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

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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 focusses on how the concept of mental models 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 the design for the development of interfaces (Carroll & Olson, 1987; Norman, 2002; Jenkins et al., 2010; Williges, 1987) to promote usability (Jenkins et al., 2011; 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, Rafferty et al., 2010; 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 it is possible the mental models and behaviour patterns found in Kempton's (1986) study may have been specific to that period in history (with associated heating technology) and sample group (Michigan, US, middle class householders). 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) . He identified a 'valve' shared theory, that considered the thermostat worked like a gas valve, and a 'feedback' shared theory, that recognized the thermostat working like an 'automatic switch' based on temperature sensing. The feedback theory is a simplified version of the actual workings of the thermostat, but does not consider the thermodynamics of the dwelling. Kempton (1986) proposed that night set back, a specific behaviour characteristics evident in householders with a 'valve theory', may result in lower consumption than those with a more accurate 'feedback theory'. Since Kempton's (1986) study, further 'typical' models of the home heating thermostat have been offered by Norman (1988), who described a 'timer' model, and Peffer et al (2011), who refers to a 'on/off switch' model. 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.

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

A comprehensive literature review identified that for the notion of mental models to have utility in design and behaviour change, consideration of bias in methods of access, description and analysis of mental models is essential (Bainbridge, 1992; Revell & Stanton, 2012; Richardson & Ball, 2009; 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. These resulting methods could also be applied to other domains. Insights into the specific context of domestic home heating behaviour are expected by exploring links to user mental models, the design of heating systems and resultant energy consumption. A means of conducting research into the mental models of householders, and applying the insights 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) it 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.

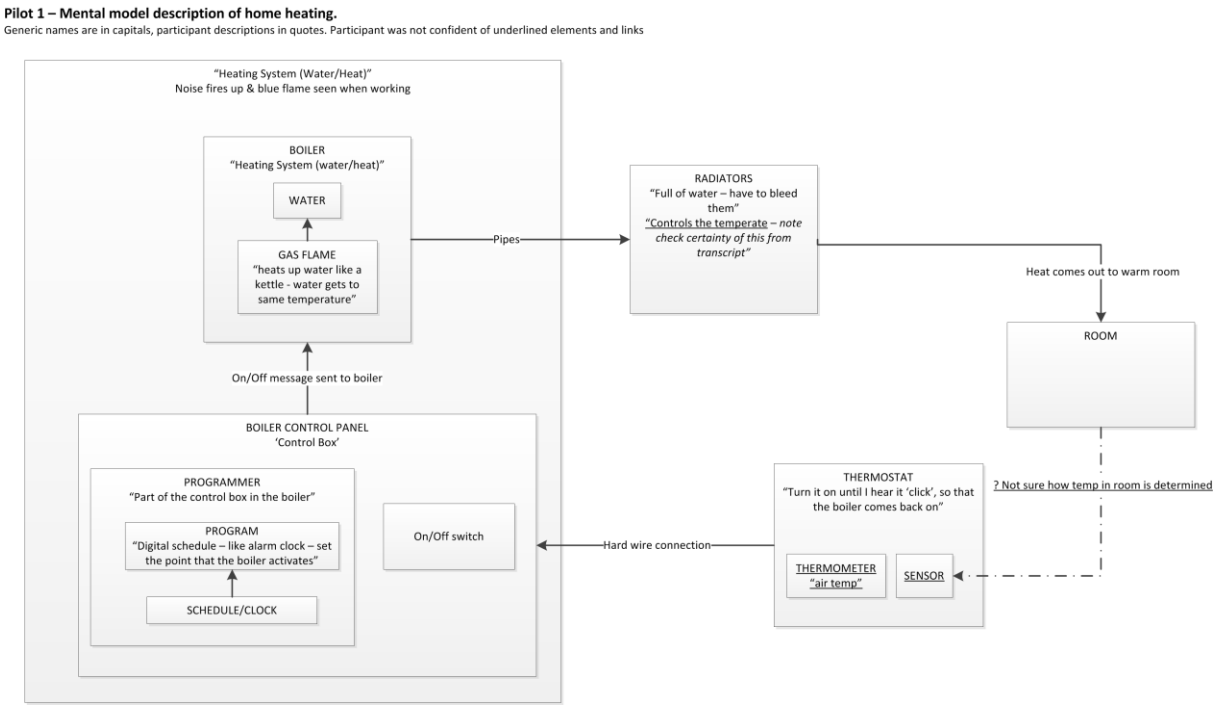

Figure 1 - Example of output from QuACK representing participants mental model description

