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Original research article

Homes as machines: Exploring expert and public imaginaries of low carbon housing futures in the United Kingdom

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ABSTRACT

Low carbon housing policies embody visions of the future that shape and constrain current choices between different technological pathways. These socio-technical imaginaries include expectations around new ways of living and interacting with technology, with implications for everyday lives. This paper investigates existing expert visions of low carbon housing, and explores these futures with members of the public; utilising empirical data from policy documents, expert interviews and public focus groups. Two competing expert visions of low carbon housing were identified: Passivhaus and Smart Homes. Whilst portrayed as divergent futures, both visions aimed to 'design out' the role of occupants, achieving emissions reductions through changes to the built environment and maintaining current lifestyles; a position that was reinforced by an imagined public that was unable or unwilling to accept the need for lifestyle change. This construction of the public did not consider the complex personal and cultural dimensions that influenced public acceptability of future housing: specifically surrounding themes of comfort, control and security that arose within the focus groups. The tensions arising between expert and public imaginaries highlight the difficulties that may surround any transition towards a low carbon future and demonstrate the need to work with, rather than around, the public.

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1. Introduction

Accounting for 23% of national carbon emissions [11] and 29% of total energy consumption [18], housing is a crucial site for achieving emissions reductions if the ambitious 80% target set out within the UK Climate Change Act 2008 is to be met. Due to the relative difficulty of achieving emissions reductions in other sectors (such as aviation), it is predicted that the domestic sector will need to reduce emissions to nearly zero by 2050 [10]. As such, radical demand reduction strategies will be required, in addition to the provision of low carbon energy. Over recent years, a range of approaches, policies and standards have aimed to reduce energy demand within the sector, through improving the energy efficiency of existing homes, increasing uptake of domestic renewable energy sources, or improving the sustainability of new build housing. Combining new technologies, social structures, institutions and discourses, these policies embody visions of a low carbon housing future; 'socio-

technical imaginaries' that will shape and constrain future choices between different technology pathways [36].

Over the last decade, the precise vision of low carbon housing embedded within UK policy has shifted. The concept of a zero carbon house rose to prominence around 2006 with the Code for Sustainable Homes and Zero Carbon Homes Target, both advocating sustainable, carbon neutral housing that is highly energy efficient, makes use of renewable energy sources and is acceptable to eco-conscious consumers who would purchase them. However, by 2015, this vision of the future had fallen into disfavour, with national policy shifting towards energy security and affordability. Despite this, the urgency of the challenge to reduce carbon emissions from UK housing stocks remains unchanged. Beyond the material and technical challenge of reducing carbon emissions associated with housing, low carbon houses are also homes, where complex material and social elements interact (relating to both how the building is made and how it is used) to determine household energy use [69,50]. As such, low carbon housing imaginaries will include visions of new ways of living and interacting with technology, which have implications for everyday lives. The ways that scientists and experts imagine the future and users is known to have

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a significant influence on the material technology and design, the 'scripting' of user behaviour, and policy development [38,1,37,70].

The ways in which occupants are constructed as 'imagined publics' [46] will play a key role in the visions of a low carbon housing future held by housing and energy professionals and will be crucial in shaping the future of UK housing. As such, low carbon housing presents an ideal case study through which to explore visions of a low carbon future from a range of different perspectives. The first aim of this paper is to explore the socio-technical imaginaries of a low carbon housing future, paying particular attention to the links between these visions of the future and the imagined publics that inhabit them. In a novel addition to this approach, the paper also seeks to explore these expert derived visions of a low carbon housing future with members of the public themselves, investigating their acceptability alongside the values and concerns which shape their perceptions of these possible futures. Before considering such questions, we provide a discussion of the theoretical and empirical literature that informs this study, as well as an account of low carbon housing policy in the UK, exploring how visions of a low carbon housing future have developed within UK Government over the past 15 years.

2. Socio-technical imaginaries and imagined publics

Expectations and visions of potential futures are co-constructed from both social and technological dimensions; embodying innovative technologies, emerging industrial and institutional structures, and broader social and political discourses [7,30]. These visions shape technology, policy and society through dynamic processes that maintain and create socio-technical networks [30]. Termed 'socio-technical imaginaries', Jasanoff and Kim [36]:120 define these visions as 'collectively imagined forms of social life and social order reflected in the design and fulfilment of nation-specific scientific and/or technical projects, [which] at once describe attainable futures and prescribe futures that the state believe ought to be attained'. Reflecting normative prescriptions of what is socially and technically possible, desirable and morally right, imaginaries can be understood as performative; these imagined futures have power to shape both the present and the future when evoked and discussed [58].

Various studies have explored socio-technical imaginaries at different scales and in relation to different socio-technical systems e.g., [59,51,41,58,3,37], demonstrating how they act to shape and constrain choices between different socio-technical pathways. Imaginaries are therefore not neutral and act as frames, or rhetorical tools, to include and exclude different rhetorical and material aspects of the debate and promote a specific vision of the future. As such they can be used to: guide and co-ordinate action; justify decision making and the inclusion of different actor in this process; and establish the need for political action [3]. A longstanding strand of Science and Technology Studies which explores the relationship between technological design and future users, highlights the way in which designers and engineers imagine users exerts performative function on the development pathways of technology, and 'scripts' user behaviour [38,1,42]. In addition, the ways in which publics are constructed within broader socio-technical imaginaries has also been shown to have a significant influence on policy development and material technology and design e.g., [70,5,58,37].

