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The changing landscape of thermal experience and warmth in older people’s dwellings

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HIGHLIGHTS

- Thermal variations across space affect the use of space within a dwelling.
- Older people show interest in and understanding of thermal behavior of dwellings.
- Older people pursue the thermal conditions they desire.
- Older people take actions to modify the quality of the thermal environment in their house.
- Changes made to the house may not be solely motivated by thermal comfort concerns.

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ABSTRACT

The UK's carbon dioxide reduction policy initiatives often treat environmental conditions in buildings as averaged values of air temperature that flatten spatial variations. This discounts the influence of varying thermal conditions on how people use buildings and the impact this may have on energy consumption. This paper explores the intersection between older people's thermal experience, spatial and temporal variations in thermal conditions in a dwelling and the influence this has on occupants' use of space. The paper reports on qualitative studies in homes with both conventional and newly installed low carbon heating systems. The results suggest that older people are sensitive to and adept at exploiting variations in the dynamic ‘landscape’ of warmth to achieve desired thermal preferences and that they modify their dwellings to improve the quality of the thermal environment. There is also some evidence of a ‘spatial rebound’ effect after energy upgrades, when occupants inhabit rooms they previously could not afford to heat. The nature of qualitative research precludes robust recommendations for policy. However, one important avenue to explore further appears to be that householders may be more strongly motivated by interventions offering improvements across a range of aspects rather than on energy savings alone.

1. Introduction

The UK's energy policies aimed at reducing carbon dioxide emissions are driven by global and European commitments. Those targeting energy consumption in the domestic sector currently include financial incentives such as the Green Deal[1] (DECC 2010a), through which consumers can secure loans to carry out energy upgrades to their homes, and Feed In Tariffs[2] (DECC 2010b) to promote investment in renewable energy sources, primarily solar photovoltaics. The details of such policy instruments are derived from models of the current state of the country's housing stock and a set of underlying assumptions about how people use their homes, which is often reduced to a representative whole house average temperature (Shorrock et al., 2005). The premise is that if improvements are made to the building fabric and heating systems, predictable energy savings will follow. However, this has proved to be misleading because of “performance gaps” between predicted and actual energy savings (Sunnikka-Blank and Galvin, 2012). Although it is possible to identify various points where performance gaps can be found in the procurement of new and retrofit of existing buildings, the most significant of these appears to be in the differences between assumed and actual occupant behaviour and the impact this has on energy consumption (Milne

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[1] https://www.gov.uk/green-deal-energy-saving-measures/overview

[2] http://www.fitariffs.co.uk/FITs/

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and Boardman, 2000; Marsh et al., 2010). This is evident in retrofit when the predicted savings are often far in excess of what is achieved after the interventions. Much of this is attributed to the behaviour of occupants who, it is argued, operate the upgraded home in ways that negate the energy efficiencies provided by improved insulation levels or better heating systems by choosing higher temperatures rather than reduced energy consumption, for example (Gill et al., 2010; Hamilton et al., 2011). There are many reasons for the discrepancies between predicted, assumed and measured thermal conditions, but perhaps the most discussed is the rebound effect (Sorrell et al., 2009). Rebound normally refers to phenomena such as ‘temperature take-back’ when occupants negate some or all of the energy savings by heating their homes to a higher temperature, thus promoting greater heat losses through a higher temperature difference between outside and inside. However, another form of rebound might be labelled ‘spatial rebound’ in which occupants, because of the cost savings gained through greater energy efficiency, are able to heat more rooms, which again can lead to increase in heat loss from the dwelling (Winther and Wilhite, 2014).

The paper is based on research into how older people respond to the thermal environment in private residences and care homes. The work was carried out as part of a collaborative project across four universities (Manchester, Cardiff, Lancaster and Exeter), with fieldwork in different types of dwellings for older people, from those living in their own homes to those in sheltered accommodation and to those in care settings. The project was concerned with occupants' responses to the introduction of low carbon heating technologies. The research was conducted using qualitative methods with small numbers of participants rather than a larger quantitative study because the team sought to understand the range of responses rather than their frequency. This paper discusses results in relation to one of the themes that emerged from the research across three of the sites: the way in which thermal conditions in the home vary according to space and time and how occupants respond to these variations.

