Using the notion of mental models in design to encourage optimal behaviour in home heating use

Kirsten M A REVELL, Neville A STANTON
University of Southampton, UK

ABSTRACT

Introduction: Understanding how to influence householder's energy consuming behaviour, could inform far reaching strategies to combat climate change. A Mental Model (MM) approach to design, to encourage optimal behaviour was explored. Challenges exist in accessing, describing and analysing user MMs and associated behaviour. **Method**: A method that considered bias in interpretation was developed, involving a structured interview, concept maps and graphical self-reported behaviour. Using this method, 6 householders in matched accommodation, over winter 2011/2012, participated in a home heating case study. Thermostat set point data was also collected from participant's households. A home heating expert was interviewed using the same method, for comparison. **Results and discussion:** Key variations in MMs of home heating were found. The differences in user MMs from each other, and an expert, were insightful in explaining non-optimal home heating operation. These suggest design solutions that could promote or compensate for user mental models to influence energy consumption.

KEYWORDS

Mental models; Design; Behaviour change; Domestic energy consumption; Home heating

INTRODUCTION

User behaviour with home heating systems, contributes to climate change

The U.K. has legislated to cut carbon emissions by 80% by 2050 (*Climate Change Act 2008*) with 25% of total UK carbon emissions from domestic customers. Lutzenhiser and Bender (2008) report that variations in domestic energy use are due to the behavioural differences of householders. Home heating accounts for over 25% of domestic energy use in the UK (Department of Energy and Climate Change, 2012). This research focuses on how the concept of mental models (MMs) can be applied in design to elicit behaviour change to reduce domestic heating use.

Mental models research could inform behaviour change strategies

Mental models are thought to be representations of the physical world (Johnson-Laird, 1983; Rasmussen, 198, Veldhuyzen & Stassen, 1976), constructs that can explain human behaviour (Kempton, 1986; Wickens, 1984) and internal mechanisms allowing users to understand, explain, operate and predict the states of systems (Craik, 1943; Gentner & Stevens, 1983; Hanisch et al. 1991; Kieras and Bovair, 1984; Rouse and Morris, 1986) The notion of mental models has been used in design for the development of interfaces (Carroll & Olson, 1987; Norman, 2002; Jenkins et al., 2010; Williges, 1987), to promote usability (Mack and Sharples, 2009; Norman 2002) and in the human factors domain, to enhance performance (Bourbousson et al., 2011; Grote et al., 2010; Stanton & Baber, 2008; Stanton & Young, 2005) and reduce error (Moray 1990a, Stanton & Baber, 2008).

Kempton (1986) proposed that different patterns of behaviour when operating a home heating thermostat result from the user holding different mental models of how the heating system works. This association is yet to be proven, and may no longer be relevant. Kempton (1986) identified two typical types of mental models of home heating. These represented common elements found in his participants' individual 'mental models' (this is distinct from concepts such as 'team' or 'shared' mental models) . The 'valve' model considered the thermostat like a gas valve. The 'feedback' model recognized the thermostat as an automatic switch based on temperature, without considering the thermodynamics of the dwelling. Kempton (1986) proposed specific behaviour characteristic evident in householders with a 'valve theory', may result in lower consumption than those with a 'feedback theory'. Further 'typical' models of the home heating thermostat have been offered by Norman (1988), and Peffer et al. (2011) who describe 'timer' and 'on/off switch' models respectively. Understanding the cause of user mental models of home heating, and their effect on behaviour, offers a novel approach to influencing domestic energy consuming behaviour, to help combat climate change.

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Contributions to mental model methods and specific insights into domestic heating domain

A comprehensive literature review identified that consideration of bias in methods of access, description and analysis of mental models, is essential for practical application of the notion (Bainbridge, 1992; Revell & Stanton, 2012; Rouse & Morris, 1986; Wilson & Rutherford, 1989). A generic framework for considering bias in the research of knowledge structures was developed. This framework informed the development of methods to capture and analyse user's mental models and behaviour with home heating systems. Insights into the specific context of domestic home heating behaviour are expected by exploring the link to mental models, heating system design and domestic energy consumption. Application of these insights in design strategies will also contribute to the field.