Based on Maranta et al.'s [46] notion of 'imagined laypersons', describe how publics 'exist as imaginaries given agency and invoked for strategic purposes' [70]:932, assigned a presumed subjectivity within shared discourse that can be invoked during decision making that may frame continuing layperson-expert interactions. Barnett et al. [5] thus highlight the role of experts as 'layperson makers', whose perceived subjectivities shape the roles

and opportunities for public participation and engagement, with these conceptualisations of the public used to define and support the underlying normative rationales of these interactions. A recurring theme throughout such research has been the construction of the public (by professionals and scientists) as deficient in some way, in terms of their knowledge, skills, rationality or sense of environmental responsibility [73]. As such, they are often seen as a barrier to achieving technological potential; a view which has become tantamount to common sense in many professions [21]. Research into innovative nano- and bio- technologies, also demonstrates this othering of publics by scientists, who see them as ignorant and ill-informed [47,53]. As such, these imagined publics may actually have more influence than the 'real' publics they purportedly represent [70].

Together these approaches have been used to explore the expectations and visions of the future that are tied to sustainable technologies and the imagined publics that are embedded within them, including: renewable energy siting [70,22], solar panels [2], hydrogen fuel cells [9] and smart grids [57,3,67]. Skjølvold's [58] research in Norway is of particular interest, demonstrating the importance of exploring the performativity of visions of the future retrospectively. The way in which the smart grid was imagined influenced policy development over the preceding 15 years; occurring first through stage-setting (encouraging debate and enrolling new actors) and second through acting as a regulative tool (establishing the need for political and technical change). Beyond this, imaginaries also acted through a more subtle process, leading to an evolution in the vision of what the smart grid was and could be in the future.

Two competing imaginaries of publics were identified within expert visions of the smart grid [57]. An active public that was engaged with new smart technologies was considered an essential component of demand management within the broader socio-technical imaginaries of the smart grid. Paradoxically, this vision of the economically and technically rational 'Resource Man', who will both benefit from and make possible this transition [66] was opposed (and eventually defeated) by an imagined public that was seen as irrational and deficient in knowledge. This contradiction eventually led to the development of a set of idealised rational publics through which to script the technology, effectively bypassing the public input that had originally been desired. This finding is echoed by research in other areas, where experts attempt to design out the role of the public through a combination of technical optimism and cultural pessimism [2]. How experts communicate on and engage with members of the public has thus also been seen to be dependent on imagined publics. Ballo [3] highlights how an almost utopian vision of the future smart grid led experts to cultivate a glossy vision of the technology within public messaging, omitting legitimate concerns and likely to alienate rather than enrol the public.

3. Case study: the rise and fall of low carbon housing futures in UK policy

This section retrospectively traces the transformation of low carbon housing imaginaries over the last 15 years. Prior to 2001, housing policy debates were largely silent on issues surrounding climate change and sustainability [71]. At this time, links between energy and housing policy focused heavily on fuel poverty and the energy efficiency of public sector housing developments. Whilst a sustainable housing movement had grown in the UK since the 1970s [44], the concept didn't arrive on the policy agenda until around 2003. In addition to the rising importance of climate change, which was fundamental to the development of low carbon housing policy, the EU Parliament (through the Energy Performance in

Buildings Directive – EPBD)¹ and environmental campaigners put pressure on the UK Government to produce a framework for sustainable housing. Following a number of key reports on housing and sustainability [49,455], 2005 saw the concept of a ‘zero carbon house’ set out within the Environmental Audit Committee’s ‘Housing: building a sustainable future’ report, which recommended a zero carbon target for all new build housing [24].

Sustainable housing began to be reimagined as a solution to climate change [44], marking the beginning of a new low carbon vision for UK housing, with the then Minister for Housing and Planning, Yvette Cooper declaring the need ‘to go further and faster’ [27]:3 in tackling emissions from the housing sector. Acting as a stage-setting device [58] to encourage debate and engage new actors, this vision for a low carbon housing sector remained vague at first, primarily a rhetorical call for new sustainable, carbon neutral approaches to housing that would tackle climate change, energy security and affordability in a cost effective way. Whilst still primarily considered consumers, the public were conceptualised as environmentally conscious ‘eco-consumers’ that desire low carbon, environmentally friendly homes, and are willing to pay for more expensive low carbon properties.

With the announcement of the Code for Sustainable Homes [15] and the Zero Carbon Homes Target [34], this vision of a low carbon housing future finally gained more explicit agency within regulatory tools in December 2006. Aiming to achieve completely zero carbon homes, these policies challenged the construction industry to produce zero carbon housing by 2016 through a gradual tightening of building regulations and a series of sustainability requirements [16] and led to the institutionalisation of this low carbon housing vision through the creation of the UK Green Building Council (UKGBC) and the Government-Industry sponsored Zero Carbon Hub. Responding to criticisms of the technically vague specification of zero carbon housing, a number of reports [68,74,17] culminated in the introduction of the Fabric Energy Efficiency Standard (FEES) and the Carbon Compliance Level (CCL), which set out the maximum energy demand (for heating and cooling) and the minimum onsite low carbon energy requirements of a ‘zero carbon’ house.

However, this vision, as set out within UK housing and energy policy, was ultimately short lived. With the election of the Conservative-Liberal Democrat Coalition Government in May 2010, support for low carbon housing policy decreased, leading to repeated redefinitions of zero carbon housing and reduction in the strength of the Zero Carbon Target. This saw a number of previously key policy requirements excluded, including unregulated emissions associated with energy use in the home (from cooking/appliances), as well as reductions in the CCL and approval for off-site offsetting of emissions that cannot be cost-effectively reduced on-site [75]. These changes highlight a significant reduction in the Government’s ambition to transform the housing sector, with the focus on sustainability and climate change replaced by concern for energy efficiency and cost competitiveness. Over time, further announcements progressively weakened low carbon housing policy, and in 2015 the Code for Sustainable Homes and the Zero Carbon Target were officially scrapped [33]. Despite the shifting policy agenda and rhetoric, both the Labour and Coalition Government visions of a low carbon housing future were deeply embedded within the techno-economic paradigm. Both Governments characterised the problem as about ‘changing buildings rather than about changing lifestyles’ [52]:342, largely neglecting the question of behaviour change in the home.

