bought by investors or used as Airbnb rentals. Although learning that all homes had been purchased by an RSL gave some reassurance, participants still expressed concern that all the additional building facilities associated with low carbon energy and biophilia would lead to unaffordable service charges. Ensuring that new developments addressed pressing needs in the local area was highlighted as important across the three groups. However, several participants spoke of how such a building, while novel and expensive now, will be increasingly demanded by younger generations, reducing costs and becoming mainstream through time.

> "The younger generation which probably looking at maybe, like, 20 years on now, I mean they may well look at the house with the solar panels and electric car charger as it's not, it's not a desirable, for them it will be an essential." (Resident focus group)

Participants expressed positivity about the green spaces planned for the building, which included a combination of private balconies, shared resident spaces (such as an urban farm) as well as publicly accessible spaces. However, some questioned whether the type of people needed to make these spaces work (perceived as people interested in food growing and with time to contribute to activities) would also be the type of people wanting to live in the city centre (perceived as younger professional people who were time-poor). Some participants expressed that initial resident participation in the maintenance of the green spaces may be an

initial novelty that would wear off, which would have a detrimental impact on the entire building. Therefore, support for residents to establish skills and knowledge in maintaining green spaces, and also, the need to maintain this knowledge and involvement as residents moved on from the building and new residents moved in, was seen as vital. The community group in particular highlighted the value of any new community organisation establishing connections with their pre-existing expertise and food-growing networks. Developer plans to remain involved with the building post-completion and occupancy, assisting with the establishment of the CIC, maintaining community skills and knowledge, and to be responsive to resident queries, was well regarded by participants. This reflects the value of ongoing relationships between developers and residents discussed in our resident interviews (section 5.2.3).

Participants generally expressed positivity about the mixed-use nature of the building, combining residential, retail and commercial spaces. However, several questioned the demand for large spaces following changes to working arrangements in light of the Covid-19 pandemic and indicated that smaller retail units would be preferable. Participants also suggested that it would be desirable to see businesses in the building that held similar ideologies around the environment, sustainability and biophilia that were symbolised in the building's design. This was expected to potentially strengthen the impact of the building on the wider community, encouraging even more people to think more about the environment and live sustainably. As one participant suggested, the ethos underpinning the building could 'permeate outwards.' Again, this echoes the value of a coherent development ethos, as discussed in our resident interviews (section 5.2.1).

> "I was wondering whether some of the retail units and some of the office spaces particularly, whether actually as a building there would almost be, some values that they would expect those people to be working to. So, whether you would have, I know we have a few shops here where you can, kind of, take your packaging to be refilled, kind of, like zero plastic shops and things like that, whether, kind of, the whole ethos of the building would, kind of, filter into all of those elements as well? So, you might have businesses there that are involved in, kind of, technology, that's gonna help us be more sustainable and that, kind of, thing. 'Cos again I think bringing all of that together, kind of, under one roof, and I think there's, kind of, a lot of power in that." (Resident focus group)

The building developers planned to include facilities for supporting active travel, such as bicycle storage and maintenance areas. Residents generally expressed support of this but suggested that without developments in wider infrastructure (such as investment in local cycling routes and bike hire facilities), efforts to change travel behaviour may be limited. Therefore, the necessity of wider connections to support the success of the development, recognising local place and infrastructure context, was highlighted as important.

Finally, participants expressed positive reactions to the plans for the building to achieve a certification that recognised residents' health and wellbeing, as well as meeting technical performance measures. Whilst some expressed a concern that this could be a paper exercise with little material impact for residents, others suggested that it was important that the developers were recognising the significance of resident satisfaction and wellbeing to the overall success and potential wider impact of the development.

> "I think having that accreditation is important because it sets the precedent. It's achieving high… I think having some kind of accreditation that recognises and acknowledges all that's been put into that building, which is going to be homes for people as well as multi-use, I think is really, really important. And for people to value themselves in that way. 'Actually, I live in a Gold standard building.' You know? I think that says something for people as well and how they will feel living there and the pride that they will feel, and they'll want to talk to people about that. You know?" (Community focus group)

The focus groups concentrated on plans for a particular Active Home development, but have highlighted salient issues for other developments. By initiating these discussions at an early stage of the development, there is opportunity for these insights to be drawn on to inform the design of case site 5 and how this Active Building is eventually realised.

6. 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. We argue that it is imperative that as Active Homes begin to be realised and occupied, the lived experiences of residents are understood, and insights applied to future developments (O'Sullivan et al. 2022). Bringing together insights from experts, residents and communities as part of an original qualitative longitudinal study has enabled us to garner a unique holistic picture of Active Home developments.

Our research highlights that across residents, communities, businesses and expert stakeholders, the opportunity that Active Homes propose to offer in addressing climate change through decarbonisation of housing was largely recognised and perceived as important. Moreover, participants spoke about the developments enthusiastically, expressing pride in having contemporary, novel developments that aimed to address a number of societal scale issues. Furthermore, most participants indicated that they thought such developments would become more commonplace through time. However, some pointed to instances where the ideologies and ambitions of Active Home developments could potentially be undermined, for example, where materials used appear to contradict the building ethos, high energy consuming appliances (such as tumble dryers) are advocated or where dependence on personal vehicular transport is reinforced.

Our research has illustrated the significance of information provision and sense of control over homes and the technologies that they encompass. 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 this critical perspective, contemporary and evolving smart energy systems and smart building design will

perpetuate and embody simplistic consumer archetypes, whilst homes may not perform as expected (Shirani et al. 2022).

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 (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.

