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From health to harmony: Uncovering the range of heating needs in British households

B. Mallaband[a], M. Lipson[b,*]

[a] Mechanical Engineering & Design, Aston University, Birmingham, UK
[b] Consumer Insight, Energy Systems Catapult, Birmingham, UK

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ABSTRACT

Effective low carbon heating products, services and policies are critical if the UK is to meet its climate change commitments. However, these are normally developed for the hypothetical or 'modelled' household. The activities, behaviours and needs of 'real' households cannot be anticipated based on their income or makeup, nor do they remain static for any length of time. Drawing from a mixed methods approach, this paper discusses the range of needs which affect how households use the heating in their homes. These needs are grouped into 4 categories (wellbeing, resources, ease of use and relational dynamics), and 8 subcategories (health, comfort, cost, waste, control, convenience, harmony and hospitality). The paper discusses the individual and changing nature of these needs through a 'continuum of priority' and the factors affecting decision making. This categorisation aims to educate technologists and policy developers of the scale of flexibility required for impactful change. Low carbon policies, products and services will be more successful if they enable consumers to meet all of these needs. The challenge is to develop tools that enable designers and developers to recognise what needs each household has and how their needs change over time.

1. Introduction

Approximately 20% of carbon emissions come from the way people use heat and hot water in the home [1], and less than 5% of energy used for heating homes comes from low-carbon sources [2]. Despite efforts to increase uptake of low carbon heat, progress has been slower than expected and reduction has stalled [3]. Historically, research in the energy domain, as well as related technology and systems, have presumed a household model which is constant and inactive, or 'static' [4]. The commonly used Energy Performance Certificate (EPC) [5] or RDSAP [6] also use these standardised assumptions, where either all rooms are heated consistently [7] or where all homes are heated and used in the same way. Whilst assumptions used by this type of modelled data can be useful in some instances, they can differ greatly to the actual use recorded from monitored data [4]. Examples of variations include: the difference between living room and other room mean temperatures, which is often less than predicted by models; the difference between weekday and weekend mean temperatures, which whilst assumed by RDSAP, does not exist in monitored data; and the length of monitored heating seasons, which are actually shorter than the 8 month period predicted by SAP [8]. Modelling has also revealed that less than 40% of observed variation in gas consumption can be explained by physical factors of the property (size, type and age), household income and tenure [9,10]. Much of the remainder must be related to the way occupants are using their home. Stazi et al. [11] attempted to categorise the different factors that influence occupants' behaviour in buildings as: environmental, time-related, contextual, physiological, psychological, social, and random. Wei et al. [12] identified 27 different factors from existing studies which influence space-heating behaviours. These ranged from dwelling type to thermal sensation, however, only a few of these factors were found to be represented in building performance simulation.

Some research has attempted to address these variations, by including more occupant behaviour in simulations (e.g. [13,14]). Of course occupant behaviour, such as opening windows, affects the thermal performance of buildings [13,15], but to understand home energy use, such as how occupants heat specific rooms, it is important to remember that people use energy as part of, and as a by-product of, accomplishing social practices [16]. Based on these types of findings, other research (e.g. [17]) has called for an understanding of the relationship between house type, household composition, demand temperature and heating pattern in order to make more realistic predictions and models of energy use. Part of understanding this relationship is understanding why occupants use their homes and heating in the ways

* Corresponding author.
E-mail address: Matthew.Lipson@es.catapult.org.uk (M. Lipson).

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they do.

It is clear that heating use across different home structures is varied, however, there is also significant variation between homes which have similar structures and heating systems (as demonstrated in the UK [18] and Denmark [19]), as well as variation within individual properties [7]. Other studies have highlighted the importance of other factors in energy usage, e.g.: psychological motivators [20]; comfort versus spending [21]; comfort and economy [22]; or occupant age, gender, culture, education level, social grade, household size, family income, house ownership, and health [12]; as well as the impact of historical, formative experiences of heating [23]. Rubens & Knowles [21] highlighted the complexity of understanding user needs in this area by identifying 5 different user types using 5 scales of: spending vs comfort, single space vs differential space, regular vs irregular routines, unpredictable vs predictable routine, and self vs others. However, this paper suggests there is still a much wider range of factors, especially when understanding the needs that the occupant is trying to fulfil through their use of the heating.

With the combined importance of physical and social factors on heating use, it is therefore necessary to view the home as a socio-technical system [24–27], where the specific sociotechnical makeup of every individual home determines how heat is used [28]. This requires a 'redefinition of the relationship between people and technology', which recognises the constantly changing nature [27]. In order to do this, it is necessary to understand the habits, needs, patterns and lifestyles of the occupants, as highlighted by Social Practice theory [29].

Alongside the 'sociotechnical' nature of the home, each household has an individual 'socio-structural' makeup [30], a combination of social and material factors which reflect their personal concept of 'home'. Thinking of the home as this 'socio-structural' entity ensures that occupants are not simply viewed as passive 'users of a material structure' (i.e. the building and associated technologies), but where their everyday practices require variation in levels of heating and flexibility [7]. Each individual's concept of 'home' has an emphasis on either a place of security and control, activity, relations and continuity, or identity and values [31].

Despite this acknowledgement of the importance of the socio-technical nature of this issue, there is still some uncertainty of what household occupants actually need from a heating system and the impact that the individual behaviour and practices within households have. It is historically difficult to uncover these needs, which are often unconscious or related to habitual and mundane behaviours [32,28], and which vary depending on the consideration needed for others in the household, for example, those with babies in their homes [21]. There is also often a gap between the stated attitudes of people and their observed behaviours, referred to as the 'value-action gap', 'attitude-action gap' or 'intention-action gap' [33]. There are also inconsistencies in the motivations behind occupant behaviours, where for some 'cost' is the driving factor in heating decisions, whilst for others it is 'comfort'. Specific households prioritise certain needs above others, for example, where occupants are willing to waste heat (and money) to achieve adequate ventilation [34]. It is important to understand the ways in which occupants prioritise their needs, as the least important human needs can be 'minimized… forgotten or denied' until the greater goals have been satisfied [35].

Previous research has already highlighted the effect of comfort and health priorities on variability in a household's energy consumption including: the use of the thermal environment to alleviate health symptoms [36]; how general practices in the home impact on heating demand [37]; how temperature-related comfort actions impact on consumption [38]; the impact of guests [39]; the desire of occupants to live 'a fairly comfortable life' [40]; and the differences between individuals' perceptions of being thermally comfortable [34]. Personal values of occupants can also provide a useful explanation of behaviour [41], including how they use their heating. However, there are often conflicting value sets between individuals in a home, for example in relation to how they value and prioritise comfort, relationships, money, health, pleasure, status and freedom [42,43], which have to be considered.

Moving forward, if the next generation of low carbon heating systems are to be appealing to users, or future policies are to be accepted, adhered to, and beneficial, it is essential that there is an understanding of what occupants want to use their heat provision for. If policy recommendations and design solutions are based on untested, incorrect or ambiguous assumptions, policies will be ineffective (or potentially backfire), outcomes will be limited and uptake may be affected.

This paper reports findings from research conducted by the Energy Technologies Institute as part of the Smart Systems and Heat Programme (see also [44]). This work aimed to understand what households might want from low carbon heating solutions, and how their behaviour and lifestyles affect this. Specifically, focus was placed on mapping the wide range of needs that people seek to meet through heating use. Whilst much research has attempted to segment households to show different groupings in their behaviours and attitudes towards energy use, e.g. [45–48], this research attempts to understand and categorise the needs which individual occupants have for using heat energy, and considers how households make decisions about their heating use in order that product, service and policy designers can facilitate these requirements, without the use of carbon.