¹ The Directive was later recast in 2010, to include a mandatory target of all new buildings to be nearly zero energy by 2021 (European Council, 2010).

Table 1

Participant’s primary areas of expertise (secondary areas of expertise included in brackets).

Area of expertise	No. experts
Housing and Energy Policy	6 (3)
Industry and Architecture	6 (1)
Academia and Research	3 (2)
Campaigning and Lobbying	4 (3)
Sustainable Living	3 (0)

With climate change no longer central to low carbon housing policy, efforts to reduce emissions now advocated reducing home energy bills through energy efficiency measures. A purposeful effort was made to reframe energy efficiency improvements as ‘home improvements’ [28]; a framing that was reflected in the media discourse [14]. A shift in imagined publics coincided with this, with members of the public considered as individual and economically rational consumers, concerned only with the costs and benefits of installing energy efficiency measures, and thus no longer the eco-consumers envisioned by previous policy. With energy efficiency framed as a consumer good, cost, along with the hassle of installation and a lack of education/information, were seen as the major barriers to consumer adoption of demand reduction measures. Combined, the promotion of this adapted vision for a low carbon housing future led to the omission, if not purposeful marginalisation, of other aspects of low carbon housing, including the role of social and behavioural change in reducing emissions, as well as the issue of embodied carbon emissions within the construction of the house (estimated to be as high as 50% of lifecycle emissions [16]).

4. Methods

‘The strength of an argument about imaginaries often depends on creative juxtaposition of evidence from a variety of sources, using multiple methods’ [29]. As such, we adopted an approach that combined documentary analysis with expert interviews and public focus groups to explore the visions of a low carbon housing future from different perspectives. Policy documents provide a useful and accessible source of national imaginaries. A collection of over 50 relevant documents was compiled, comprising of official UK and EU policy documents and statements, Government white papers, NGO reports and guides, and Parliamentary Committee reports and consultations. These were examined for the visions of a low carbon housing future they described and the ways the public were imagined within them.

Semi-structured interviews were utilised to facilitate a ‘communicative opening up and analytical reconstruction of the subjective dimension of expert knowledge’ [6]:52. These were designed to access and explore shared meanings within expert imaginaries of low carbon housing, focusing particularly on 1) the conceptual and technical meanings of low carbon housing, 2) visions of a low carbon housing future, and 3) conceptualisations of the public within this context. 22 expert interviews (lasting approximately 1 h) were conducted between May 2013 and February 2014. A diverse range of experts were sampled based on their professional expertise in the areas of housing and energy, falling into one or more of the following categories (see Table 1): Government Policy; Industry and Architecture; Academia and Research; Campaigning and Lobbying; or Sustainable Living. Sampling and analysis progressed through a theoretical sampling strategy [25] associated with the analytical grounded theory method utilised within this research, until theoretical saturation was deemed to be reached (with no new themes or relationships arising within later interviews).

Focus groups, were chosen to explore this topic with members of the public due to their ability to explore the ways in meanings are (re)produced in everyday life [45]. The protocol was designed

Table 2

Key characteristics of focus groups participants including location, gender split, age range, living arrangements and range of occupations.

Group characteristics	
Focus Group 1 Postgraduate students Cardiff	2 Female and 3 Male participants, aged 25–33 Living in rented or shared accommodation Postgraduate students
Focus Group 2 Farming community Newcastle Emlyn	4 Female and 2 Male participants, aged 27–56 Homeowners (houses, cottages and farmhouses) Farmers and veterinary staff
Focus group 3 Church group King's Lynn	2 Female and 2 Male participants, aged 26–87 Homeowners (houses and bungalows) Machine engineers, a teacher and retired individuals
Focus Group 4 Grangetown residents Cardiff	5 Female and 1 Male participants, aged 26–81 Mixed homeownership (houses) and renting (flats) Housewives, a cleaner and a builder
Focus Group 5 Environmental group Barmouth	3 Female and 3 Male participants, aged 60–68 Homeowners (Houses, bungalows and cottages) Retired professionals

to follow from the discussions held during the expert interviews, exploring 1) public perceptions of low carbon housing options and 2) the social and technical concerns and assumptions associated with assessing the suitability of low carbon housing as a future home. In order to maximise group interaction and discussion, pre-existing groups or communities were sampled. Although not recreating a truly 'natural' setting for group discussion, this provided a greater approximation to everyday conversation with family, friends and colleagues [39]. Increasing the ease of conversation in this way led to a deeper probing between participants than may have otherwise occurred and allowed an insight into shared sense-making around novel concepts and technologies. Five homogenous groups were conducted (a group of postgraduate students; a farming community; a church group; an inner-city, local community; and an environmental group), selected to represent a broad range of backgrounds and provide a diverse mix of participants in terms of gender, age, socio-economic status and living arrangements (see Table 2).

Most participants were previously unaware of the existing low carbon housing options. In order to stimulate discussion of the material and technological features of these houses, as well as the implications these may have for everyday life within these houses, photo and video elicitation tasks were designed. Seven photographs of existing low carbon housing options were presented, chosen to demonstrate the aesthetic variation of the broad range of housing types available. Video tours of five different low carbon houses were presented, chosen to represent as broad a range of options as possible, focusing on demonstrating a range of different technological systems, as well as a split between new build and retrofitted properties. See [13] for more information on the photographs used and links/transcripts of the videos. Discussions lasted approximately 3 h and include open questions before specific prompts were used to explore the aesthetic, technical and social dimensions of these houses.