METHODOLOGY & RESEARCH UNDERTAKEN

Development of the Quick Association Check

A quick, inexpensive, method for exploring association between users mental models of home heating systems, and their behaviour, was sought. The Quick Association Check (QuACk) is a structured interview method which includes activities and templates to produces verified outputs ready for analysis. Examples of the key outputs from QuACk, describing a user mental model, a self-report of user behaviour, are shown in figures 1 and 2.

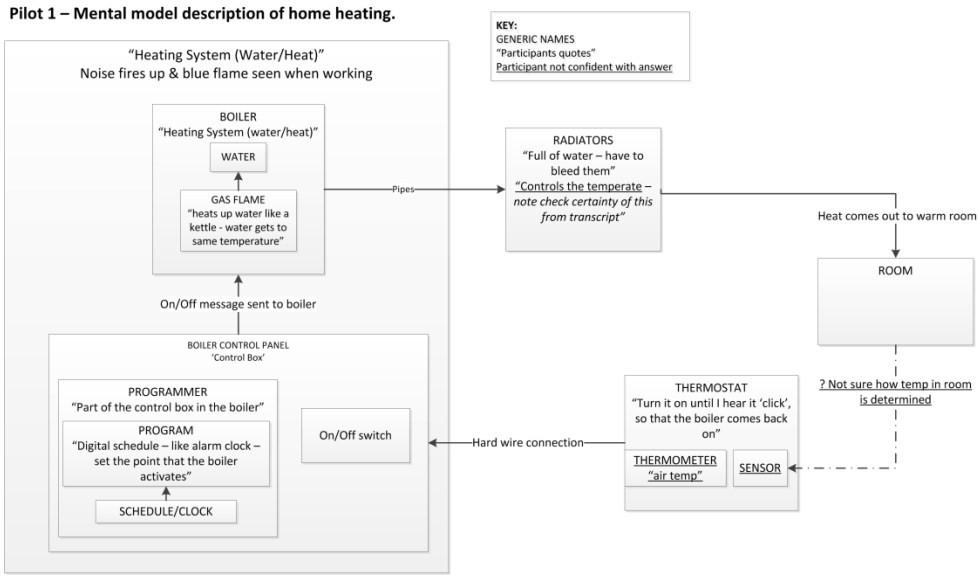

Figure 14. Mental model descripton of home heating from QuACK

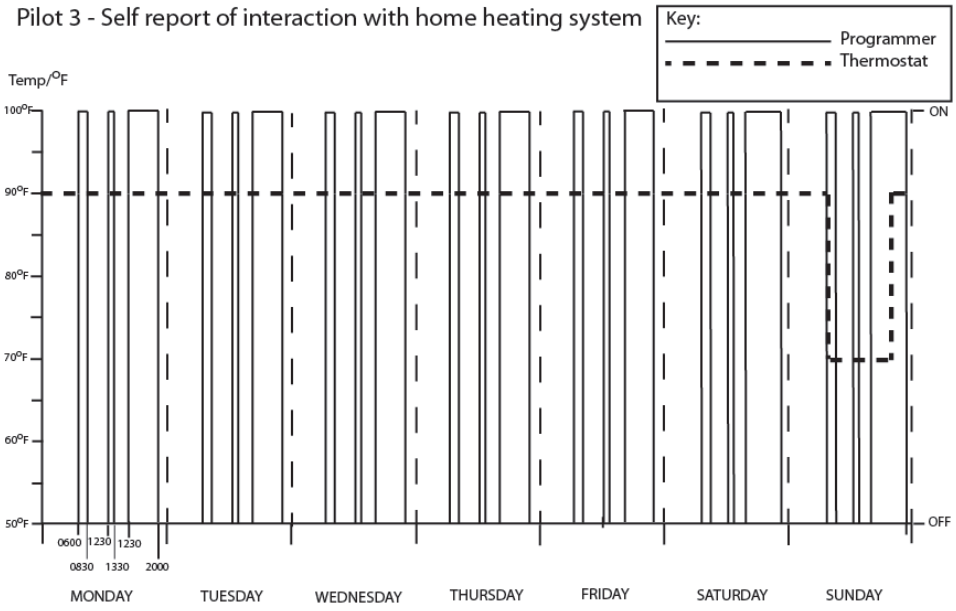

Figure 15. Self report of home heating interaction from QuACK

The development of the QuACk was undertaken systematically (see figure 3). This approachcould benefit researchers exploring the association between mental model and behaviour in other contexts and domains.