2. Methodology

This research was conducted as part of the Smart Systems and Heat Programme in the UK during 2013 & 2014. It was spread over a number of work packages and focused on the integration of technical and social data to address the complexity of studying energy in the home.

2.1. Literature review

The work began with an extensive literature search (see appendices for search terms) which identified over 80 consumer behaviours and needs relating to energy in order to design two comprehensive stages of qualitative and quantitative research. The aim was to understand how home life shaped heat and hot water use, rather than study the use of heat too narrowly (however, this paper focuses on the use of heat energy). The literature review resulted in the identification of 15 heat needs, which were organised into 5 groups.

2.2. Qualitative study

2.2.1. Stage 1: workshops

Following the literature review, four workshops were carried out which aimed to generate and map a set of needs and behaviours. Group interaction was used to try and uncover subconscious needs and behaviours, along with a pre-workshop diary to stimulate critical reflection. Workshops lasted half a day and comprised of two breakout sessions, involving four group discussions each with up to ten individuals. The first session involved a heterogeneous group of individuals and aimed to generate a map of heat energy behaviours and needs. For the second session, individuals were grouped based on their household composition, in order to explore the priorities of the different subgroups and interdependences between needs. There were 32 group discussions held in total across the workshops.

The sample was purposively selected to represent the diversity of the general population in relation to key characteristics such as household composition, property type, income and heating type (rather than being statistically representative). The workshops were carried out in the heating season, to ensure that heat energy was at the forefront of the participants' minds.

Each workshop was carried out in a different location in England (London, Manchester, York and Norwich). The locations were selected to reflect a range of urban, suburban and rural areas. Participants were

Table 1
Workshop sample distribution across specific criteria.

	Category	Total participants
No children living at home	Adults over 60 (single, couples, sharers)	35
	Adults under 60 (single, couples, sharers)	39
Children living at home	One or more child under primary school age	39
	All children over primary school age	40
Total		*153*
Location	Urban	111
	Rural	42
Total		*153*

Table 2
30 Home sample demographics.

Criteria	Category	Total
No children living in home	Adults over 60	6
	Adults under 60	7
Children living in home	One or more child under primary school age	7
	All children over primary school age	9
	Unknown	1
Location	Urban	21
	Rural	7
	Unknown	2
Specific income ranges	Less than £13 k	7
	More than £50 k	6
Tenure	Owner occupier	17
	Private renter	8
	Social renter	4
	Unknown	1
Property age	Property built before 1980	15
	Property built since 1980	14
	Unknown	1
Energy/heat supply	Off gas grid	8
	District heating	5
	On grid & unknown	17
Unusual working patterns	Works at home	6
	Works shifts	2

invited to attend through on-street and door-to-door recruitment. There were 40 participants in each workshop, with 153 participants in total (see Table 1). Through the workshops, an initial range of heat energy needs were identified and categorised through further thematic analysis.

2.2.2. Stage 2: 30 household study

30 of the workshop participants were selected, from volunteers who met the sampling criteria, to participate in a longitudinal study which included four interviews over 2013 & 2014,[1] along with data collected through monitoring devices (e.g. ambient temperature, relative humidity, occupancy, luminance and CO_2 levels). The interviews aimed to gain a deeper understanding of the needs and behaviours of participants. The monitoring data (whilst not reported here, other than in high-level examples) was used to bridge the gap between reported and actual behaviour. The longitudinal element of this stage of the research provided further insight into how needs and behaviours changed over time.

The sampling criteria was set to ensure diversity in particular characteristics, namely: household composition, urban/rural location, income, tenure, property characteristics, energy/heat supply, and occupancy (see Table 2).

Initial one-hour interviews were carried out in the participants' homes which enabled the use of in-situ prompts and walk arounds to aid reflection. The subsequent three interviews allowed participants to reflect on monitoring data recorded as well as discussion of household routines and heating patterns. This stage of the research observed 21 different heat needs from the participant households.

2.2.3. Stage 3: 33 additional home interviews

Home interviews were carried out with an additional 33 participants who had not been represented in the initial workshop and interviews to explore sub-group variation, including: single occupants, fuel-poor, time-poor with high income, and those with specific energy features (well insulated, heat pumps or district heating). These interviews were conducted to explore a broad range of socio-demographics and specific household measures (Table 3), not to compare them. Through the 30 household study and additional interviews, a subset of 8 needs were refined.

2.2.4. Stage 4: subset of 8 homes

Additionally, a subset of 8 homes were chosen from the original 30 homes (Section 2.2.2) to be part of more detailed case studies. These homes were chosen to reflect a diverse range of characteristics, including: household composition and decision-making, property age/type, heating system, area, tenure, and household income. The sample also included households with specific health conditions, those in fuel poverty, and those where home modification or change in household occupants was expected in the next year.

The samples were not intended to be statistically representative of the population, but were intended to give an insight into the range of needs and behaviours across different population characteristics.

Table 4 details the case study sample in more detail and shows the spread across characteristics.

2.3. Quantitative study

Quantitative investigation was carried out to measure the prevalence of the needs identified in the qualitative study in Great Britain. A detailed structured survey of heating behaviours and needs was conducted face-to-face with a statistically representative sample of 2313 occupants. The sample for the quantitative work was identified

Table 3
Additional 33 homes sample demographics.

Criteria	Category	N (Total = 33)
Socio-demographic characteristics	Aged over 75	3
	Time poor/high earners	4
	Fuel poor	4
	Single Occupancy professionals	4
Energy features	Well insulated homes	4
	Air source heat pumps	4
	Ground source heat pumps	4
	District heating	6

[1] Two winters, spring and summer.

Table 4
Additional 8 homes sample demographics.

Household composition	Single occupant	2
	Couple	1
	Family	3
	Multi-generational family	1
	Single sharers	1
Age of primary participant	18–35	1
	36–45	1
	46–59	3
	60–75	3
Income level	Low	4
	Medium	2
	High	2
Tenure	Owner	4
	Private Renter	2
	Social Renter	2
Heating System	Gas central heating	4
	Storage heaters	1
	Off grid	2
	District heating (with controls)	1
Property age	Pre 1945	2
	1945–1980	4
	Post 1980	2
Property type	Detached	3
	Semi-detached	2
	Flat	3
Location	Urban	5
	Suburban	1
	Rural	2

Table 5
Quantitative survey sample demographic (quota characteristics).

		% of sample
Tenure	Owned home	65
	Rented home	35
Property	House	78
	Flat	21
	Other	1
Presence of children <18	Children	32
	No children	68

using quotas where earlier work had indicated aspects which were closely linked to heat needs and behaviours, namely: tenure, property type, and the presence of children (see Table 5). To achieve the sample, interviewers were asked to conduct ten interviews in each of 250 sample points, chosen at random across England, Scotland and Wales using the Census 2011 Output Areas. The sampling was based on the household, whilst the interviews were carried out with individuals, and therefore anyone over 18 in each household was asked to take part. This was to avoid self-selection bias based on energy use and knowledge, and aimed to achieve a sample of participants who had a range of interactions with their home heating.