Data from both the interviews and public groups was transcribed and coded within the NVivo qualitative analysis software package. A grounded approach to data analysis (derived from grounded theory – see [25,32,65,12]) was adopted for each data set to develop a coding framework that was grounded within the data collected and not prescribed prior to the analysis. The process involved: open-coding to generate codes at different levels of theoretical complexity (from simple descriptions to conceptual categories); constant comparison between/within codes to ensure good 'fit' with the data; the keeping of theoretical memos of emerging thoughts, insights and concepts; and finally a process of (re)grouping these codes within broader and more theoretically

relevant *meta*-codes. This process was continued until theoretical saturation was reached and no new codes, themes or insights were being generated.

5. Homes as machines: expert imaginaries of a low carbon future

This section explores the visions of the future through which experts imagined low carbon housing in the UK, first discussing expert perceptions of the vision set out with UK housing policy before moving on to describe the different ways that the experts themselves imagined a low carbon housing future. The term zero carbon was almost exclusively associated with UK low carbon housing policy (described above), and was in a sense seen as a non-future, unconnected to discussions surrounding the future of UK housing. A firm (if challenging) commitment to tackling emissions from the housing sector, many discussed how they had initially supported the policy definition of a sustainable and net-zero carbon house. However, as subsequent announcements redefined the meaning of zero carbon, this term became seen as conceptually problematic.

The exclusion of unregulated emissions (those related to the use of the home *i.e.*, through cooking and appliances) from the emissions scope of the calculations determining the zero carbon status of a house was of particular concern [69]. This was especially true in the light of pre-existing objections to the exclusion of embodied carbon emissions (associated with the raw materials, manufacturing, transport and construction of the building). The introduction of Allowable Solutions in 2013, which allowed developers to significantly widen the scope of mitigation measures counted towards the achievement of the zero carbon standard, was seen as a significant limitation to achieving significant emissions reductions, compounding this contempt and leading to a lack of belief in the proposals.

For many, a net-zero carbon house (that over a year uses no more energy than it generates, including both regulated and unregulated emissions), remained the only credible vision for a low carbon housing future. This narrowing of the boundaries within which a zero carbon house was conceptualised, was seen as 'watering down at the behest of the house builders' (Interview 3: Environmental campaigner), with the policy no longer seem as appropriate to the task of transitioning towards an environmentally friendly housing stock. However, despite the 'loss of faith that [zero carbon] really means zero carbon' (Interview 4: Environmental policy expert), this term, as a label, was still seen by some to play a role in reflecting the aspirations of the Code for Sustainable Homes, acting as a boundary

object [62] that allowed diverse actors to work towards this vision of the future.

In contrast to the policy prescribed meaning of zero carbon housing, the term low carbon house (and the often interchangeable low energy house) was understood in relation to complex expert visions of future housing that were rich in both technical and normative detail. Within these visions, two distinct and socially shared ideals for future low carbon housing emerged: Passivhaus and Smart Homes. The basis of both these housing options was rooted in the longstanding discursive and technical dominance of energy efficiency, stressing the need to address the fabric of the house; this would perhaps include 'more insulation, triple glazing windows, [or] heat recovery ventilation systems, so it's very high-spec compared to a normal current house' (Interview 4: Environmental policy expert). However, beyond this, experts predominantly advocated only one of these forms of housing, with the Passivhaus and Smart Home visions held up as distinct and contrasting imaginaries, as equally feasible but divergent visions to transform the UK housing sector.

Within both visions for a low carbon housing future (discussed in detail below), assumptions surrounding both the role of household occupants and the nature of 'the public' more widely are clearly intertwined with these technological imaginaries. Whilst most experts did not consider 'the public' to be one homogeneous group, the term was used consistently, often leading to broad generalisations about public opinion and acceptability. Often, the public were characterised as made up of individuals who are either actively against low carbon housing and technologies or simply ambivalent towards the concept, and only a small minority were thought to be concerned for the environment or climate change. For this reason, and echoing previous research discussed above, the public were often characterised as self-interested and financially motivated when discussed in relation to low carbon housing. In addition, experts believed the visual appearance of housing was the key barrier to public acceptance of both visions for low carbon housing:

[T]he only one that anybody liked was the one that looks like a traditional house, [...] it just tells you about what goes on in people's minds, what's their aversion. And it's about funky designs, they don't like it, they want houses. (Interview 5: Housing and construction expert)

This belief laid the foundations for the general assumption that low carbon houses simply needed to look 'normal' (meaning as close to traditional terrace or semi-detached houses as possible) in order to improve adoption rates *cf.*, [70]. Likely stemming from recent Government reports surrounding the hassle factor associated with adopting home retrofit measures [19], the hassle and disruption caused by installing, using and maintaining low carbon housing and technologies was also considered a significant barrier to adoption. Combined, a generally narrow conceptualisation of a public was imagined, that could not (or would not) pay the extra cost of low carbon homes and technologies, and even if willing and able to pay, would be put off by the hassle and disruption surrounding these new technological systems.