1.1. Occupant behaviour and energy consumption in the home

Despite a number of monitoring studies that show variations in thermal conditions within dwellings both time and space (Hong et al., 2009; Kavgic et al. 2012; Tweed et al., 2014; Chiu et al., 2014), most of the discussions around potential reductions in carbon dioxide emissions assume a whole house average temperature (Shipworth, 2011). This approach may be useful for generalised prediction, but is not so good for understanding the detailed variations that occur and, most importantly, why they occur. Most studies addressing energy efficiency tend to focus on quantitative aspects of thermal comfort[3], such as measurements of air and mean radiant temperatures, relative humidity, air velocity and CO_2 levels (Summerfield et al., 2007; Gupta and Chandiwala, 2010). These indicators are used to calculate various indices and determine the indoor air quality. In non-domestic spaces, the Predicted Mean Vote (PMV) is used to indicate the likely satisfaction across a typical population with the thermal environment. The PMV works reasonably well for homogenous environments, such as offices, though Humphreys and Nicol (2002) note that in specific buildings it can differ significantly from actual mean vote. Its use is less reliable in domestic settings, where there is often a large variation in the thermal conditions from room to room (Hong et al., 2009; Oseland, 1994; Feriadi et al., 2003). Field studies have shown that building occupants can be thermally satisfied with conditions outside the boundaries predicted by current theory (Humphreys, 1976; Sharma and Ali, 1986; Busch, 1992; Baker and Standeven, 1995). Becker and Paciuk suggest this is particularly so in residential settings (Becker and Paciuk, 2009). Proposals for a new approach to thermal comfort based on empirical studies emerged in the 1990s (Nicol and Humphreys, 2002). The adaptive comfort[4] hypothesis argues that contextual factors and past thermal history influence building occupants' thermal expectations and preferences. One of the key postulates of the adaptive comfort theory is that satisfaction with a given thermal environment is not solely a matter of physics and physiology. It recognises three categories of adaptation: physiological adaptation, psychological adaptation and behavioural adaptation.[5] Behavioural adaptation comprises a range of actions occupants may undertake to create and maintain their own comfort. Typically this refers to changing the levels of clothing or activity, but it can include other forms of adaptive behaviour—opening and closing windows, switching on fans, adjusting thermostats, consuming hot drinks, etc. According to Nicol and Humphreys, the adaptive principle is “if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” (Nicol and Humphreys, 2002).

As actions are determined by available opportunities, the variety of adaptive opportunities present in the home is generally much greater than in other settings.[6] The key difference between the home and other environments is that householders are usually in charge of their own comfort. They have agency at home that they would not enjoy in ‘managed’ environments. Occupants are usually free to turn heating on and off, open windows and doors and, most importantly in the context of this paper, move around a dwelling and spend time in places that meet their preferences. It is rare to have these options in a more regulated environment such as the workplace. They may also be freed from feeling the need to conform to social norms about clothing and other aspects of their behaviour that may restrict the availability of these adaptive opportunities elsewhere. Our interpretation of ‘available’ in this case is akin to how social influences determine the perceived availability of affordances as highlighted by Dreyfus (1996).

More recent discussions about comfort introduce social practices as a way of understanding how notions of comfort are constructed and evolve within a broad social and cultural context. The work by Shove Shove (2003), Shove et al. (2008) and Chappells and Shove (2005) has brought a fresh perspective to a field that previously has been dominated by building science and offers a useful reminder that the perception of comfort is neither stable nor predictable.

Adaptive thermal comfort theories recognise there is a variety of thermal preferences and expectations, and that people exert actions to achieve comfort. In addition to these aspects, there are specific issues that emerge when considering the thermal experience[7] of the older population: (1) physiological changes

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[3] It should be noted that studies addressing quantitative aspects of thermal comfort are likely to build upon theories that focus on the physiological responses of people to thermal stimuli (Fanger, 1970; Markus et al., 1980)

[4] A useful summary of the current position on different approaches to thermal comfort and the models that are in use is provided by Yau and Chew (2014), and Nicol's introduction to a special issue (Nicol, 2011) describes recent developments in adaptive comfort theory.

[5] The research reported here is mainly interested in the behavioural opportunities for adaptation.

[6] Although the lack of research on psychological and cultural aspects of thermal comfort is significant, perhaps the greatest gaps arise from too much emphasis on non-domestic environments (Humphreys et al., 2005; Wagner et al., 2007; Brager and Baker, 2009). As a result, there is a dearth of information about comfort in the home. The primary purpose of this study is to investigate how people create and maintain thermal conditions at home.

[7] We use the term “thermal experience” rather than the more common place “thermal comfort” as a recognition that people sometimes express preferences for thermal conditions that lie outside comfort zones, even if temporarily.

related to age which are likely to result in special needs and potential vulnerability of older people to the variations in thermal conditions (Yochihara et al. 1993; Guergova and Dufour, 2011); and, (2) the thermal preferences and expectations of older people and their practices to achieve thermal comfort (Day and Hitchings, 2011) People's physiology changes as they age. Older people tend to be more vulnerable to extremes of heat and cold (Collins, 1988; Age Concern, 2001; Daanen and Herweijer, 2014). Hypothermia and heat death are directly attributable to the thermal environments (Collins, 1986; Rudge and Gilchrist, 2005; Burholt and Windle, 2006). Cognitive abilities also decline in older age, possibly making it more difficult to operate complex systems and understand new technologies (Devine-Wright et al., 2014). On the other hand, older people, simply by having lived for longer, will have a richer and more varied history of thermal experiences that embraces a wider range of heating strategies and technologies. They may have a cultural perspective and history of thermal experiences that feature obsolete adaptive opportunities and devices, some of which may have provided a better quality of thermal comfort.