Data relating to heat energy needs were collected from participants following detailed behaviour related questions. As part of the face-to-face survey, respondents took part in a card sorting exercise which aimed to identify the household's heating needs (2287 respondents completed the sort). During the card sort, respondents were asked to identify which of the 21 possible heating needs (identified through the workshops) constituted a) big factors, b) small factors or c) not a factor, for their household. Participants were also provided with specific examples of heat energy needs to clarify their meaning. The 21 needs were:

(1) Doing what you think most people do
(2) Wanting to avoid arguments within the home
(3) Doing what you have traditionally done
(4) How you and your home appear to other people
(5) Concern for the environment
(6) Energy costs
(7) Being comfortable
(8) Caring for other members of household
(9) Keeping to everyday routines
(10) Value or cost of the home
(11) Needs of visitors
(12) Avoiding wasting energy
(13) Keeping healthy
(14) Feeling in control
(15) Doing what's easiest
(16) Wanting to be productive
(17) Wanting to feel safe and secure
(18) Keeping the home looking/feeling/smelling nice
(19) Being able to rest and relax
(20) Wanting to feel clean
(21) Wanting to keep the home clean

Analysis of the ways in which participants sorted the cards revealed five factors. These mapped quite closely to the qualitative results as shown in Fig. 2 and are discussed in the next section.

3. Results & discussion

This research aimed to identify what participants were trying to achieve through the use of heat energy, and how their lives affected their heating use, in order to better develop systems, technologies and services which can meet these needs.

The needs identified through the qualitative work, were used in the quantitative study where participants were asked to select which individual needs were a 'big factor' to them, the results of which can be seen in Fig. 1.

These needs have been categorised in order to better understand how the attitudes and behaviours have an impact on the way occupants use their heating. Fig. 1 indicates that the *wellbeing* needs were identified most frequently as 'big factors' by survey participants, followed by *resources*. However, this did not always match the priorities of needs revealed by participants in the qualitative research.

Fig. 2 illustrates how the quantitative and qualitative needs were overlaid and combined to form the final subset of 8 needs, divided into 4 categories (see Fig. 3). This paper discusses each of these categories next and then returns to the differences between the two studies in Section 3.6.

All of the households discussed needs within each of the four categories (wellbeing; resources; ease of use; and relational dynamics), but each household prioritised these in different ways. All needs were important to some households in the qualitative research, and identified as important by at least 7% of participants in the quantitative research.

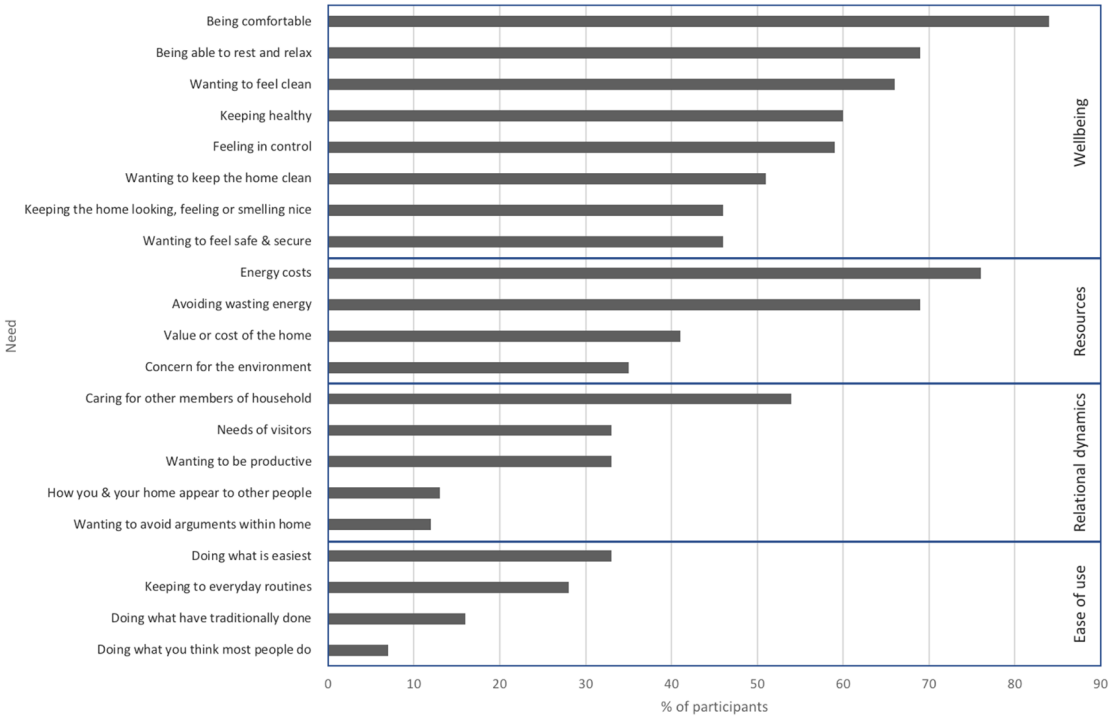

Fig. 1. Percentage of quantitative study participants selecting individual needs as a 'big factor'.

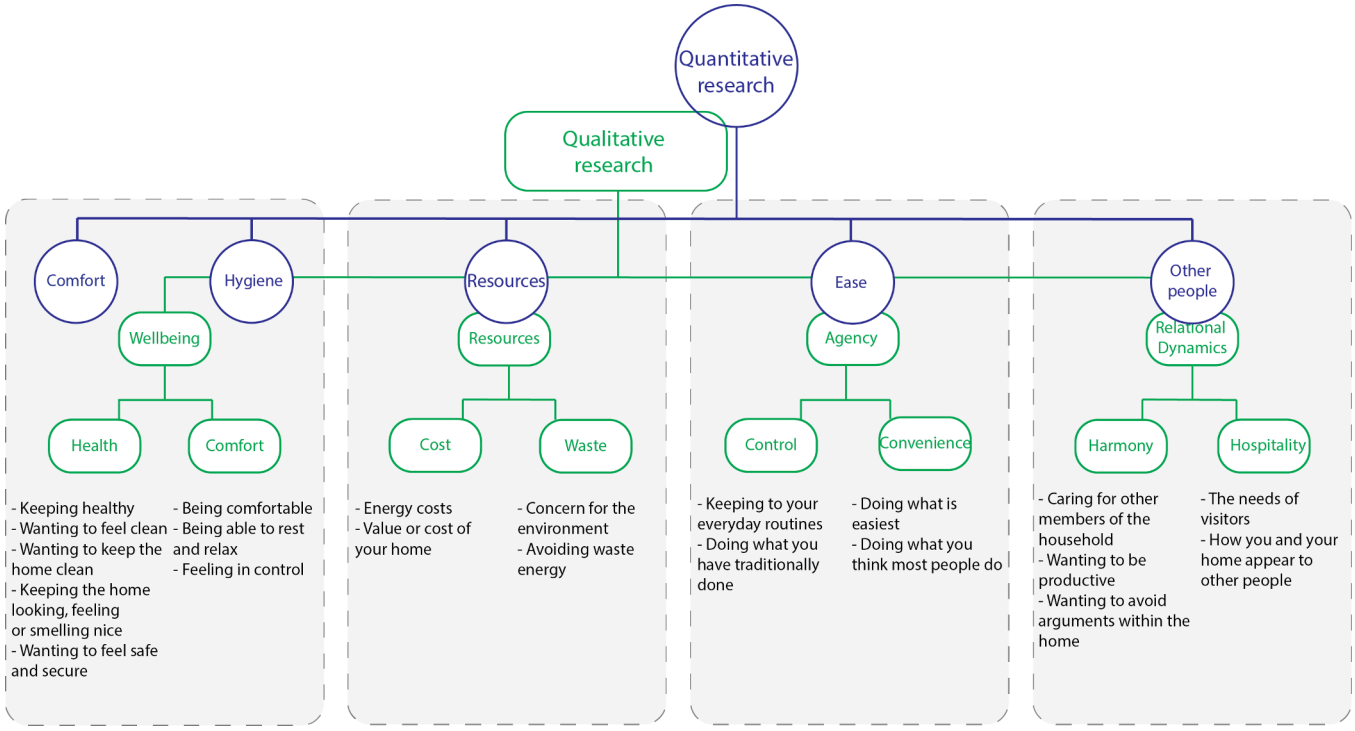

Fig. 2. Needs identified by the qualitative and quantitative studies.

