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Original research article

Mental models: Exploring how people think about heat flows in the home

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ABSTRACT

To achieve energy efficiency targets, the behaviour of building occupants is critical in counteracting or enhancing efficiency measures. Yet behaviour and decisions are construed through the lens of the mental models that occupants hold. We used a mental models methodology to extend previous research in order to elicit occupants' (N = 25) wider models around how they believe heat operates in their home. The research aim was to analyse the stories of heating, to reveal beliefs that occupants use when 'operating' their buildings. Twenty-five participants were asked to relate how they imagined (i) how their thermostat operated, (ii) how quickly their home heated up, (iii) where heat goes to when the heat source is switched off, (iv) how insulation works, (v) how heat flows around the home. We document the variety of mental models and specific features, e.g. how a high internal temperature can stem from a goal to feel warm fast, that when occupants use 'technical' vocabulary they may be imagining a different process from 'experts', how people use analogies such as wetsuits and weather patterns. We discuss the implications for energy efficiency. The stories of building users around how they operate their heating systems reveal assumptions that influence behaviour and can inform future communications.

1. Introduction

1.1. Energy use and occupants

Using energy efficiently is a key element in reaching EU targets for saving 20% of energy consumption by 2020 [1]. The behaviour of occupants and building users is a critical element because this can enhance or counteract the benefit of energy efficiency measures [2,49]. However, attempts to promote the energy efficient use of buildings are rarely based on an understanding of how occupants think and make decisions regarding energy use and energy efficiency in the home [3]. Every day actions in the home are underpinned by the "competences, skills, routines, attunements and working knowledge of the homes that are involved in the ….management of energy flows" [4,p. 155]. One way to approach these practices and underlying understanding is to explore the *mental models* that occupants draw on as they operate their buildings.

Mental models can make an important contribution to improving building literacy [5,6] because they describe people's beliefs about a system, its elements and connections, which guide actions. As people strive to achieve warmth and comfort in their homes, everyday actions contribute to energy use (and efficiency). Occupants decide the temperature set point in the home, whether to insulate the loft, how long to keep the heating on, for example. All these considerations contribute to the efficiency with which energy is used in the home and can be conceptualised as being part of socio-cognitive mental models. Specifically, the research in this paper explores mental models in the context of space heating. Space heating is important as it, with water heating, accounts for approximately 80% of household energy use in domestic buildings [57].

1.2. Mental models, storytelling and the social construction of knowledge

Mental models have been variously described as socio-cognitive representations of the outside world, as beliefs held by individuals or 'folk' theories held by people [7] as naïve physics or representations that people have of themselves and the things they interact with [8]. A mental models research approach is concerned with understanding human knowledge about the world [9] "through the careful examination" of the way people understand very specific domains of knowledge [9,p. 1]. The mental models methodology involves asking participants to retell their stories or understandings, sometimes using a scenario to prompt the discussion. These domains of knowledge are typically complex physical and technical systems or devices. A mental model

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approach has been applied to the understanding of climate change [14] radon in homes [15], how liquids flow [16] and the understanding of the day/night cycle [17,18,see Boase et al. (in press) for an overview]. A particular example of how findings are applied to guide the development of risk communication literature can be found in Linville, Fischer & Fischoff [19] who investigated the mental models of the transmission of the AIDS/HIV virus and used these findings to redesign public communications. Within the energy field, previous research has sought to capture and understand the mental models occupants hold of thermostat operation in the home [10,53–55] the heating system [11] and electricity more generally [12].

Encouraging occupants to talk in detail about a specific domain of their knowledge and understanding is important to accessing a person's representations and their mental models. It is not uncommon for participants to use seemingly scientific terms but with an interpretation of that term which is quite different from the 'expert' interpretation. Without unravelling occupant understanding of these sorts of terms, experts and occupants appear to talk about the same topic, but at crossed purposes. An example illustrates this point. When asking occupants to 'tell me about radon gas in homes' occupants used the words 'radioactive' and 'gas' frequently, but their interpretation of these terms differed from how the expert would understand and use these words [7]. Similarly the communications in literature about radon gas in homes uses the word 'decay' to describe the depletion of radon over time. However, in the householders, this word evoked a mental model of radon emerging from decaying garbage in the ground [14,p. 98]. These 'miscommunications' can be discovered during in depth discussions with occupants where they can tell their version of their understanding, as they have learned about the issue in their own context, location and everyday life [20].