Hancock and Szalma (2004) emphasised the need to embrace and integrate qualitative methods in ergonomics research. QuACk was therefore developed using case studies and participant observation to provide rich feedback, that drove iterative developments to the prototype.

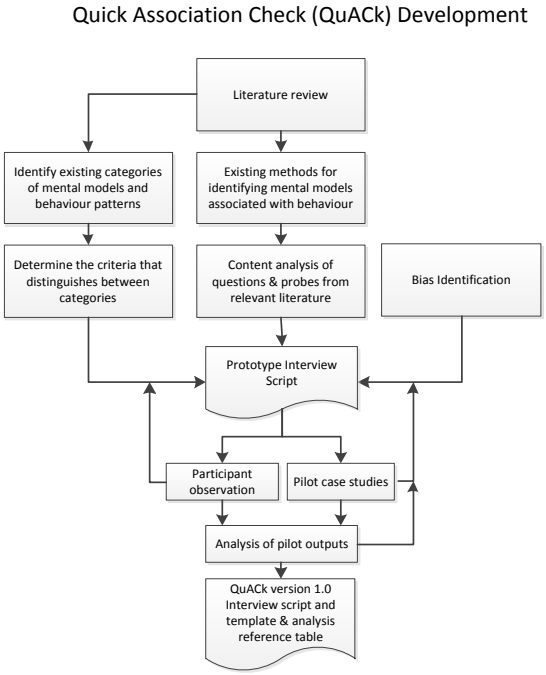

Figure 16. The stages of development of the Quick Association Check (QuACk)

Conducting a naturalistic case study of home heating

The QuACk method was applied to a case study comprised of non-randomly selected, postgraduate students with families, new to the UK and residing in semi-detached university owned accommodation. Accommodation, heating devices and insulation levels were matched, so variations in mental model descriptions could be attributed to characteristics of the participant, rather than the environment. Interviews with 6 participants from 5 households were undertaken. The impetus for this case study, was to seek evidence of the 4 typical mental models described in the literature, and explore association with user behaviour patterns.

Capturing an expert mental model of home heating, to inform design specifications

Norman (1986) described how problems users have interacting with devices was caused by the 'gulf of execution and evaluation'. He attributes this gulf to differences between a device's 'design model' and the 'user's model' of the device. To capture a representation of the 'design model' of home heating, an expert from the heating control manufacturer who provided the devices for the naturalistic study was interviewed using QuACK. This provided verified outputs in the same format as the case study data, allowing us to gain insights into the differences between the expected and actual way householders think and interact with their heating system. These insights are key to inform the development of design specification intended to promote appropriate behaviour through better user mental models.

RESULTS & DISCUSSION

Mental models research should view domestic settings as complex systems

Different types of mental models were identified from the naturalistic case study, showing that people view the home heating system in quite different ways. Switch and feedback mental model types were useful for categorizing the thermostat, and all types identified in the literature helped to categorize other heating controls. A range of different strategies for using the system were reported, as well as differences in users' goals, the number of people who operated the heating system, and the control devices favoured. The interplay of the thermodynamics of participants' houses and responsiveness of the heating system installed, also coloured householders' mental models and behaviour choices. The impact of these variables on user behaviour emphasised the need to consider the household as a complex, sociotechnical, dynamic setting.

Key differences in expected and actual use of home heating systems

Comparisons of the 'design model' derived from an expert in home heating, and 'user's models', concluded that householders need assistance to bridge Norman's (1986) gulf of execution and evaluation. The role of control devices and the way they interact varied in user mental models. Some participants with an appropriate mental

model at the system level, but inappropriate mental model at the control level reported non-optimal behaviour. The usability of control devices (e.g. programmer), also affected the choice of control when adjusting comfort levels. These findings provide direction to design specifications targeted at promoting appropriate mental models at both the system and device level.

CONCLUSION

The 1986 study by Kempton, inspired the focus of this research. Our research has built on this by; a) devising a systematic generic method for exploring association between mental models and behaviour, b) gaining an understanding of the way domestic home heating behaviour is linked to mental models of the heating system, and, c) comparing user mental models to an expert model to identify the gap in expected and reported thinking and behaviour. Further work will be investigating home heating control as a complex system, involving goals, strategies and considering device usability. The insights gained from this research will help inform approaches to design that aim to reduce energy consuming behaviour in the home, as a novel approach to help combat climate change.

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