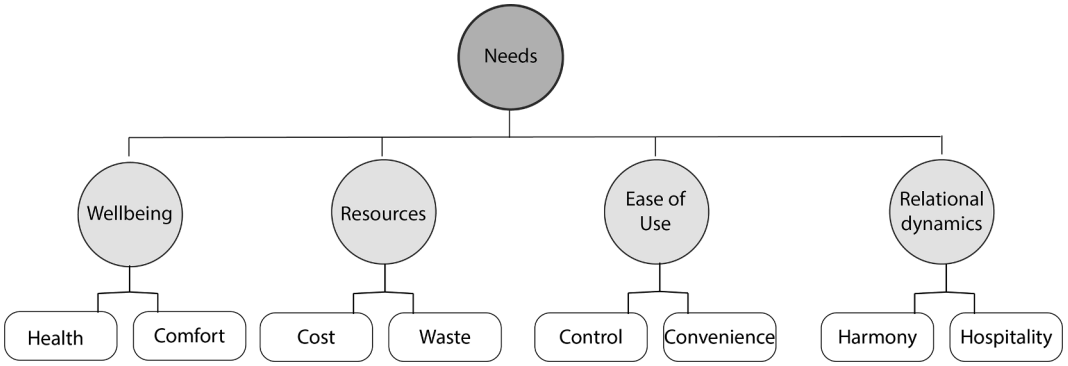

Fig. 3. Final categorisation of needs.

3.1. Category: wellbeing

The needs within the 'Wellbeing' category were the most widely discussed by participants, particularly in the qualitative research. Some of these needs were expected, whilst others were unconscious and deeply embedded in the everyday lives of participants. These needs focussed on what was to be achieved through heating, rather than how to achieve these ends. The key factors that were highlighted in relation to these needs were: keeping healthy; wanting to feel clean; wanting to keep the home clean; keeping the home looking, feeling or smelling nice; wanting to feel safe and secure; being comfortable; being able to rest and relax; and feeling in control. Within 'wellbeing' there were two distinct needs of health and comfort.

3.1.1. Subset need 1: health

Health was seen as a basic need for all participants and essential for life, but it was often expressed in behaviours and everyday activities that served a very functional purpose. An average of 54% of respondents in the quantitative survey rated the individual needs in this category as 'big factors' for their household; *wanting to feel clean* (n = 1166, 66%), *keeping healthy* (n = 1372, 60%), *wanting to keep the home clean* (n = 1166, 51%), *wanting to feel safe and secure* (n = 1052, 46%), *keeping the home looking, feeling or smelling nice* (n = 1052, 46%).

Within some households, health was a more prominent need, particularly where there were vulnerable occupants such as young children, elderly occupants and those with a specific health condition. Quotes from participants added further detail to these behaviours: "*Because she's old …they've still got the heating on in their house … but obviously I need to look after her."* (Household of adults over 60, semi-detached). "*We've got two young grandchildren up the street who come here on a very regular basis…if they're popping in and out…we'll put the heating up if it's cold…they've always got colds and stuff…I'd better just keep them a little bit warmer, you know, just so that they're comfortable.*" (Household of adults over 60, detached).

Whilst health was the need prioritised above all others in the qualitative research, and has a clear impact on the heating use, it was less visible in houses where there were no health-related concerns, where participants didn't realise how heat related to their health until they fell ill, at which point it was often prioritised above any other need. This was echoed in the quantitative research, where whilst it was an important need, it was not the most highly rated by participants. Specific patterns of behaviour were witnessed when the health requirements of more vulnerable occupants were prioritised including:

- Frequent use of the primary heating system (often in combination with supplementary heating) e.g. using electric blankets.
- Pre-emptive heating e.g. turning the heating on in anticipation of needing it or reactive heating (common in households with very young children) e.g. A parent putting the heating on when they go to the bathroom in the middle of the night, so that the house is warm when the children wake up.
- Distinctive control strategies e.g. timing the heating to align with the routines of a vulnerable occupant, or households who mapped the heating schedule around the routines of young children, but at the sacrifice of their own comfort.

Health and comfort often seemed to go hand-in-hand, where strategies to improve comfort, also encompassed health-related needs, but people were less conscious of these health needs.

The monitoring data highlighted that despite the fact that many households prioritised health needs, some households were actually creating unhealthy environments. One example of this was a father who expressed his desire to alleviate his young daughter's asthma. He felt that radiators would dry the air, aggravating her condition, and to combat this, he placed containers of water on top of the radiators. The monitoring data revealed excessive humidity levels in the home, placing it at risk of mould and dust mites, both of which are known to exacerbate asthma. These types of results highlight the need to collect data on occupants' actual behaviours as well as their attitudes and opinions, as they do not always correspond (31).

3.1.2. Subset need 2: comfort

Each individual need in the subset of *Comfort* was chosen by over 50% of the participants as a 'big factor': *being comfortable* (n = 1921, 84%), *being able to rest and relax* (n = 1578, 69%), and *feeling in control* (n = 1349, 59%), with an average of 71%. Comfort encompassed a wide range of meaning for participants, which was both physiological and psychological. Physical comfort related to achieving thermal comfort, which enabled different activities at home, alongside rest and psychological wellbeing e.g. "*A stable and comfortable [temperature], which nobody finds is too hot or it's not too cold"* (Household of adults under 60, semi-detached). This was seen as important to allow occupants to 'get on with life': *"If it was winter and it was too cold then it's not comfortable. If it's too hot, it's not comfortable; something which is right in the middle, ambient temperature or whatever you want to call it…well, then you can get on with your day-to-day life without…worrying about this, that, or it's too hot one minute. Oh no, it's too cold!"* (Household of adults under 60, semi-detached). *"If we were too cold we'd not be able to concentrate and enjoying relaxing and things…and if we were too hot we'd not be able – so it's important that we have the correct temperature then we can enjoy films and movies and relaxing … Human beings can't work or have leisure If [the] temperature [is] wrong."* (Household of adults under 60, terraced).

The different conditions that participants found comfortable varied between individuals, and depended on a range of factors including; current activity levels, gender and age. For example, participants wanted their homes to be warmer when doing sedentary activities such as watching TV, but cooler when being more active, such as doing housework. There was also perception from some that the very young and old require more warmth to be comfortable: "*Your body changes as it gets older and … I think really old people don't always know when they're*

cold." (Household of adults under 60, terraced).