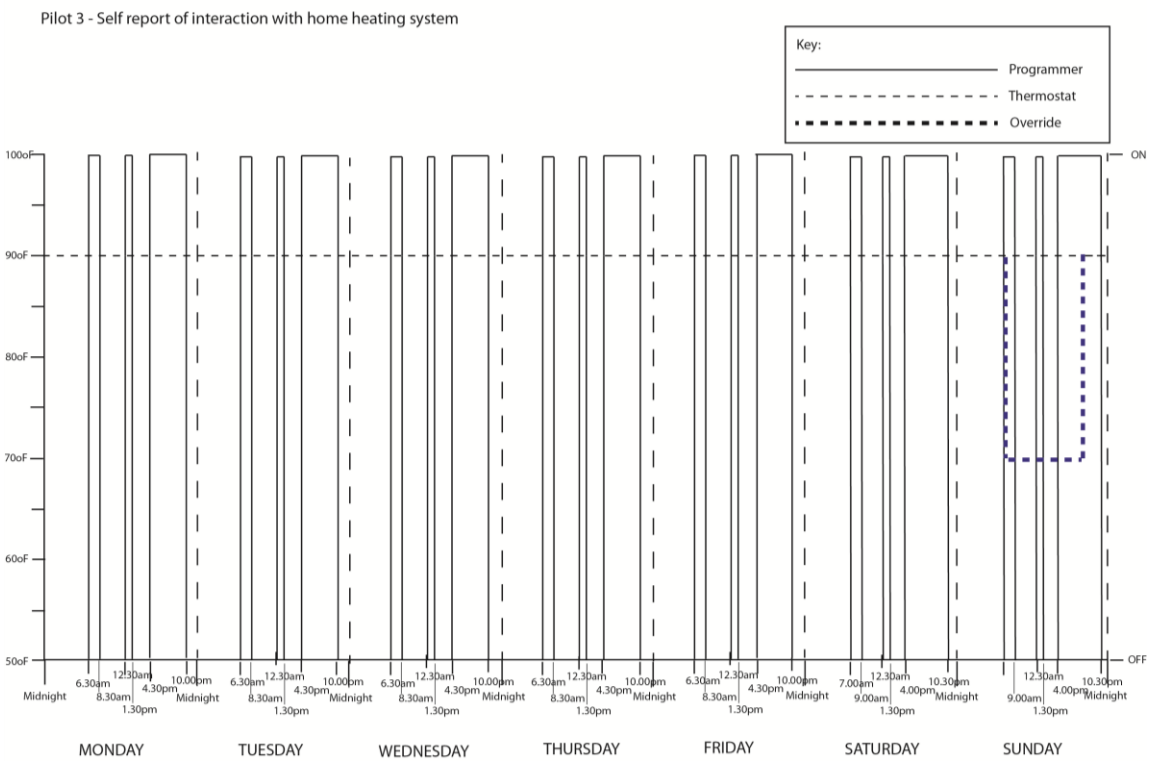

Figure 2 - Example of output form QuACK - Self report of home heating interaction

The development of the QuACk was undertaken systematically, as shown in figure 3. This approach, the authors beleive, could 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. In response, QuACk was developed using case studies and participant observation as methods that provide rich feedback. This feedback was used to drive iterative developments to the prototype.

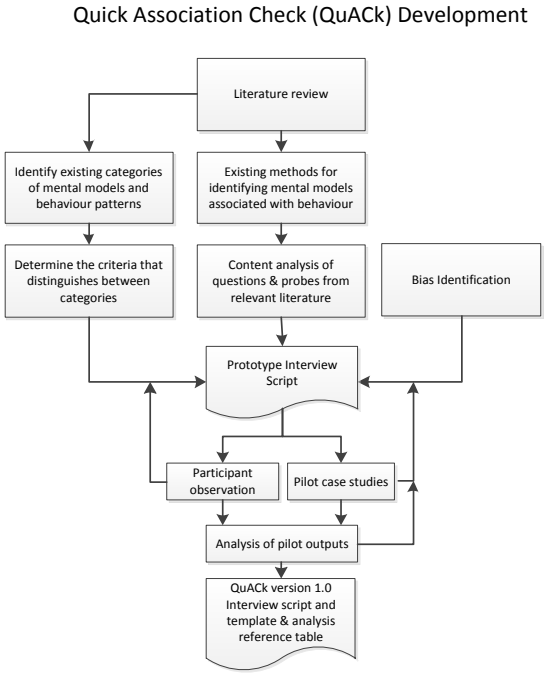

Figure 3 - The stages of development of the QUick Association ChecK (QuACk)

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. These families were new to the UK, and resided in semi-detached university owned

accommodation. The accommodation, home heating devices and levels of insulation were matched, so that variations in mental model descriptions could be attributed to characteristics of the participant, rather than the environment. Interviews with 6 participant 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 behaviour patterns resulting from user interactions with their heating system.