In addition, the behavioural changes that may be needed within a low carbon home were also problematized. Conceptualisations of publics as resistant to changing their behaviours and practices, and as primarily concerned with cost, visual aesthetics and ease of use, thus fed into a techno-fix discourse:

We need to [...] remove the user from having to do anything. It just is efficient, you don't have to worry, you don't have to put pressure on people to change their behaviour. (Interview 14, Housing policy expert)

In contrast to the construction of rational publics in relation to the acceptability of new forms of housing, when discussing the use of technologies occupants were described as irrational and unpredictable. As such, a framework for these visions was constructed in which occupants, and the public more widely, are characterised primarily as a barrier to achieving the low carbon futures, where 'building a house is fine, it's putting the people in that's the problem [laughs]' (Interview 1: Construction project manager). We now contrast these two visions of a low carbon housing future, paying particular attention to the constructions of the public embedded within them and showing, ultimately, how both visions act to frame the home as a machine, designing out occupants in order to reduce carbon emissions and energy use.

5.1. Passivhaus

Developed in Germany, the Passivhaus standard aims to 'dramatically reduce the requirement for space heating and cooling, whilst also creating excellent indoor air quality and comfort levels' [35], removing the need for traditional heating systems. Focusing on thermal efficiency and MVHR (Mechanical Ventilation with Heat Recovery) systems to ventilate near air-tight houses, Passivhauses were generally considered a simple and effective way to reduce heating requirements, whilst maintaining a comfortable temperature:

[It's in] the fabric of the building, not throwing lots of equipment inside and systems, because, matter of fact, it doesn't normally have heating in there. You know, you become the heating source and the light bulb almost. (Interview 1: Construction project manager)

Passivhaus was often seen as the pinnacle of low carbon/energy housing, advocated as a replacement for the Code for Sustainable Homes and forming the basis of a low carbon housing imaginary. Whilst initially discussed as a solution to climate change through energy demand reduction, embedded at the heart of the Passivhaus vision was the belief that exceptional thermal efficiency could solve a range of other social problems (*e.g.*, energy affordability, fuel poverty, health concerns), improving living conditions for occupants. Ideals of simplicity, passivity and comfort were central, with many drawing on personal experience to express how enjoyable and warm Passivhauses are, the associated low energy bills and the possible health benefits they could bring (due to increased warmth and improved indoor air quality).

However despite firm beliefs in their technological effectiveness, questions about the role and influence of the Passivhaus occupant remained. Pervading this vision was a characterisation of the public as lacking in knowledge (both surrounding specific technologies and wider understandings of climate change) and as a barrier to achieving a low carbon future. Public acceptability of such housing was questioned on the basis of both increased cost of build and the visual appeal of these homes. In addition, the acceptability of the technical configuration of Passivhauses was also questioned. Social preferences for indoor temperature were seen as particularly problematic, raising concerns that although technically deemed to provide acceptable heating services, the lack of any heating focal points within Passivhauses was a possible barrier to adoption, due to lack of control over heating levels and timings.

The perception that 'people don't understand technologies' (Interview 5: Housing and construction expert) was also a strong theme. Despite their professed simplicity, concerns arose regarding the correct operation of these homes, evoking a sense that 'it takes a certain type of personality to live in and operate a Passivhaus in the way that it needs to be operated' (Interview 2: Professor of architecture). Complex interactions between the house and occupants, the influence of unruly occupant behaviour on energy use, and beliefs

regarding the need for the correct use of technology, led many to advocate that the 'best way to drive down the carbon use in properties is actually to take people out of the equation' (Interview 5: Housing and construction expert). Underlying this, the metaphor of homes as machines brings to light a desire to design out public the influence on household energy use, hinting at a deeper belief in the power of technology alone to solve environmental problems *c.f.*, [60]. This echoes assumptions within academic and policy arenas that technologies can and should be optimised to achieve energy reductions by working around occupants rather than with them *e.g.*, [43,63].

5.2. Smart homes

Contrasting largely passive, low-tech houses of the future offered by the Passivhaus imaginary, the Smart Home provided a divergent, high-tech vision of future housing. Whilst there is no single definition, a smart house incorporates 'information and communication technologies (ICTs) distributed throughout rooms, devices and systems (lighting, heating, ventilation) relaying information to users and feeding back user or automated commands to manage the domestic environment' [72]: 463. Smart meters (intelligent gas and electricity meters that provide information and feedback on home energy use, communicating directly with energy suppliers) that connect every home to the smart grid (a flexible electricity supply network, allowing two-way communication and rapid response to changes in demand), formed the key technological components of this vision. Smart appliances, which make use of wireless technology, provide information on energy consumption and communicate with the household smart meter and other products, were also prominent. The fundamental purpose of smart housing is demand management and reducing peak energy demand. Whilst energy security was the primary focus of this vision, it was also promoted as crucial for low carbon energy systems due to its ability to cope with variable renewable energy supply; and as such was premised on the successful large-scale adoption of low carbon energy sources. Interestingly, this vision omitted other frames previously highlighted as benefits of smart housing such as health benefits, assistive living and security [72].

The role of the public was less of a concern, with the acceptability of Smart Homes largely unquestioned following assumptions that technologically savvy citizens would easily adapt to novel Wi-Fi and app-enabled systems. Rejection of smart, automated technology due to reduced personal control over heating and appliances was dismissed. Media concern surrounding this issue was perceived as hype, relating to a number of (then recent) newspaper articles, such as the Daily Mail's 'Big brother to switch off your fridge' [48]:

I can't see why, as long as you get the service you want, you know your fridge stays cold enough and your hot water is there when you need it, why you'd worry about that, but it's presented as an incredibly invasive technology, which I find strange. (Interview 4: Environmental policy expert)

Constructed as rational actors, willing and able to participate in and benefit from this transition, the possibility of reduced energy bills was thought to override any public resistance to the intrusion of smart technologies, with people happy to relinquish control in exchange for cheaper energy services (*c.f.*, 'Resource Man' [66]). However, although cost savings are an important consideration [72], recent research has highlighted the complexity surrounding public perceptions of smart technologies, highlighting unease over sharing personal energy data, with the individuals most concerned with household energy affordability most likely to demonstrate concern [61].