Participants also discussed psychological aspects of comfort, for example, how comfort was linked to general psychological well-being and mood: "*I think being uncomfortable would make you grumpy and not… happy and I think if you're warm, you're happy*" (Household with teenage children, semi-detached). As well as more symbolic notions of 'home' which represented a place of personal freedom, and the feeling that comfort is a 'right' which should not be compromised, in which heating plays an essential role: *"I'm getting too long in the tooth to be sitting around freezing, you know, I don't smoke, I don't drink to excess, I don't drive a BMW, but I do like to be able to sit around in shirt sleeves."(Household of adults under 60, semi-detached)*. Participants gave a few examples of voluntarily compromising their comfort to meet the needs of others, in particular those they considered vulnerable, e.g. very young or old visitors.

The quantitative research found comfort to be the most important factor for participants (84%), this is reflected in previous research e.g. [40,22,21]. However, sensor data and longitudinal qualitive research revealed many examples where health was prioritised more highly than comfort.

3.2. Category: resources

The needs within the 'resources' category were discussed by participants in terms of avoidance e.g. reducing cost or waste (rather than a need which is sought), and were the means by which an aim is achieved. The key elements were broadly: finances, waste and property maintenance, or more specifically: energy costs, the value or cost of your home, concern for the environment, and avoiding wasting energy. Within 'resources' there were two distinct need subcategories of cost and waste.

3.2.1. Subset need 3: cost

An average of 59% of the respondents rated *cost* as a 'big factor' in the quantitative survey, but this varied significantly between the two individual needs of *energy costs* (n = 1738, 76%), and *value or cost of home* (n = 938, 41%).

Whilst many participants were vocal about energy prices, their responses and actions indicated that they prioritised comfort above cost. For example, they rationalised spending to ensure comfort, which was often linked to their concept of home: "*The home should be a comfortable place; it shouldn't be a place where you should be making economies and living frugally…"* (Household of adults over 60, semi-detached).

Some households used strategies to manage cost so that comfort wasn't compromised, which could perhaps be viewed as *comfort-seeking* rather than *cost-saving*. One strategy focused on management of finances, rather than management of heating use. For example, making adjustments elsewhere in the household budget such as cutting back on luxuries e.g. holidays, new clothing or 'fancy' food brands: "*If [energy prices] go up and it costs me another £20, that's £20 that's got to come from somewhere, so it's either got to come off your shopping …or you don't go out … you have to adjust. It's like, you don't have roast beef on Sunday dinner, instead you buy mince because it's cheaper"* (Household of adults under 60, terraced). Quotes like this demonstrate the lack of willingness to reduce energy usage in the home just to save money, meaning policy and incentives need to offer more than just financial savings to occupants.

Another strategy described using different payment options to manage energy spend without adjusting heating behaviours. As might be expected, the most extreme strategies were evident in fuel poor homes, where examples included:

- Avoiding using the primary heating system.
- Using personal insulation (e.g. clothing and blankets) or secondary/*local* heating rather than heating the whole space.
- Staying in one room and heating only that room (restrictive zoning).
- Spending time in other homes or public spaces.
- Using physical activity to keep warm.

Whilst these strategies were employed, often there was no guarantee that they would actually save money. Income was not the overriding determinant of occupant heating behaviour as is often assumed by building models. Therefore, households were not primarily governed by the amount of money they had to spend on heating. This included participants living in fuel poverty, who still demonstrated a range of needs, and did not prioritise cost saving alone.

3.2.2. Subset need 4: waste

An average of 52% of participants selected *waste* as a 'big factor' in the quantitative research, but there were large differences between the number of participants who selected the individual needs of *avoiding wasting energy* (n = 1578, 69%) and *concern for the environment* (n = 800, 35%), indicating that any motivation around waste is not necessarily related to concern for the environment.

Amongst the participants, there were a number of different attitudes towards waste with varying levels of influence over behaviour. For some, waste was a fundamental concern, with several participants reflecting that this was influenced by the way they had been brought up: "*We will put on extra clothing rather than whack the heating up especially because our heating, well I don't know how much it costs, I'm not that au fait with it but it feels quite wasteful … It's driven by finance to a degree but it's honestly more predominantly how we've both been brought up 'cause both our parents, independently of each other, were much like that, you know, you put something extra on.*" (Household of adults under 60, terraced); "*I'm not used to wasting stuff…No, just don't see the sense of using stuff for the sake of using it, 'cause that's what you're doing.*" (Single household over 75, terraced property). This concern with waste did not seem to be driven by cost saving, but more about an increase in efficiency.

The monitoring data provided the opportunity to query the participants on some of their more wasteful behaviours. For example, one participant stated she never opened windows in winter. She had forgotten that she opened the window when she smoked, until she was shown the temperature sensor data collected from her home, which prompted her memory.

On the whole, participants seemed willing to engage in inefficient behaviour if it served a core need (such as comfort). For the slight majority, waste did not seem to feature as a need, or would only feature once comfort and cost requirements were met sufficiently, or when waste avoidance behaviours served the interest of comfort or cost.

3.3. Category: ease of use

The needs within the 'ease of use' category focussed on the capacity and willingness of a person to act and make choices independently, and the extent to which people want to be actively in control of their heating. This included key elements of convenience, control and habit, or more specifically: keeping to your everyday routine, doing what you have traditionally done, and doing what is easiest. Within 'ease of use' there were two distinct need subcategories of control and convenience.

3.3.1. Subset need 5: control

Control was not rated highly as a 'big factor' by participants in the quantitative survey (average 22%), where 28% (n = 640) of participants selected *keeping to everyday routines,* and just 16% (n = 366) *doing what they have traditionally done.* Amongst participants, the need to feel in control of heating use in the home had both a functional and symbolic purpose. When linking to symbolism in the home, participants described control in terms of influence, choice and freedom: "*In summer, it can be red hot and I don't like that and in winter, it can be minus, I don't like that…I don't think it gives me a sense of control…My choice is to be as warm as I feel comfortable with."* (Household with school age children, semi-detached).

Control rarely seemed to be a standalone need and was more often understood in terms of having control over other needs such as comfort, cost or convenience. Control is a complicated area to discuss and examine as it is multi-dimensional, manifesting as both a need and a behaviour, as well as being reflected as a feature within the heating system itself.

The participants displayed the need to be in control of something and disliked that they felt that something they valued, e.g. comfort, might feel out of their control. This lack of control might be uncertainty over practical control of the heating, or a perceived lack of control over how much money, time or effort was required to achieve a feeling of comfort. Often participants only identified this need when they felt they had lost control, for example, because they couldn't make a room feel warm, or control how cold the weather was. The element of control was important to households in various ways and was also evident in other categories. For example, participants were seen to be far less tolerant of waste if they did not feel in control of it (subset need 4), whilst for others, having control and choice was important to feel comfortable.

3.3.2. Subset need 6: convenience

Convenience was rated as a 'big factor' by just 20% (average) of participants in the quantitative survey, including the individual needs of *doing what is easiest* (n = 755, 33%) and *doing what you think most people do* (n = 160, 7%). Convenience needs focussed on making life easier, particularly in relation to resources of time and effort. The pursuit of convenience was reflected in strategies and behaviours that reduced the amount of time or effort involved in heating use, for example, participants choosing to take off clothing to cool down rather than adjust the heating system: "*[In] regards [to] setting temperatures and having heating on and that, I think you want it set so that you don't think about it.*" (Household with school age children, semi-detached).

Convenience was also seen to be highly situational and meant very different things for each household. It was only generally seen in households where the needs of health, comfort and cost had been met. Some households sacrificed convenience to meet their other needs. For example, one fuel poor household saved money by only heating the living room, even though this meant he and his daughter had to get dressed and even sleep in that room to keep warm.