The literature on older people and their experience of thermal environments is inconclusive. Whilst a comprehensive review by van Hoof and Hensen (2006) suggests that older people tend to perceive thermal comfort differently to the young due to a combination of physical ageing and behavioural differences. They suggest that further research is needed particularly in the field studies, where older adults might be given greater personal control over their thermal environment. The results from a study by Schellen et al. (2010) indicate that thermal sensation of the elderly was, in general, 0.5 scale units lower than for their younger counterparts. However, thermal sensation of the elderly was related to air temperature only, while that of the younger adults was related to skin temperature also. During a constant temperature session, the elderly preferred a higher temperature in comparison with the young adults. As with much of the previous work in the field of thermal comfort, this study was conducted in a laboratory setting where thermal conditions could be controlled more precisely than in a real building. Similarly, most previous studies are firmly routed in the heat balance tradition of assessing thermal and focus on the physiological differences between young and old, continuing the approach pioneered by Fanger and others. There are measurable physiological changes differences among older people in many cases, such as reduced muscle strength, work capacity, sweating capacity, ability to transport heat from body core to skin, hydration levels, vascular reactivity, and cardiovascular stability (van Hoof and Hensen, 2006). However, this does not necessarily lead to a need for higher air temperature in cold conditions because older people may wear more clothing. As a special case, which is not pursued here, van Hoof et al. suggest that people with dementia are more sensitized to the thermal environment and therefore may have more exacting needs with narrower bands of satisfaction (van Hoof et al., 2010). This is recognized as a special case and none of the participants in the study reported here suffered from dementia.

The heat balance approach suffers from an over-reliance on the PMV and PPD models. In some cases, results from field studies support their use; in others they do not. It is not possible, therefore, to claim consistent differences between older and younger people in their experience of thermal environments because of a lack of research in this area. Whilst there are clear physiological changes that come with ageing, they are not distributed evenly across a healthy population, their impact on how people perceive and create thermal conditions cannot be predicted straightforwardly since there are other influences on how older people may engage with the thermal environment, such as their present attitudes to money, their longer history of thermal experience, and their familiarity with older heating technologies and cultural norms in appropriate levels of clothing.

Any useful discussion of thermal comfort, therefore, must consider multiple perspectives: the physiological, the socio-cultural and the individual. It seems clear that none of these provides the definitive understanding and yet each offers a different take on the problem of understanding the complex relations between people and the thermal environment in buildings. However, the preferences for and satisfaction with the thermal environment in any given situation as expressed by an individual is not wholly a product of the prevailing measurable thermal conditions, nor is it socially constructed or totally idiosyncratic. The relationships are complex and dynamic. A potential shortcoming of policy initiatives for energy efficiency is that they are oblivious to the myriad of thermal experiences and preferences in the residential sector. Assuming uniformity of the thermal environment in the house and ignoring the special requirements of different segments of the population, such as the elderly, might result in a failure to achieve the expected policy targets. People may not engage with the energy efficiency initiatives as expected by policy-makers (Hamza and Gilroy, 2011; Dowson et al., 2012). As Gram-Hanssen argues, making effective policies requires a more nuanced understanding of what people do in their homes and the practices they engage in (Gram-Hanssen, 2010). In a similar vein, Williamson et al. (2010) find that “regulatory concept of ‘meeting generic needs’ fails to account for the diversity of socio-cultural understandings, the inhabitants’ expectations and their behaviours.” Therefore, this study investigates aspects related to the thermal experience in the home from an alternative perspective, exploring how older people use their homes to achieve the kind of indoor environment they desire. The aim of this paper is to develop a deeper understanding of older people's relationship to warmth and space so as to bring light to energy policies such as the Green Deal, and the smart meter rollout.

2. Methods

The research reported here draws on fieldwork conducted as part of a project funded jointly by Engineering and Physical Sciences Research Council (EPSRC) and the French utility company Électricité de France (EDF), under the People, Energy and Buildings programme. The particular focus of this project, *Conditioning Demand: Older People, Diversity and Thermal Experience*, was on how older people respond to the introduction of low carbon heating technologies in their homes. Fieldwork was carried in four locations across the UK by four different teams collaborating on the project. Despite differences in emphasis across the teams, the methods used were broadly similar and consisted of interviews conducted in people's homes or, in the case of the Lancaster team, in care home settings, which were subsequently analysed to identify themes within the data grouped according to codes established by the entire project team.

Responding to the aim of “investigating how older people create and maintain desirable thermal conditions in their homes” the approaches discussed later in this section were adopted to recognise the diverse range of domestic environments, building performances, heating technologies, locations, seasons, ages and people. The range of low carbon heating systems included air source heat pumps, ground source heat pumps, and biomass boilers. The sample included some properties with solar thermal installations used to heat the domestic hot water supply. Some properties with conventional existing heating systems were included and these comprised electric storage heating, oil fired central heating, gas fired central heating and gas fired district heating. The studies were aimed to complement each other while

Table 1
Summary of main characteristics of studied buildings and occupants.