Despite this conceptualisation of the public, few believed that merely providing information regarding personal/household energy use would lead to behavioural change (echoing [57]). An ability to learn and adapt to occupant behaviour was often considered fundamental to success:

If you had controls that learn about patterns of user behaviour and then adapt it to that, that would be a smart control. But there's nothing smart about one that tells you're wasting energy. If you get a smart meter at the moment all it does is tell you're really wasteful. (Interview 5: Housing and construction expert)

Aimed at designing out the influence of occupants on household energy use, in this sense occupants were, at best, considered to be unruly decision makers. The homes as machines metaphor is thus also present, with the need for fully automated smart systems (that control heating, lighting and appliances) widely advocated.

6. Reconfiguring homes: public acceptability of low carbon housing visions

We now move on to explore public acceptability of future low carbon housing, focusing specifically on the Passivhaus and Smart Home visions before discussing broader values and concerns that influenced perceptions of how a low carbon housing future should unfold. Passivhauses were popular, with several participants already aware of the concept. In addition to lower energy bills, their simple design, high energy efficiency, and comfortable nature made these houses appealing. New ventilation systems (MHVR) were reasonably well received, although concerns were raised over possible implications for the comfort and atmosphere of homes due to the 'noise pollution' from the system's 'constant whir' (Gemma, Focus Group 1: Postgraduate students, Cardiff), which despite the noise of existing technologies such as boilers and radiators, was seen as potentially intrusive. The associated changes to heating configurations, such as the removal of radiators, were rarely seen as an issue, with many in favour of removing radiators completely:

Glen: Yeah, as long as the house is warm.

Russell: Yeah if you don't need radiators. You've only got radiators because you need them to heat your house. If you're heating it in different ways, you don't need radiators.

Glen: If you don't have radiators you don't drape damp washing over them to dry them out and put damp into the air.

Russell: They are nice for putting a towel on and trousers. I think I'd miss that. (Focus group 3: Church group, King's Lynn)

This contrasts with previous research that suggests that the lack of heating focal points may not satisfy residents' requirements for comfort, despite reaching the temperature deemed technically acceptable within the home [23]; although this may in part be due to the lack of personal experience with such changes, or perhaps due to the wider age range of participants sampled here.

Public awareness of smart and automated technologies or the concept of a Smart Home was low. Contrasting the discussions surrounding Passivhaus, the aesthetics of these homes was not concerning due to the relatively minor changes to the fabric of smart homes. The additional control over home energy use that smart technology could provide was appreciated, especially the idea of controlling your heating while away from home:

Chris: I've got nothing against that. As long as it would be easier for me to use than the dodgy dial on the wall that doesn't seem to do much.

Louise: Yeah, you can properly regulate things a lot more effectively.

Gemma: Yeah, there's a new thing you've got on your phone. You can get an app where you can turn the heating on before you get home, which means you can make your house warm. (Focus group 1: Postgraduate students, Cardiff)

However, automatic heating systems and appliances, that reduce occupant control, were viewed with suspicion and scepticism by many. This was seen as raising issues around personal privacy and security (discussed below), and as practically and financially infeasible, being 'hugely expensive to implement [as everything] would have to have its own little logic device' (Mervin, Focus Group 5: Environmental group, Barmouth).

Increasing renewable energy use was popular, and in principle at least, participants were not averse to adopting new household energy technologies in the future. Photovoltaic panels were the least controversial, considered the only viable micro-scale electricity generation system. Some participants had direct experience of installing these in their homes, while others had tried (and failed) to adopt solar panels, or been offered them through Government or energy company schemes. However, despite support in principle, the relatively high upfront costs were seen as prohibitive to many, as well as concerns about the unstable nature of national energy policy, with the Government seen as always 'changing the goal posts' (Deborah, Focus Group 2: Farming community, Newcastle Emlyn). Harnessing solar energy was seen as a key component of the national energy mix in the long term *c.f.*, [20], with possible technological innovations, such as inbuilt solar roof tiles, suggested to moderate objections to the visual appearance of this technology. In contrast, transitioning towards new low carbon/low energy heating systems was a topic of extensive debate, with new technologies such as personal biomass boilers proving controversial (due to both practical and safety concerns).

Whether for environmental or economic reasons, most participants demonstrated some desire to move towards low carbon/energy housing. However, a range of concerns were raised, some of which matched expert expectations of public acceptability, some of which did not. The cost of low carbon housing was of course a concern, focusing on personal rather than national affordability, with both capital costs and payback times of concern. Most participants felt low carbon homes and technologies were only an option for the very wealthy and were currently out of reach for the average citizen, despite a desire to 'live in a house that saved electricity or brought the bills down' (Glen, Focus Group 3: Church group, King's Lynn).

More complex than simply unwillingness or inability to pay, the issue of payback times (the time taken to recoup the initial investment and begin making cost savings) was a key concern. Personal, family and financial circumstances were considered highly relevant given the unpredictable nature of modern life, with payback times above 10 years seen as particularly unreasonable. Retrofitting existing homes, was thus seen as the more worthwhile compared to the long payback times presented by the purchase of a new low carbon house (from the slow rate that home energy bill savings accrued). These concerns were strongest amongst younger participants who couldn't afford to buy a house, and whose desire to get on the housing ladder was dominated by other priorities (primarily cost and location). Later in life, the desire to remain settled within one's existing home dictated opinions on low carbon new build. As such, attention returned to retrofitting; with no intention of moving, participants were more willing to pay for efficiency improvements, although concerns over financial security, including family responsibility and preparing for old age still took priority.