3.4. Category: relational dynamics

The needs within the 'relational dynamics' category focused on social relationships within the household and was the most peripheral of the categories in discussions with participants. This included social interactions with household members and guests, social interactions beyond the home, and wider implications of heating use, or more specifically: how you and your home appear to other people, the needs of visitors, wanting to avoid arguments/disagreements within the home, and caring for other members of the household.

Within 'relational dynamics' there were two distinct need subcategories of harmony and hospitability.

3.4.1. Subset need 7: harmony

Harmony was selected as a 'big factor' by an average of 44% in the quantitative survey, including the individual needs of *caring for other members of the household* (n = 1235, 54%) and *wanting to be productive* (n = 755, 33%). Harmony was reflected by participants in the desire to maintain or facilitate particular relational dynamics or social interactions in the home. This need was depicted in the decision making around heating use within a household, as well as in the way space was used in the home e.g. keeping doors open to communicate with one another. It was rooted in social identities and roles within the home, where decisions were made to promote household unity, or at least allowing individual occupants to live alongside each other harmoniously. In some households, this harmony was achieved by assigning heating decisions to one person, e.g. in one household the husband deferred all heating decisions to his wife, even though she had the heating set higher than he would like it. Whilst in other homes, decisions were made more democratically amongst the whole household.

3.4.2. Subset need 8: hospitality

Hospitality focused on the interactions with visitors to the home. As would be expected, this was one of the least prominent of the needs in relation to everyday behaviours, as it is both situational and occasional, with 23% (average) of quantitative survey participants choosing it as a 'big factor' (*Needs of visitors, n = 755, 33%, How you and your home appear to other people, n = 297, 13%*), and it was even less prominent in the qualitative research. This need focussed on facilitating a type or quality of interaction with others, and for some meant projecting a particular personal identity to others. This was seen more in households where other needs were already taken care of, where there were less complex routines, and where visitors were an important feature of home life. This need was about social acceptance, pride and self-esteem, and again linked back to the symbolism of home. For example, some households discussed how having a warm, welcoming home for visitors was important. One household was very stringent in their use of heating for their own family, but made sure the home was warm for visitors, *"If you've got somebody in your home and you want them to be happy, comfortable, and heat is part of comfort and happiness…….you wouldn't want them going your way thinking 'God, I don't want to have to go back there again'…..it's just uncivilised.*'" (Single adult household with school age child, semi-detached). Another occupant liked to give overnight guests control over elements of the home, such as the heating.

It is interesting to note that whilst relational dynamics were the most peripheral of needs in the way they were discussed by participants in the qualitative research, many of the other categories, and the example quotes, featured a relational element. This relational decision making and prioritising will be discussed in Section 3.5.3.

3.5. How and why did heating priorities and behaviours vary?

The findings showed that there was huge diversity in how different participants chose to use their heating. The longitudinal nature of the qualitative research showed that participants' priorities also changed over time depending on their sociotechnical situation. Finally, different households took different approaches to decide how to use their heating to meet their needs. This section discusses these varied heating priorities, how the situation made different needs salient, and the diversity in decision making.

3.5.1. Shifting priorities

Participants prioritised the needs discussed above in different ways as illustrated in Fig. 4. This shows that for each individual, some needs were core and more fundamental (shown left), whereas others were more peripheral, or more of a *want* (shown right); sitting on a continuum. Participants used their heat to try and meet their core needs first and then more peripheral needs once these had been met (as suggested by [35]).

Fig. 4 demonstrates the principle for two different participants. Participant A prioritised the health of their child, who suffered from a heat-related health condition, even above their own comfort. For instance, they heated their child's bedroom to make sure they were warm, even though this sometimes made other parts of their home feel too hot. The participant often described their frustration that it was hard to control their heating to keep their child safe without overheating their own bedroom. Harmony and hospitality are positioned to the right because they put their child's welfare above their partner's comfort and rarely had guests in their home.

By contrast, Participant B was primarily focused on getting comfortable. They kept most of their home warm most of the time and made sure their guests felt welcome; by checking they felt comfortable and adjusting the heating if they were too hot or cold. Though they spoke

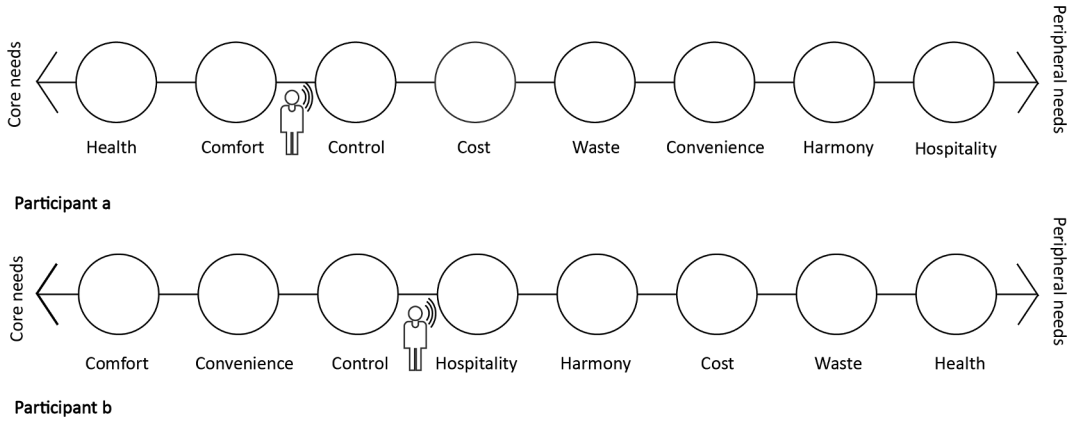

Fig. 4. Continuum of priority for two specific but different participants.

about cost and waste, they spent little time adjusting their controls.

In this way, the needs sit along a continuum, i.e. a *continuum of priority*, from core to periphery, though of course, priorities can change over time. For instance, Participant A was less worried about health before their child fell ill, whilst Participant B became more worried about cost when their salary reduced, and they discovered what they were spending on their heating.

Other studies have also reported that households prioritise some needs above others. For instance, some occupants open their windows because they value ventilation to get 'fresh air' and cool down, even if this means wasting energy and spending more than they need on their heating [34].

3.5.2. The sociotechnical situation makes some needs more prominent

This research collected a comprehensive set of data about participants' lives, homes, heating systems, energy use and the temperatures in each room. This showed how various factors: people, heating system, and property (see Fig. 5), influenced the needs which occupants were aware of. The combination of all three elements, or the household sociotechnical situation [24–27], also constrained the choices each household had available to meet their needs.

People factors related to the circumstances of occupants within the home, specifically: personal preferences, values and attitudes; knowledge and beliefs; tenure and income; and the symbolic meaning they ascribed to their home. As described above, occupants' personal preferences were a prominent factor in influencing their behaviour. Sometimes preferences were developed through formative experiences (as discussed in [23]). *Property factors* included the characteristics of the property and the neighbourhood, elements that have a strong influence on heating use within the home [9,10]. Whilst the physcial heating system and control features constitued the *heating system factors, and* influenced the way heat was used in a home, and how needs were met.

Changes in the sociotechnical situation can make some needs more salient than others. For instance, when heating systems stopped working participants became more aware of how much they valued heating to get comfortable. Alternatively, the onset of an illness or arrival of a partner revealed the importance of health and harmony (see participants A and B in Fig. 4).