Building ref.	Location	Building type	Occupancy	Heating system
D1	South Wales	Semi detached cavity wall house	Retired couple	Air source heat pump and electric radiant heaters
D2	South Wales	Detached cavity wall house	Retired couple	Gas central heating and air source heat pump
D3	South Wales	Semi-detached stone house	Retired lady	Air source heat pump with electric convectors
D4	South Wales	Semi-detached cavity wall house	Retired couple	Oil fired central heating with electric radiant heaters
D5	South Wales	Detached stone wall with cavity wall extensions	Working couple	Ground source heat pump and an open fire
D6	South Wales	Detached masonry cavity wall house	Retired couple	Gas fired central heating with electric convector
D7	South Wales	Detached solid stone wall with extensions. Former school house.	Working couple	Biomass boiler, stove and open fire
D8	South Wales	Semi detached stone house	Working couple	Oil fired central heating, stove and open fire
D9	South Wales	Detached masonry cavity wall house	Retired couple	Gas fired central heating and stove
D10	South Wales	Two stone cottages joined together	Retired couple	Biomass boiler, stove and open fire
D11	South Wales	Semi detached stone cottage	Working couple	Range and heat store, log burner and solar collectors
D12	South West England	Detached farmhouse (listed – late 17th Century) plus barns (13 acres land)	Husband and wife - Pilot/homemaker	Ground source heat pump: borehole (underfloor heating downstairs; radiators upstairs – upstairs still being finished)
D13	South West England	Detached new cavity wall house	Husband, wife, and son - Farmer/Deputy head of school	Ground source heat pump (underfloor heating downstairs, radiators upstairs)
D14	South West England	Bungalow with cavity wall	Husband and wife - Gas company executive/ Administrator	Oil fired central heating, woodburner in lounge
D15	South West England	Detached house	Husband and wife - Air Force/homemaker	Oil fired central heating
D16	South West England	Detached house, with outbuildings	Husband, wife and wife's mother - Mechanical engineer/ School administrator	Biomass boiler
D17	South West England	Bungalow with cavity wall	Husband and wife - Pilot/'Jack of all trades, master of none'	Biomass boiler
D18	South West England	Detached stone cottage	Sole occupant - Paediatrician	Rayburn (oil fired), electric storage heaters
D19	South West England	Detached stone farmhouse (Grade 2B Listed) plus outbuildings	Husband and wife; one daughter lives in barn next door - Hardware retailer/Art teacher, now Potter	Oil fired central heating
D20	South West England	Semi-detached cottage	Sole occupant - Community Psychiatric Nurse	Rayburn (solid fuel), open fire
D21	South West England	Bungalow with cavity wall	Sole occupant - Unknown	Elecgtric storage heaters
D22	South West England	Semi-detached cottage	Husband and wife - Regional Arts Board/ Housing Assoc	Oil fired central heating
D23	South West England	Semi-detached cottage	Mother and daughter - Geriatric nurse then Horse charity organiser	Electric oil filled radiators; open fire in sitting room
D24	South West England	Detached cottage	Husband and wife - Unknown	Oil fired central heating
D25	South West England	Detached barn conversion	Sole occupant - Pharmacist	Oil fired central heating; woodburner
D26	South West England	Mid-terrace cottage	Husband and wife - Teacher then writer/ Community counsellor	Rayburn (solid fuel) with radiators
D27	South West England	Detached cottage	Sole occupant - Head Teacher	Multi-fuel burner and two woodburners
D28	South West England	Bungalow with cavity wall	Husband and wife - Accountant/homemaker	Air source heat pump

adding value to the overall outcomes of this research and focused on:

- Private 'rural' dwellings (D) in South Wales with retrofitted low carbon heating technologies. Eleven households were selected and four 'seasonal' studies were conducted with 23 participants. The low carbon heating technologies included air source heat pumps, ground source heat pumps, and biomass boilers. The sample included five 'neighbouring' households that had no low carbon interventions, such as oil-fired and gas-fired central heating. The studies included interviews and building surveys. In addition, the respective four 'installers' of the low carbon technologies were interviewed and a workshop conducted. The sample age of the occupants ranged from 55 to 78 years.
- Nine private 'rural' households in South West England with retrofitted low carbon technologies were selected and three 'seasonal' studies were conducted (winter, summer, and either autumn or spring depending on when the households were recruited). The low carbon heating technologies included air and ground source heat pumps and biomass boilers. The sample included a further eight 'neighbouring' households which had no low carbon interventions. A total of 30 participants were involved. The sample age of the occupants ranged from 60 to 89 years.
- Five extra-care housing schemes in 'urban' Manchester, York, London and Dundee were selected and summer and winter interviews conducted with 23 participants. The low carbon heating technologies included air and ground source heat pumps, biomass boilers and gas fired district heating with a range of heat delivery methods: three underfloor, one storage heater, and one conventional radiator system. The sample included nine residents in schemes that had no low carbon interventions. In addition, the designers of the schemes were interviewed. The sample age of the occupants ranged from 60 to 87 years.
- Six residential care homes (CH) in England and Scotland with low carbon heating technologies were selected and used as a context for 34 semi-structured interviews. The participants included; five elderly residents, eight staff, nine managers, three owners. The low carbon heating technologies included air and ground source heat pumps, and biomass boilers. Some of the care homes used conventional systems – oil-fired and gas-fired central heating and electric storage heating – either entirely or alongside the low carbon systems.