Complicating somewhat the expert belief that the 'hassle factor' related primarily to the practical impacts of building work in the home [19,8], public experiences of home improvements suggested instead that gaining planning permission, choosing effective

and appropriate technologies and employing trustworthy installers was of greater concern. The ability to adapt and change your home for whatever reason was deemed a non-negotiable aspect of home ownership, with the implications of making functional changes (*e.g.*, the impacts of installing a cat flap on thermal efficiency) off-putting in relation to new build housing. Regarding the practicalities of everyday life, several issues were highlighted around the appropriate and effective use of low carbon/low energy technologies. Whilst experts' concerns centred on the correct operation of Passivhauses and Smart Homes, participants focused on the new routines and practices would be required, such as the implications of removing radiators (see above) on drying washing indoors, highlighting the need for a dedicated drying area to be provided. Concerns were also raised regarding new heating systems such as wood burning stoves and biomass generators due to the increased physical and storage demands of buying, storing and using wood or pellets.

Safety and security implications were also of great concern. The economic, functional, and social risks of adopting new technologies [40] were seen as paramount, generally falling into three categories: fear of financial loss, fear of malfunction and fear of personal danger. Contrary to some experts' beliefs, the social risk that low carbon choices might be considered unacceptable by peers or wider society was not a salient concern. Financial security was often seen as crucial in feeling at home within your house, with rising energy bills adding to this pressure. Adopting non-mainstream energy technologies was considered particularly risky following suggestions that innovative technologies may: have a shorter lifespan; fail to become widely adopted; or become rapidly obsolete. Another common fear was that new or immature technology would malfunction, leaving occupants vulnerable within their homes. Losing power or heating (or both) through malfunction was seen as a fundamental risk, leading to anxiety surrounding the inconvenience of disruption to key services within the household, and the hassle and responsibility involved in making repairs *c.f.*, [54].

This reluctance to increase risks that already exist when using mainstream technologies was repeatedly highlighted, and led some to conclude that low carbon/energy houses would always need 'a back-up generator, and a back-up, back-up generator' (Louise, Focus Group 1: Postgraduate students, Cardiff). Although rarer and often contested, high levels of anxiety were displayed towards the adoption of new technologies by some, exposing a fear that they pose a serious safety threat to occupants. These possible dangers were particularly acute in relation to the consequences of malfunctioning smart and automated technology, both in terms of personal safety in the home and the security of personal information and data:

Claire: I wouldn't feel safe with the electric door.

Alice: No.

Claire: I would feel unsafe. What if it locks you in? What if it locks you out?

Eleri: What if there's a fire and it meant you couldn't get out? (Focus group 2: Farming community, Newcastle Emlyn)

As with any home, visual appeal was important in determining personal opinions of low carbon houses, to some extent reflecting experts' constructions of public acceptability. However, personal preferences were varied and diverse, and far more complex than assumed by experts. Focusing on ideals of normality and homeliness, some demonstrated a desire for a traditional house that didn't look 'space-agey and weird' (Gemma, Focus Group 1: Postgraduate students, Cardiff) or 'cold and sort of experimental' (Peter, Focus Group 5: Environmental group, Barmouth). However, while the traditional features of a Victorian semi-detached house were integral

to feeling at home for some, others were open-minded and excited by the possibility of a unique home that was 'sharp, modern, cool' (Russell, Focus Group 3: Church group, King's Lynn). Homeliness was crucial, seen as something you created and that encompassed both sensual and physical elements, such as comfort, warmth, light and style *c.f.*, [23].

Related to issues of privacy, personal space and noise pollution, the configuration of local neighbourhoods that low carbon housing was situated presented a further element contributing to feelings of homeliness and comfort. This feeling was particularly relevant to more densely populated options, with housing complexes and apartment buildings described as akin to 'rabbit hutches' (Daniel, Focus Group 3: Church group, King's Lynn). The architecture and social configuration of this type of housing was perceived as constraining occupant identity, where all residents must 'wear the same, look the same, have the same car' (Lisa, Focus Group 4: Grangetown local residents, Cardiff), leading to a loss of individuality and a sense that some housing was only 'appropriate' for certain people or lifestyles.

In addition to economic, technical and social concerns, a final theme running through the discussions revolved around establishing the true environmental credentials of low carbon housing futures. Ascertaining which house was really the most environmentally friendly was seen as difficult, with many participants believing they needed more information to make the best choice. Assumptions were often made regarding which houses were more environmentally friendly on the basis of visual aesthetics, with certain styles assumed to be the lowest carbon/energy houses *e.g.*, high-tech houses with extensive solar panel arrays or grass-roofed eco-houses. However, even the environmental credentials of these houses were questioned, with discussions surrounding possible embodied emissions within these supposedly 'low carbon' houses and technology.

More broadly, the effectiveness of these houses within wider emissions reduction strategies was also questioned. The issue of rising population was seen to require a solution that can work for the entire country, rather than a niche solution for only a small number (due to either financial or spatial constraints). From this perspective, apartments (the least attractive option on a personal level), were considered the most eco-friendly, as more people are housed within an area, conserving both energy and materials. However, despite reflections regarding the balance between 'what we want as an individual' (Joan, Focus Group 5: Environmental group, Barmouth) and achieving large-scale emissions reductions, this insight does not make these low carbon housing options more appealing. Considering possible compromises to this dilemma, the concept of a Passivhaus was seen as a more appropriate low carbon mass housing option.