Where households do not manage to meet their most prominent or core needs (see Section 3.5.1), perhaps due to household factors such as an inefficient heating system or a draughty property, they will unlikely become aware of the more peripheral needs at all. Therefore, the prioritisation of needs discussed above is important to consider, whilst also understanding that it is likely to change over time.

Finally, the impact of any change will depend on all sociotechnical elements. The 'people' or social elements will affect and limit the amount of carbon any technology will save, for instance, if participants install insulation, they may decide to use (and heat) rooms they can now make feel comfortable. Similarly, the 'heating system' and 'property' elements will limit the carbon that any behaviour can save, where, for instance, participants could choose to turn down set points on thermostats, but their heating system will still emit CO_2 if it burns natural gas.

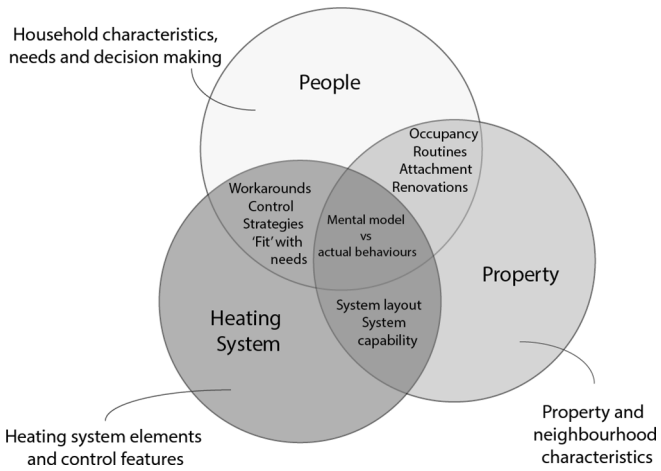

Fig. 5. Household sociotechnical factors.

3.5.3. Household decision making

Over 80% of people live with others [49], and therefore it is important to think of households as a collection of individuals with differing needs, as opposed to individuals behaving alone. The makeup of households within this research determined how (and why) decisions were made, and there were often conflicts between the priorities of

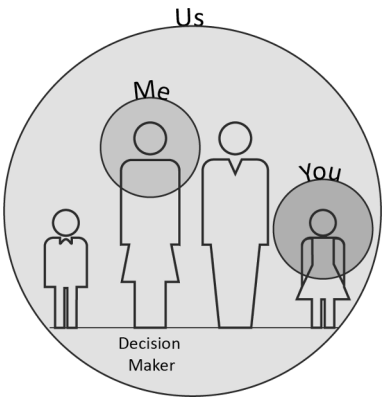

Fig. 6. Types of decision making.

individuals living in the home [see also 42,43]. Three classifications of decision making emerged from the data (see Fig. 6):

(1) *You* – Decisions were made on the basis of the needs of an dependent individual (individualised).
(2) *Me* – Decisions were made on the basis of self-interest of individuals (individualised).
(3) *Us* – Decisions were made on the basis of the needs of multiple household members (collective).

It is important to note that the decision type was not dictated by the household composition, rather by the specific priorities of the individuals within that household. For example, one couple might make decisions as *Me*, whereas another couple as *Us,* therefore household decisions should not be modelled based only on the number of occupants.

Previous research focuses on decision making and prioritising around more vulnerable occupants, such as infants, the elderly, or those with poor health e.g. [22,21]. However, this underestimates the number of factors involved in a household's decision making.

3.6. Importance of a mixed method approach

This section discusses the advantages and drawbacks with combining different methods to understand domestic heat use.

Sensor data revealed that participants often used heat in different ways than they discussed. Comparing reported behaviour with sensor data gave researchers the opportunity to explore *attitude-action* or *intention-action* gaps [31] with participants which revealed a deeper understanding of their priorities.

Revisiting households four times over the course of two winters showed how changes in participants' home lives shaped the way they used heat. For example, participants discovered how much they valued heat for maintaining health when someone in their household fell ill. Participants were aware that they used heat to get comfortable (as has been previously reported by [21,34,38] etc.), and clean, however, it required exploration to reveal needs that they were unaware of, and were therefore less likely to articulate. For instance, that they valued heat to protect and maintain their property, to enhance their health and to enrich their relationships.

Surveying a large sample of participants meant statistics could quantify the variation observed across households in the qualitative research. Conducting these surveys in participants' homes enabled interviewers to record details (like the type of heating system) that participants did not report accurately themselves in the qualitative research. It also meant interviewers could record reference to artefacts around the home to get more accurate information about how heating was used, e.g. recording how heating controls were set.

However, the survey produced some findings that differed to the qualitative longitudinal study. For instance, the 'factor analysis' conducted on the survey responses identified patterns in how participants prioritised their needs in a card-sorting task. These patterns were slightly different to those which emerged from qualitative work. For instance, participants often grouped the '*feeling in control*' card with cards for '*being comfortable'* and *'being able to rest and relax*' (see Section 3.1.2). On the other hand, the qualitative work found that the sense of feeling in *'control'* was combined with *'convenience'* as part of a broader need for '*agency*' (see Fig. 2).

This may be because the qualitative research showed that participants often used heat as a by-product of daily life [16], rather than making conscious choices. For instance, one participant left doors open so their children could see lights on outside their bedroom, another opened windows to remove cooking smells. Sensor recordings showed that this changed how heat flowed around their homes even though this was not their aim.

Qualitative interviews discussed this sensor data with participants to reveal these sorts of behaviour. Survey respondents may have been less likely to report these sorts of behaviour because they were not aware that they used heat to meet these sorts of needs (e.g. to care for children or improve indoor air quality).

Similarly '*cost*' appeared to be a more important need in the quantitative survey and initial workshops, than in the qualitative study, where participants often used heat to meet other needs without appearing to consider the cost. Everyone appeared to want to feel comfortable at home (i.e. comfort-seeking), but chose to spend different amounts of time, effort, money and energy using heat to get comfortable.

Diary studies and tasks enabled participants in the qualitative research to reflect on how they used heat at home. It showed how the social dynamics in their homes reflected very different patterns of decision making which the quantitative survey was then able to quantify. Revisiting participants revealed how their priorities changed with their sociotechnical situation. Some realised they prioritised using heat to enhance their health above saving money when they fell ill, whilst others only discovered they valued using heat to host guests over reducing waste when they entered a relationship with a new partner. The survey was able to quantify the stated prevalence of these needs but may have underplayed their importance because participants were less aware of them and therefore less likely to report them.

Overall there was considerable overlap between the results produced by these different methods, enabling the joint categorisation discussed here. This mixture of methods also introduced significant management complexity, increased costs and lengthened the duration of the study, however, it revealed deeper insights than could have been generated by employing any method alone.

4. Conclusion

This research shows that occupants were trying to use heat to meet a far broader range of needs than is often assumed by those trying to decarbonise domestic heating use, meaning occupants' needs are not being met. Fig. 7 highlights some possible implications for improving the success of heating policies, products and services, based on this framework.

However, this will be highly challenging as people use energy as a by-product of daily life [16], not a conscious choice, so they may not understand their own needs, or be able to express them. Individuals also hold very different priorities for how they want to use heat at home and their priorities change dynamically with their situation. Low carbon heating 'solutions' will need to cater for a broad range of needs as a household's situation changes [24–27], or new residents move in. This may mean, for instance, designing heating systems that are flexible and perform well in various contexts, rather than perfectly in one.

Further research into behaviours, attitudes or needs in the home should consider mixed methods, with a longitudinal element, to capture the changing nature of a household's needs. Critical to this research is the use of sensors to monitor actual heating use within the home, allowing comparison of what participants think or say they do, with their actual behaviour.