Across the two-year study, all interviews were conducted and recorded *in situ*. The study was conducted according to the guidelines issued by each university and with full Ethics Approval, requiring written consent, confidential interviews and all data to be anonymised.

The interview themes were designed and agreed by the partners prior to the study and, when possible, provided opportunity for comparability and further analysis. Details of the interview schedule are provided in Appendix 1. The interviews recorded details of the participants, life history, expectations and experiences in relation to thermal experience. Details of the building including history, layout and heating interventions were recorded to provide context to the interviews. In some cases energy efficiency surveys were conducted using the UK Government's approved Standard Assessment Procedure (SAP). Details of the heating system, including design rationale, implications, costs, maintenance, schedules and seasonal practices were gathered in line with the aims of the research.

The seasonal interview structure permitted the discussion on how circumstances and opinions changed throughout the seasons.

CH1	Northern England	Care home in a new build with very high levels of insulation and double glazing	60–70 beds	Gas fired central heating
CH2	Eastern England	Care home in a recently extended building in an off gas location with double glazing throughout	30–40 beds	New section: gas fired central heating. Older section heated by electric panel heaters and storage heaters.
CH3	Southern England	Care home in an older house (100–120 years old) with a recent (5–10 years) extension. New section has modern insulating materials, the older section does not. Double glazing throughout.	50–60 beds	Gas fired central heating in the old section and underfloor heating in the new section.
CH4	Scotland	Care home in a building roughly 200+ years old with high ceilings, large rooms and very thick walls, but single glazed.	20–30 beds	Two boilers, biomass boiler and oil fired central heating (for backup) connected to radiators.
CH5	Northern England	Care home in a building roughly 15–20 years old, which is highly insulated and double glazed.	150+ beds	Gas fired central heating with large surface radiators. This is controlled by a Building Management System that monitors and controls temperatures. This is controlled remotely from a company head office.
CH6	Scotland	Care home in a newly built home in a remote location.	10–20 beds	Oil fired central heating connected to underfloor heating. These are operated via a Building Management System controlled from a remote head office.

It also allowed a rapport to be built up between researchers and participants, which helped with the elicitation of details and aided clarification.

Details of the dwellings (D) and care homes (CH) that reported connections between warmth, experience and space are summarized in Table 1.

None of the extra-care interviews reported any connection between warmth, experience and use of space, which is why there is no reference to those properties in the Table above.

As with many qualitative research projects conducted using small samples, the findings are not intended to be representative of the wider population but can highlight possible issues about thermal experience in the older population across a diverse range of environments, systems and people.

The results from the survey work are captured in transcripts from the interviews with occupants and residents. The interviews were professionally transcribed before being coded by the project partners using *Atlas.ti* qualitative analysis (QA) software. A coding schedule was developed recognising the common themes and subsequent specific ‘sub headings’. This two-tiered approach allowed the QA software to sort and manage the array of information and facilitate data sharing across the project partners for analytical purposes. The coded quotations form the basis of the discussion below.

3. Discussion

The field data suggest that older people register the conditions of the thermal environment and make changes to the environment to achieve the desired thermal conditions. The changes are based on folk wisdom and experience embodying some degree of awareness of how the thermal environment is influenced by microclimate and landscape. One of the key aspects found in the data is that existing thermal conditions within the dwellings are likely to influence the use of the space at home, as a form of behavioural adaptation to pursue desired thermal experience. People also take actions to reconfigure the space within the house and the operation of the house so as to meet their thermal preferences. Desired thermal experiences alone, however, may not be the main driver for changes made in the house. Another aspect inferred from the data is that low carbon heating systems may lead to the reconfiguration of expectations and result in spacial rebound. In summary, four main findings emerged from the analysis of the research data:

- thermal conditions influence the use of the space at home;
- people make changes to their homes to condition the thermal environment;
- people make changes to how they operate their homes; and
- low carbon heating systems may reshape the thermal expectations of occupants due to the differences in the way heat is delivered as compared to conventional heating systems
- These are discussed in greater detail below.

3.1. *The influence of thermal conditions on people’s use of space*

The results of the fieldwork confirm that the thermal characteristics of the environment can play a significant role in how people use space in the home. This undermines the prevalent treatment of occupants in energy policies as passive consumers of the thermal conditions delivered by any given combination of building fabric, heating system and controls. Instead, the data reveal active inhabitants who move, modify and operate their homes to achieve the thermal conditions they want. Underpinning such activity is an awareness of the thermal environment and how it is created by features in the landscape around and in the building.