7. Concluding discussion

Despite recently dropping down the UK policy agenda, the need to transition towards a low carbon housing future is becoming increasingly urgent. As such, the visions and expectations of the professionals to be charged with delivering this future will play a key role in determining the pathway by which this transition takes place. We identified two competing visions of a low carbon housing future: Passivhaus, advocating the low-tech building standard that provides high thermal efficiency; and Smart Homes, advocating a high-tech and automated approach to controlling home energy use.

Whilst often portrayed as contrasting possibilities, both futures shared the objective of 'designing out' the role of occupants, and hence achieving emissions reductions through changing the built environment and maintaining current lifestyles. An ambivalent imagined public populated these visions, with the idealised indi-

viduals needed to ensure the successful transition to a low carbon housing future, simultaneously critiqued as deficient in knowledge, skills and environmental concern *c.f.*, [31]. Concerns were thus raised whether publics were able, and indeed willing, to adapt to these new housing systems due to the increasing level of expertise and engagement needed to understand and properly operate these technologies. Stressing the need for simple design, experts took the approach that reducing energy use needed to be achieved as passively as possible or with automatic systems that were easy to understand and control.

This is not to say that complex socio-technical interactions were not acknowledged within the discourse surrounding low carbon housing. Rather that, whilst recognising the role of occupants in correct operation of the technology, many were sceptical of the possibilities for enacting behaviour or lifestyle change, advocating an increasingly technical approach to bypass this issue. In many ways, Strengers' [66] vision of Smart Utopia encapsulates the visions of the future bound up within these techno-centric visions of low carbon housing. Here smartness is seen as an extension of broader societal discourses of convenience [56,26], in which services are delivered in the background of daily life, increasing automation so that occupants retain less control over energy practices. The combination of preserving the status quo of everyday life and increasing technological dependence within these imaginaries is important, especially considering the likely impact on the ability of these homes to actually achieve emissions reductions.

As Walker et al. [69] discuss, the high level of socio-material interdependence embedded within the socio-technical system of a low carbon house, is instrumental in determining the carbon emissions of a given home. Recent research highlights the discrepancy between the normative assumptions made by experts surrounding how technology will be used within the home and actual use [50], with individual energy practices found to undermine or subvert the principles on which this form of housing is based [66]. As part of this system, imagined publics thus play an active role in shaping the development of technologies and policy [70,57]. The imagined publics within the dominant socio-technical imaginaries of low carbon housing clearly influenced expert perceptions of future possibilities, leading to a techno-centric focus on the role of technology in reducing carbon emissions and a desire to 'design out' occupant influence on household energy use.

Questioning the reliability of these imaginaries, we explored visions of a low carbon housing future with members of the public to identify the values and concerns that influenced their perceptions. Whilst participants did, of course, show concern for aesthetics, cost and hassle (believed to be key determinants of public acceptability), these concerns were not confined within the narrow expectations of experts' imagined publics. Specifically, claims that publics: wanted a house that looked like a house; would not pay the extra cost of low carbon homes and technologies; and even if willing and able to pay would be put off by the hassle and disruption of installing and using new technologies, did not fully take account of the complex personal and cultural dimensions of comfort and identity. Comfort took on many forms in addition to aesthetics, warmth and light of any house. Both personal and cultural identity were bound up with design and technology, manifested in the importance of personalising the home, and through the wider social connotations associated with housing configurations; houses were deemed appropriate only for a certain type of individual, with acceptability judged primarily on personal identification with the style of the property, the wider neighbourhood in which it was set, or imagined occupants that might be living within it.

Control formed the second broad value under which these houses were evaluated. Freedom to modify the house was important for personal autonomy, with any restrictions to this, such as not

breaking the thermal envelope of a building, considered an unreasonable expectation. Personal control over energy use was also desirable, with participants ambivalent to smart and automated technologies that on one hand offered increased control through monitors and app-enabled systems, whilst on the other hand raised fears over relinquishing control over energy use (and personal data) to energy companies. Personal security was also foregrounded, with insecurity permeating discussions of low carbon homes and technologies, focusing on risks around financial loss, the loss of energy services (and thus the comfort and convenience they provide), and the loss of time and effort due to increased maintenance requirements, as well as some concerns about the safety of such technology. As such, whilst concerns around affordability are often interpreted by experts as an expression of financial concerns for returns on investment, participants concerns were instead in part rooted in deeper insecurities relating to the unpredictable nature of modern life.

This gap between the imagined publics inhabiting expert visions of a low carbon housing future and the preferences and values of participants, hints at tensions that may arise as we attempt to transition towards new socio-technical systems. Radical change in both the material and social aspects of our homes are required to successfully tackle climate change. We argue here that both idealised and deficient imagined publics are unhelpful for this task, acting as a barrier to envisioning future lifestyles change, and closing down debate surrounding demand reduction strategies and the future of housing [64]. Underpinned by a common perception of the public as preoccupied with cost and visual aesthetics and thus unable/unwilling to accept any level of lifestyle change, the socio-technical imaginaries and imagined publics of low carbon housing acted to reinforce each other. This contributed to the perpetuation of the perception that a technological approach to mitigation is the only possibility for achieving a low carbon housing future. As such, the construction of such visions of the future must now be opened up. In order to understand public acceptability of low carbon housing options, these houses must be understood not just as a combination of the material and technological elements of low carbon housing, or even through the interactions between occupants and these elements, but also as a home, embodying broader values of comfort, control and security that moderate economic, technical and environmental concerns. Visions of a low carbon future that look towards an ever more automated and high-tech approach are thus unlikely to succeed in achieving the desired emissions reductions until they accept the need to work with, rather than around, the publics which inhabit them.

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