Occupants value being free in their own home to control how they use heat to meet their needs, which may present difficulties for completely autonomous systems which restrict occupants' choices. A key challenge for designers of these systems will be to identify the elements that occupants want automated, particularly as this will vary between households and over time.

There is increasing urgency to decarbonise domestic heating to reduce carbon emissions and avoid climate change [2]. Therefore, it is imperative that products, services and policies are designed around how people will actually behave in real life, and how they want to behave. Policies and commercial propositions will fail if they are based on incorrect assumptions. Households, including those vulnerable to fuel poverty, value using heat to meet many needs, and they are not

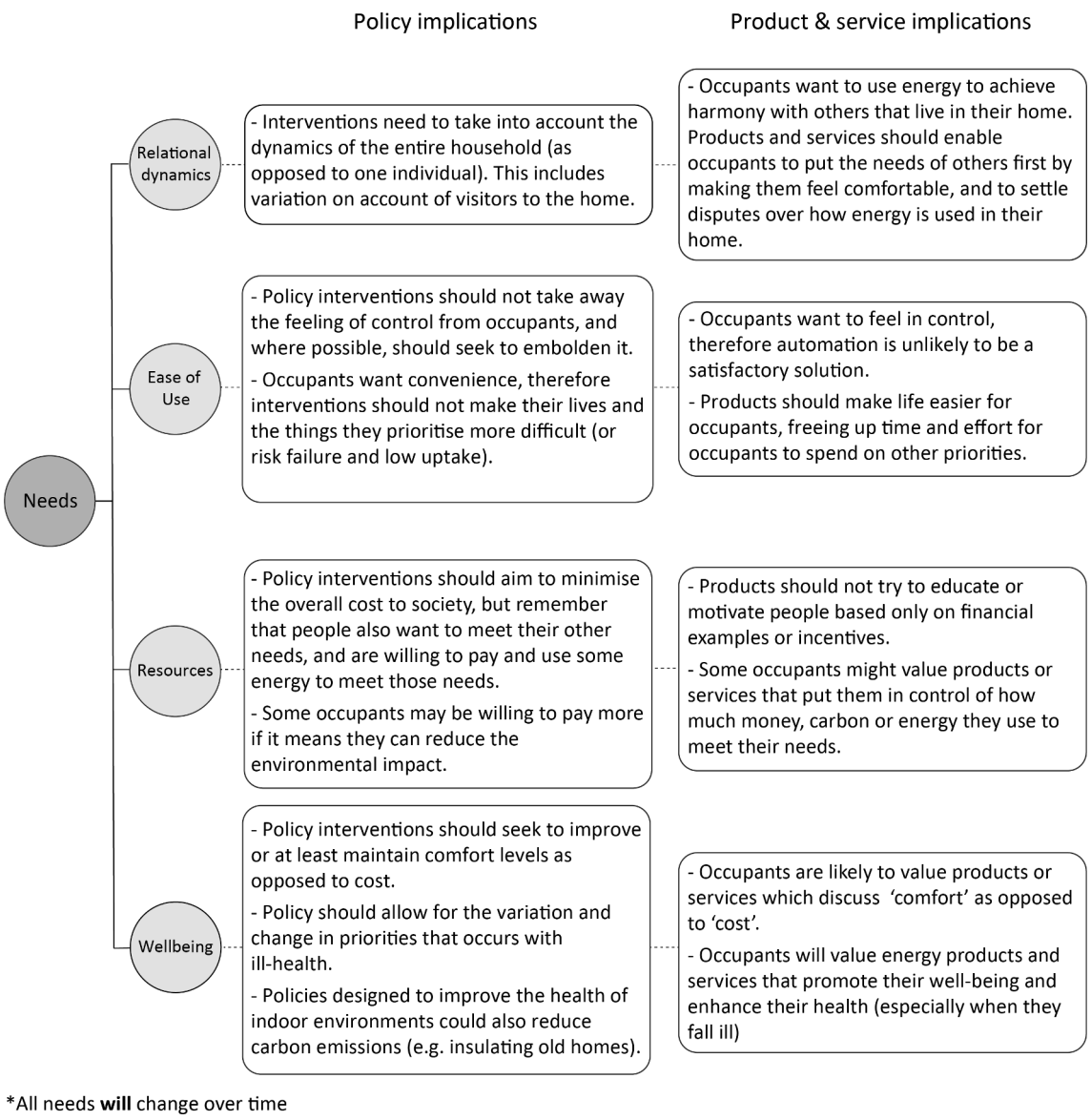

Fig. 7. Policy and product implications aligned to need categories.

focused only on minimising what they spend. People who insulate their home may prefer to pay for a more comfortable home instead of saving money on their heating bill [50].

Households will adopt low carbon heating products faster if they meet their needs as well as, or ideally better than, the systems they have today. Future research and development should investigate how this can be achieved. Automotive manufacturers, supermarkets and mobile telecoms have learnt how to understand consumers' preferences and manage complex supply chains to deliver products and services they value. Perhaps policy makers could enable the energy sector to apply these lessons to accelerate decarbonisation of domestic heating.

Declaration of Competing Interest

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

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Appendix A. Literature review search terms

A.1. Buildings and technologies

- Household energy usage portfolio
- Smart house
- Home improvement
- Home renovation
- Boiler
  - Repairs
  - Replacement

- Servicing
- Passive Stack ventilation
- Heat technology
- Energy efficient ventilation
- Dwellings
- Energy efficiency programme
- Energy technology
- Distributed energy
- Microgeneration
- Heat recovery system
- Domestic energy recovery
- Heating degree-days
- Monitoring of buildings
  - Temperature
  - Air flow
  - Air changes
  - Energy consumption

A.1.1. Consumer characteristics

- Building user
- Consumer profile
- Consumer needs
- Consumer requirements
- Consumer attitudes
- Fuel poverty
- Motivation

A.1.2. Consumer behaviours

- Consumer behaviour modelling
- Consumer response
- Behaviour constraints
- Energy use behaviour
- Emergent household behaviours
- Consumer behaviour trends
- Behaviour change

A.1.3. Barriers and drivers for consumers

- Thermal comfort
- Behavioural drivers
- Barriers to consumer change
- Household energy use drivers
- Social norms in energy

A.1.4. Segmentation/sampling

- Response-based segmentation
- Sampling
- Household structures
  - Population statistics
  - Household composition
  - Demographic trends
  - Per capita energy use

A.2. Types of energy use

- Smart energy
- Residential heat use
- Energy re-use
- Heating energy use
- Cooling energy use
- Indirect energy consumption
- Electric vehicles
- Energy demand activities
- Consumer energy use
- Energy in schools
- Energy in offices
- Energy in retail
- Domestic energy

A.3. Demand side response

- Demand response
- Dynamic pricing
- Time of use tariff
- Energy feedback

A.4. Scenarios

- Green
  - Innovation
  - Adoption
  - Diffusion
- Grid decarbonisation
- Low-carbon
- 2050 scenarios
  - Energy
  - Demographics
  - Fuel prices
- 2050 projections
  - Energy
  - Demographics
  - Fuel prices

This manuscript has not been previously published and is not under consideration for publication elsewhere. All authors listed have contributed sufficiently to the project to be included as authors, and all those who are qualified to be authors are listed, but please note there has been a change of authorship since the first submission. To the best of our knowledge, no conflict of interest, financial or other, exists.

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