3.1.1. *Occupants’ understanding of the thermal environment*

The participants proved to be adept at identifying where to find different thermal conditions in their homes and its surroundings, displaying an intuitive knowledge of cause and effect in the thermal environment. For example:

“We are down in a dip and we seem to get prevailing wind from the back of the house um … and when we've got frost here you can go a hundred yards up the road and they haven’t got it. This little spot will freeze first …” (D23, South West England).

Others (D8, for example) show similar levels of awareness and interest in the how the thermal environment changes according to location and time, for example, which houses get sun light at different times of the year. This embedded awareness of the changing environment and how it relates to built form (and vice versa) is often cited as a virtue of vernacular architecture, and these results confirm the existence of a folk wisdom about the thermal environment and how it is shaped by microclimate and surrounding landscape. That level of knowledge includes a degree of understanding of the influence of the internal architectural features on the thermal behaviour of the dwelling. Occupants can exhibit a fairly sophisticated knowledge of the behaviour of the building which informs what occupants do to operate it and achieve the thermal environment that they desire, such as postulating about the consequences of moving the location and construction material of a chimney with the goal of improving the thermal environment. This type of reasoning about and engagement with heating technology is not considered in top-down approaches to saving energy or providing a satisfactory thermal environment.

3.1.2. *Occupants’ preferred thermal environments and spaces*

The above highlights people's sensitivity to the thermal environment in their homes. This, coupled with an intuitive knowledge of how buildings behave thermally, appears to influence how people use the spaces in their homes and the amount of time they spend in one room rather than another. Many participants cite the kitchen as the heart of their homes, and warmth is recognised as one of the reasons why people congregate there. However, the choice of a preferred main space can be seasonal, since the same participant stated:

“… But that's in the winter time, in the summer time we do use that far room and, because we use the patio in that far room then.” (D7, South Wales).

As noted elsewhere, a focal point heat source was cited as one attractor:

“… I can see that we will run the wood burning stove really ‘cause they're nice to sit round it's nice to sit round a fire … you've got the smell of … a wood burning stove and so it is lovely.”

This underlines the view that people's use of space is rarely attributable to a single characteristic—such as warmth—but may, as in this case, embrace other qualities and senses—in this case, both visual and olfactory. Existing approaches to energy interventions are blind to this, focusing exclusively on measures aimed at reducing energy consumption without regard to how people use their homes and what they value in the home environment. This may in part be one reason why so many people reject the offer of energy upgrades even when they are free (Patterson, 2008).

Similar levels of awareness of variations in the thermal environment are found in care homes, where the larger building offers greater scope and opportunity to vary the use of space to meet their thermal preference, as the following statement from a care worker suggests:

“… if you're sitting nearer the window it's cooler, if you're sitting nearer the doors … it's cooler there … If they don't like that lounge, if it's too warm or too cold for them, they could always come down to this small sitting room, where you can put the fan heater on in here, if it wasn't warm enough, or they could sit in the one down there … Or if they wanted it cooler they could come down here and open the window there and sit here." (CH6, Scotland).

The interview data reveal a consistent use of space to mitigate extremes of hot and cold conditions in both private and care homes. When conditions are not considered extreme, the preferences for spaces are not always determined by thermal conditions, as a range of factors seem to be in play in the choices people make about where they spend time. However, the thermal environment is often cited as an important factor in the interviews. In the following section, the paper examines how people modify aspects of the spaces they inhabit to alter the thermal conditions and thereby the thermal experiences that are available in different parts of the dwelling.

3.2. Changes people make to their homes to condition the thermal environment

Another theme that emerged from the interviews concerning use of space was that as well as moving around the dwelling to take advantage of the properties of existing spaces, occupants made changes to the building and its technologies to improve their thermal experiences. These changes range in scope from the addition of blinds and curtains, and purchase of supplementary heating devices, through to the addition or removal of walls, windows and doors, or the complete replacement or extension of existing heating systems, often relying on a new fuel or technology. The more substantial modifications are rarely carried out for thermal reasons alone:

"[W]e've split the living room into two because it was so big um so that … you can warm each bit as you want it so we've got two rooms not one now. … the fire's original but we changed the surround … While it's not in use I put in a piece of ply up there to stop … stop the roaring wind going up there. That closes up there … and a radiator behind there. We've changed … the patio doors … to plastic." (D17, South West England)

This type of major intervention is less common than routine alterations to fixtures and fittings such as adding curtains, blinds and draught proofing. For these, the intention is usually more focused on achieving a singular goal, which may be more obviously related to the thermal environment:

"I've got another curtain and I'd put it across there and shut this bit off and then I would be quite cosy." (D25, South West England)

The above fabric related changes are driven by concerns about thermal experiences, as well as energy consumption and cost. However, when people make changes that are driven solely or primarily by desired thermal experience and can result in greater energy consumption such as by supplementing existing heating systems with fan heaters to serve as a top-up to the main heating system:

"a fan heater is used because it's simpler just to put on a fan heater if you go in there and it's cold …" (D17, South West England)

The attraction of the fan heater in this case is its simplicity of operation and the immediacy of its effects. However, wood burners proved to be another popular supplement to the main heating system, often installed for the specific characteristics they bring: high temperature heat source and a visual glow. Neither fan heaters nor wood burners are fuel efficient or low carbon, but their appeal emerges strongly in the interviews, both in private homes and care homes. The ability of the main system to deliver heat rapidly is cited in the interviews and if inadequate, it may require other forms of adaptation, as in the case of a new biomass boiler:

"… it is an issue with that sort of a boiler. … [I]t's not like a normal gas central heating system where you can just put it on, this takes at least an hour before it starts to get warm, so it can be really cold in between time, so you just wear a fleece and wear a cup of tea, and do that sort of thing!" (D7, South Wales).

When occupants introduce supplementary heat sources and appliances, it defeats the purpose of energy upgrades. However, the underlying issue is that the new combination of upgraded fabric and heating system is unable to deliver the thermal experiences the occupants desire and so they take what seems to them to be appropriate action to achieve those. This underlines the need to consider how a proposed upgrade will alter the potential for achieving desired thermal experiences, not just crude measures of thermal comfort.

3.3. Changes people make to how they operate their homes

A further response to thermal conditions is in the way people modify the operation of their heating systems, either by adjusting settings on controls or manually by switching them on or off. A frequent misconception about occupants' operation of their houses is that thermostat settings remain constant for long periods of time. Observations in this study suggest this may not be the case. As an example, one couple said the following about about their thermostatic radiator valves:

Husband: "Oh they … they get fiddled with during the day."

Wife: "[W]e change things as we need to change them. If you want warmth but you're sitting there [at the dining table near the radiators] you can get too warm because its right at the very back of you so if you just want to keep a level of warmth then I'll reduce that one …" (D17, South West England).

The reasons for making changes may be longer term than simply fine tuning an installation, as in this case where the occupant has been recovering from an operation and had to spend more time in the bedroom:

"[W]hen you don't feel great, warmth is really important. It's like when you've got a bad cold you feel shivery don't you, you just need somewhere nice and warm to go (south facing living room)." (D7, South Wales)

As noted previously, householders are capable of developing sophisticated intuitive knowledge about how their homes behave thermally and to use that knowledge to achieve the thermal conditions they want in a range of circumstances. In one case, a householder demonstrated remarkable understanding of the behaviour of the dwelling and its heating system, timing the adjustment of thermostatic radiator valves to deliver heat to the living room when the couple had finished their evening meal. Few householders showed this level of engagement and understanding, but it raises interesting questions to pursue about the degree of automation householders may accept when it is clear they have developed a finely tuned sensitivity to the way their homes work. Since the introduction of mechanical and electrical space conditioning systems, the home has become more like a piece of equipment than a building with only windows, doors, blinds and curtains as operable elements.

3.4. Experiencing low carbon heating systems

The introduction of low carbon heating systems into people's homes will alter their experience of the thermal environment, and thereby how they use space in the home. For example, a fundamental difference between conventional and many low carbon heating systems is the way heat is delivered to spaces. They are likely to create a new set of thermal experiences for occupants. As Tweed and Dixon (2012) have noted, systems that do not use a combustible fuel are ‘low exergy’ and are unable to deliver heat at high temperatures. Radiators fed by heat pumps, for example, run at much lower temperatures, with surface temperatures that are below skin temperature (~37 °C). Thus they feel cool to the touch and create a different thermal experience to conventional fossil fuel heating systems. One might expect this to prompt complaints from occupants. In fact, the contrary view has emerged in some of the cases, for example, in a dwelling with a new air source heat pump installation:

“I've got a gas fire but it's been out of action for a year, I can't get anybody to repair it. I haven't needed it.” (D3, South Wales).

A favourable reception for heat pumps is evident in reports from others, for different reasons. A technical requirement for many heat pump systems is that they need to run continuously to be at their most efficient and to avoid having varying loads, which they may not be able to meet. As a result, the profile of heat delivery is very different to the on/off pattern for more conventional systems in that spaces remain at near constant temperature, leading to a more even distribution of heat throughout the dwelling, which is welcomed by some householders. The uniform distribution of warmth within rooms was also recognised as a benefit, eliminating “cold corners” and draughts.

However, with new technologies come new modes of operation and changes to heat delivery. For example, a move from a gas-fired central heating system to a biomass boiler introduces a lag between the system on time and the arrival of heat in a room: “… it's not like a normal gas central heating system … this [biomass boiler] takes at least an hour before it starts to get warm, so it can be really cold in between time, so you just wear a fleece and have a cup of tea, and do that sort of thing!” In this example, the householder substitutes two types of adaptive behaviour to compensate for the changed thermal experience ushered in by the change of fuel type. This type of detail is normally lost when decisions are made about the choice of fuel and yet it is clear that at least for some people this is likely to result in either discomfort or adaptation.