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

Norman (1986) described how problems with the way users interact with devices can be due to the 'gulf of execution and evaluation'. Norman attributes a differences between the devices '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 company who manufactures the heating controls in the naturalistic study was interviewed using the QuACK method. This provided verified outputs in the same format as the case study data. The intention was to gain insights into the differences between how the heating system is expected to be thought about and used, and the actual way householders think and interact with their system. These insights are then to be used to develop design specifications to help promote appropriate mental models and related behaviour.

Conducting automated data collection to seek Kempton's (1986) thermostat behaviour patterns

Kempton (1986) analysed data of thermostat set point patterns collected from a different sample than those he interviewed. To make a direct comparison between users' mental models of home heating, and their actual (as opposed to self-reported) behaviour, set point data was sought from the households that made up the naturalistic case study. Data was remotely collected at 5 minute intervals, between October 2011 and March 2012 from 6 households, varying in duration between 1 and 4 months. Data was initially analysed blind, in weekly units, to objectively categorize behaviour patterns. Set point data was then linked to households to determine behaviour consistency, and to predict association with valve or feedback mental models.

RESULTS & DISCUSSION

Mental models research benefits from viewing the domestic setting as a complex system

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 were helped to categorize other heating control devices. In terms of self-reported behaviour, 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 choices when using the system. The impact of these other 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' highlighted that users could benefit from assistance in bridging Norman's (1986) gulf of execution and evaluation. The role of control devices and the way they interact varied in user mental models. Those participants with an appropriate mental model at a system level, to the 'design model', were found to interact less optimally with their system due to usability issues, or less appropriate mental models of control devices. These influences, and variations from the design model, provide direction to design specifications targeted at promoting appropriate mental models at both the system and device level.

Insights into mental models cannot be gained from thermostat set point patterns alone

A range of thermostat patterns were identified, when analysed blind. These included patterns associated with Kempton's (1986) feedback model, and a more regular version of pattern proposed to result from a valve model was seen. Additional patterns, were also found, that could not be interpreted in line with Kempton's (1986). When data was matched to households, some behaviour patterns persisted, others varied considerably. Those that persisted had minimal or no thermostat adjustments, which proved ambiguous when attempting to determine the source model. It could be concluded that households with varying behaviour patterns favoured the thermostat as a key heating control. The overriding model directing behaviour, was not clear, from this data set alone, however.

CONCLUSION

The 1986 study by Kempton, inspired the focus of this research. From the research so far, it is clear that the way people think about and use their home heating system varies considerably. Insights into these differences have highlighted that we need to look beyond set point adjustment, to identify and mitigate non-optimal behaviour. The valve and feedback mental model categories identified by Kempton (1986) were a useful starting point to understand the way users misunderstand the devices in the home. Comparing user's models to that of a home heating expert, identified differences not only in behaviour and understanding, but also expectations. Considering the domestic setting as a complex, dynamic, sociotechnical system would allow a richer understanding of where mental models can contribute when trying to understand why people behaviour the way they do. This provides the potential to inform, guide, influence or mitigate their behaviour, to reduce energy consumption in the home.

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REFERENCES

Bainbridge, L. (1992). Mental Models in Cognitive Skill: The Example of Industrial Process Operation. In Y. Rogers, A. Rutherford & P. A. Bibby (Eds.), Models in the mind : theory, perspective and applications (pp. 111). London: Academic Press.

Bourbousson, J., Poizat, G., Saury, J., & Seve, C. (2011). Description of dynamic shared knowledge: an exploratory study during a competitive team sports interaction. Ergonomics, 54(2), 120-138.

Carroll, J. M., & Olson, J. (Eds.). (1987). Mental models in human-computer interaction: Research issues about what the user of software knows. Washington, DC: National Academy Press.

Climate Change Act 2008. Retrieved 10th November, 2011, from http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx

Craik, K. J. W. (1943). The nature of explanation. Cambridge, England: Cambridge University Press.