Indeed, in terms of domestic energy use, there have been multiple appeals for energy educators to use the processes and language of everyday life [20], arguing that energy use and energy conservation are affected by our tacit knowledge of energy. Tacit knowledge is socially constructed rather than learnt formally. Meaning emerges from the interplay between experiences, interpretation of the feedback and data in the environment. For example, Darby [23] evidences, in a study on energy transitions in a local Scottish community, how energy is used and understood differently, never the same in the same place, constructed through the experiences of social networks, the built environment, climate, geography and demographics. The retelling of past personal experiences in the home can also reveal phenomena in the private world of the home as a means of uncovering themes around energy, heating behaviour and the meaning of warmth [7,25,56]. For example, a study of the mental models of domestic energy consumption suggests that occupants are limited in how they think about and categorise domestic appliance consumption but may better understand energy usage in terms of practices rather than overall consumption [13]. This focus on occupants' personal experiences and lived behaviour, on meaning and constructed knowledge is important in order to understand how occupants think and make decisions that result in energy use, so that communication with occupants is on their terms.

Research into mental models has found that when individuals hold models of physical systems, these models tend to be stories or representations [7]. They are 'models' in that individuals use them to predict the outcomes of their actions and so guide behaviour. However, mental models are not the formal scientific models, concepts or theories characterised by abstraction, predictability and consistency. Mental models may change over time and are not necessarily real or correct; they can be fuzzy, incomplete, and conflicted [8]. However, a mental model can be seen as an abstract (folk) theory in that individuals may group mental models into analogies to refer and explain similar phenomena they encounter. An example of this is evidenced earlier in this paper when individuals applied their model of garbage decaying in the ground to explain radioactive decay [14,p. 98].

In the domain of home energy and home heating use it is important to understand the prevailing mental models that people hold, as these can influence energy use and conservation. People interpret public communications through their mental models and so understanding these is vital to inform the design of such communications [e.g. Ref. [19]]. Understanding mental models may go some way to explaining miscommunications or any unintended consequences of public appeals to conserve energy (designed by governments, climate change organisations or energy conservation agencies). For example, there is a reported gap [21,22] between actual building performance and predicted energy use performance. Authors refer to occupants taking back the higher temperatures achieved by energy efficiency measures [4]. However, Janda and Topouzi [20] advocate for a learning story approach to understand this gap, in terms of '*a search for meaning in specific times and places*, p. 520 (to complement the 'hero stories' where new (and heroic) building technologies will solve the energy demand problem as per the theoretical predictions of building simulations and models). They propose that learning stories can help in better understanding the moderating factors that affect energy use; the '*task complexity*' and the real (and potentially '*messy*') '*situational constraints*' of the real built environment [20,p. 529]. This paper presents the results of such learning stories by presenting people's representations and mental models around their in situ experience of heat flows in real situations. It contributes to a literature gap in this area. Previous research has provided some insight into mental models of heating systems but less on heat flows in the home.

1.3. Mental models of heating systems

The literature on mental models around heating controls and occupant behaviour has documented different ways that people can think about the same phenomena. Early research by Kempton [10] found evidence that individuals hold one of two mental models when operating a household thermostat: the valve or the feedback model (or a partial model of these). The feedback model described a thermostat working by sensing the temperature in the home and switching the heating on and off to maintain the desired pre-set temperature. In the 'valve' model, people predicted that the thermostat operated by opening a flow of fuel: the higher the setting the more fuel released, so the warmer the home temperature. The latter is analogous with a gas burner on a domestic cooking hob, in that as the gas control is turned up, the gas flame increases in size and provides more heat [10,8]. Norman [8] described a third mental model (the timer model) where individuals believe that the thermostat controls the time that the heating stays on, so if the thermostat is set to half way, then the heating is on for half of the time. Holding the valve model would lead individuals to predict that turning the thermostat up to its highest setting achieves the most heat. The traditional UK thermostat acts as a switch to activate the heating and then switches off once the temperature reaches the temperature set point in the home (most aligned to the feedback mental model). Further, the rate of heating is a constant, and the traditional UK thermostat does not usually control the speed at which the house heats up.

More recent studies have complemented these findings. The UK Energy Saving Trust [26] found that 32% of UK householders reported turning their thermostat up in order to heat the home more quickly, despite the fact that this action alone will not cause a space to heat