The results presented here suggest some possible responses to the introduction of low carbon heating technologies. They are inconclusive since the project did not monitor energy consumption in the dwellings. It is not possible, therefore, to say whether the interventions resulted in significantly higher energy consumption and higher running costs.

4. Conclusions

This research draws on a small sample of dwelling and care home occupants to investigate relations between warmth, desired thermal experiences and space among older people in these settings. The research focused on what types of attitudes and behaviour exist and why rather than how prevalent these may be in wider population. The conclusions, therefore, are intended to inform the development of a future quantitative study rather than stand on their own.

Results from the fieldwork suggest that people are sensitive to variations in the thermal environment, and make use of these variations across space to satisfy their thermal preferences in pursuit of specific thermal experiences. Participants report moving between spaces to take advantage of the thermal conditions in different parts of the building and outside. They do so informed by a sophisticated intuitive knowledge of how buildings behave thermally. It seems appropriate, therefore, to describe heated buildings as landscapes of warmth across which occupants are free to roam to find the thermal experiences they need and want. Precise descriptions of these needs and wants, however, are elusive and may include cosiness, associated smells as well as conventional descriptions of thermal comfort.

Occupants exhibited an understanding of how thermal conditions are generated by properties of the dwelling form, fabric and layout. It would appear that much of this understanding is the product of accumulated experience. Many conversations with participants include a historical reference to thermal experiences prior to an intervention, such as draught-proofing, the addition of curtains or the replacement of a heating system. This level of understanding is more likely to be found among older people, simply because they have lived longer and so have been exposed to a wider range of heat delivery mechanisms, appliances and socially sanctioned adaptive opportunities (hot water bottles).

Participants were able to apply their understanding of the thermal behaviour of dwellings to make changes to the spaces so as to improve their thermal conditions and meet the occupants' thermal preferences. The changes vary in scale temporally and physically and can be grouped according to timescale as follows:

- daily – taking up different sitting positions within a space, use of internal doors to regulate air movement, operation of curtains and blinds, adjustment of heating system controls, manual operation of heating appliances, movement between spaces;
- seasonal – fitting of curtains, choice of main living space, purchase of heating appliances, draught-proofing; and
- one-off – insulation of building fabric, double-glazing, modification of the main heating system.

A further observation is that the greater the scale and the effort or cost of an intervention, the more likely it has been driven by compound goals that are rarely to improve thermal experience alone, even if thermal preferences have been the main driver.

For these participants, it seems that thermal experience often trumps energy efficiency. Hence, householders reported using high energy (and high cost) heating devices, such as fan heaters, to maintain a preferred thermal state or alleviate a state of discomfort. However, this assertion is not conclusive since several householder mentioned efforts to reduce energy consumption.

The introduction of low carbon technologies changes the landscape of warmth and thermal experience in the home significantly. Spatial rebound is evident in homes in which heat pumps have been installed, mainly because of their efficiency requirement to run continuously. The uniformity of thermal conditions across the building changes the way in which people use spaces, by allowing spaces that were previously considered too cold to become habitable. Whether this results in any energy saving is outside the scope of this paper.

The expected dissatisfaction caused by the loss of high temperature heat sources was not so evident, though some occupants expressed their fondness for electric radiant heaters, wood burners and open fires. The importance of a visual manifestation of warmth was reported, suggesting that as long as spaces are thermally comfortable it may be feasible to substitute a visual representation of glow for a radiant heat source.

4.1. Implications for policy

It would be unwise to base future policy on findings from this small, qualitative study. A more detailed quantitative study is needed to ascertain how widespread the attitudes and behaviours reported here are in the wider population. However, this work suggests there are four ways desired thermal experience, use of dwelling space and energy efficiency intersect: (1) occupants appear to have intuitive knowledge about the thermal behaviour of buildings and surroundings and take appropriate actions to achieve the thermal experience they want; (2) the thermal conditions tend to affect the use of the space at home; (3) occupants exert their agency to *modify* the configuration of space and the operation of the home, in some, but not all, cases to meet their thermal preferences; (4) the introduction of low energy heating systems may bring about changes in the occupants' expectations and patterns of consumption at home that may not be driven primarily by energy efficiency concerns. These aspects draw attention to the fact that householders are engaged to different extents in the 'making of their homes' and therefore are not passive receptors of measures that affect their houses, for example, energy efficiency interventions set at policy-level. This may question the assumption that householders will be compelled to implement energy efficiency measures on the basis of their cost-saving benefits alone. It suggests householders may be more strongly motivated by interventions that offer improvements across a range of aspects, such as improved thermal experience, health, and quality of indoor environment, etc. Thus, improvements to the thermal environment may be a Trojan horse for delivering carbon dioxide reductions rather than the current approach which begins with the reductions and ends with modified thermal experiences. If energy upgrades can be presented as improvements to thermal experience they are more likely to be adopted. This, again, would need to be explored in greater detail in an extensive follow-up study.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.enpol.2015.03.011.

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