Speaking to residents prior to the move to their Active Home, in the early phases post-occupancy, and finally after 12 months, enables us to develop a more detailed picture of Active Home living across seasonal weather variation (and related energy demand), and follow the process of residents learning about their new homes and technologies. Our approach also enables us to consider the impact of wider social changes on resident experiences; most notably, recent energy price rises. However, after 12 months a number of aspects of Active Home living remain uncertain or unrealised, for example, estimated energy bills, technical glitches, incomplete outdoor or communal spaces. In addition, some participants spoke of their intentions to make further sustainable lifestyle changes in future, and a longer-term perspective is required to explore whether these plans materialise.

7. Key Insights and Recommendations

- Participants expressed satisfaction with the appearance and layout of their homes, and many expressed a desire to remain living in their homes for the longer-term.

- Participants expressed pride in living in a home that reflects their personal world views and societal concerns about climate change. Participants described perceptions that housing would have to become more sustainable in future and said that they saw themselves as pioneering or ahead of the curve in moving to an Active Home development.

- Participants expressed less satisfaction with outdoor spaces. Several spoke of issues with water retention in their gardens limiting their ability to use them. Considering the broader neighbourhood, participants reported enjoying the layout, attributing it to enabling neighbourly interactions and a sense of security. However, incomplete community green areas and roads were highlighted as detracting from other positive aspects. Clearly demarcated boundaries between private and public space were mentioned as desirable.

- Most participants said that they had found it challenging getting used to a new heating system but that they found the houses comfortable during winter. Overheating was reported to be a concern for several during the summer.

- Where heating controls were reported as unintuitive, incorrectly functioning, or unresponsive, some participants developed 'workarounds' such as adjusting thermostats and manually ventilating their homes.

- Having someone to contact with queries and who could get issues resolved quickly was described as important by participants. Participants at case site 1 particularly expressed the value of having a personal contact with whom they could raise queries, request information or ask for faults to be addressed.

- Participants said that they would like more information about how all the components of their home's energy system work together (not just information about the operation of

individual technologies) so that they could try and plan their energy demand to maximise use of renewable energy, times of low-cost grid import, or to identify and address simple faults themselves.

- Participants said that they would like information about how they can best use their homes and expressed a willingness to make changes to use energy most efficiently.

- All participants said that they had expected their Active Home to lead to reduced energy bills. Where this was the case, participants expressed satisfaction and relief, particularly in the context of wider energy price rises.

- Where energy bills were higher than anticipated, this led to self-described feelings of worry and anxiety, with some participants reporting the self-rationing of energy, which also impacted their comfort.

- The majority of participants spoke positively about their new neighbours and the sense of community that they perceived as developing. Sharing knowledge about their homes and energy technologies was said to have played an important role in establishing these relationships.

Drawing on findings from across our case sites, we highlight some insights and recommendations for developers:

- 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).

- It is difficult to take in information during the process of moving, and learning how to use new systems takes time. Residents valued ongoing relationships with developers where they were able to raise queries and where these were responded to quickly.

- Lack of engagement with smart control systems does not mean residents are disengaged from their energy use, it may indicate issues with the usability of the technology. Understanding how residents control their energy systems is important for considering both the performance and experience of residing in the homes.

- While there are challenges to communal EV leasing schemes, there was some enthusiasm expressed for individual EV or electric bike leasing. Moving to a low carbon home was reported to have provided an impetus for some participants to make other lifestyle changes, which developers may be able to support.

- Communal spaces were reported to be viewed as important for establishing a community but were often felt to be a low priority for developers to complete. Some idea of when the spaces would be completed, what the spaces could be used for, by whom and when could help to provide reassurance and avoid community confrontations.

- Residents should be fully informed about monitoring of their properties, how this data will be used, asked for their consent, and provided with feedback on insights from this process.

- 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 as this can cause particular challenges for some residents.

- While recognising that the development of Active Homes is a risky, learning process for all involved, clarity must be sought 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.

- Several participants commented that they would like to see more provision for water recycling as part of home design in light of water shortages during summer heatwaves.

Future developments could consider how to integrate this in home and green space design.

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Appendix 1

Future homes

Below are some ideas about future homes that participants in a previous research project thought were important.

We would like you to look through the list and tick the things you think will happen, the things you would like for your own home (some may be things that your home already has) and any ideas that you don't like. At the end we would like you to note what you consider the most and least important points on the list and add anything that you think is missing.

Homes will...	I think this will happen	I would like this for my own home	I don't like this idea
Make greater use of sustainable, natural materials such as wood and stone			
Be built using locally sourced materials and by local trades people			
Generate their own energy from renewable sources such as solar panels and small-scale wind turbines, meaning they are less reliant on the national grid			
Be designed with greater emphasis on connection to nature through private and communal outdoor space and integrated features such as green roofing to improve biodiversity			
Be heated via heat pumps and heat recovery systems rather than fossil fuels			
Be highly insulated to prevent heat loss			
Include mechanical ventilation systems (MVHR), as greater emphasis will be placed on the importance of air quality			
Be designed to enable householders to have a more direct connection to meeting everyday needs (e.g. generating own energy, managing waste, food growth and harvesting)			
Make use of resources that would otherwise be wasted (e.g. rainwater or grey water harvesting for flushing toilets)			
Be highly energy efficient, enabling people to use less energy and save money on their energy bills			
Be increasingly automated so heating systems and appliances can be controlled remotely **by the household**			
Be increasingly automated so heating systems and appliances can be controlled remotely **by a third party, i.e. an energy service provider**			
Have smart appliances that can run at the most economical times			
Support sustainable travel (e.g. with integrated electric vehicle charging and bike storage or on public transport routes)			
Be increasingly located in rural rather than urban areas to benefit from access to land for growing food and for recreation			