Grote, G., Kolbe, M., Zala-Mezö, E., Bienefeld-Seall, N., & Künzle, B. (2010). Adaptive coordination and heedfulness make better cockpit crews. Ergonomics, 53(2), 211-228.

Hancock, P. A., & Szalma, J. L. (2004). On the relevance of qualitative methods for ergonomics. Theoretical Issues in Ergonomic Science, 5(6), 499 - 506.

Hanisch, K. A., Kramer, A. F., & Hulin, C. L. (1991). Cognitive representations, control, and understanding of complex systems: a field study focusing on components of users' mental models and expert/novice differences. Ergonomics, 34(8), 1129 - 1145.

Jenkins, D. P., Salmon, P. M., Stanton, N. A., & Walker, G. H. (2010). A new approach for designing cognitive artefacts to support disaster management. Ergonomics, 53(5), 617-635.

Jenkins, D. P., Salmon, P. M., Stanton, N. A., Walker, G. H., & Rafferty, L. (2011). What could they have been thinking? How sociotechnical system design influences cognition: a case study of the Stockwell shooting. Ergonomics, 54(2), 103-119.

Johnson-Laird, P. N. (1983). Mental models: towards a cognitive science of language, inference and consciousness Cambridge, UK: Cambridge University Press.

Kempton, W. (1986). Two Theories of Home Heat Control. Cognitive Science, 10, 75-90.

Kieras, D. E., & Bovair, S. (1984). The Role of a Mental Model in Learning to Operate a Device. Cognitive Science, 8(3), 255-273.

Lutzenhiser, L. a. S., & Bender, S. (2008). The average American unmasked: Social structure and difference in household energy use and carbon emissions.: ACEEE Summer Study on Energy Efficiency in Buildings.

Mack, Z., & Sharples, S. (2009). The importance of usability in product choice: A mobile phone case study. Ergonomics, 52(12), 1514-1528.

Mental models in human computer, i., Caroll, J. M., & Olson, J. R. (1987). Mental models in human computer interaction : research issues about what the user of software knows : Workshop on software human factors : users' mental models : Papers: [np].

Moray, N. (1990). Designing for transportation safety in the light of perception, attention, and mental models. Ergonomics, 33(10), 1201-1213.

Norman, D. A. (2002). The Design of Everyday Things. New York: Basic Books.

Peffer, T., Pritoni, M., Meier, A., Aragon, C., & Perry, D. (2011). How people use thermostats in homes: A review. Building and Environment, 46, 2529 - 2541.

Rafferty, L. A., Stanton, N. A., & Walker, G. H. (2010). The famous five factors in teamwork: a case study of fratricide. Ergonomics, 53(10), 1187-1204.

Rasmussen, J. (1983). Skill rules and knowledge; signals signs and symbols; and other distinctions in human performance models. IEEE Transactions on Systems, Man and Cybernetics, 13(3), 257-266.

Rasmussen, J., & Rouse, W. B. (Eds.). (1981). Human detection and diagnosis of system failures. New Yourk: Plenum Press.

Revell, K. M. A., & Stanton, N. A. (2012). Models of models: filtering and bias rings in depiction of knowledge structures and their implications for design. Ergonomics, 55(9), 1073-1092.

Richardson, M., & Ball, L. J. (2009). Internal Representations, External Representations and Ergonomics: Toward a Theoretical Integration. Theoretical Issues in Ergonomics Science, 10(4), 335-376.

Rouse, W. B., & Morris, N. M. (1986). On Looking Into the Black Box: Prospects and Limits in the Search for Mental Models. Psychological Bulletin, 100(3), 349-365.

Stanton, N. A., & Baber, C. (2008). Modelling of human alarm handling response times: a case study of the Ladbroke Grove rail accident in the UK. Ergonomics, 51(4), 423-440.

Stanton, N. A., Young, M., & McCaulder, B. (1997). Drive-by-wire: The case of driver workload and reclaiming control with adaptive cruise control. Safety Science, 27(2-3), 149-159.

Stanton, N. A., & Young, M. S. (2005). Driver behaviour with adaptive cruise control. Ergonomics, 48(10), 1294-1313.

Veldhuyzen, W., & Stassen, H. G. (Eds.). (1976). The internal model: What does it mean in human control? New York: Plenum.

Wickens, C. D. (1984). Engineering psychology and human performance. London: Merrill.

Williges, R. C. (1987). The Society's Lecture 1987 The Use of Models in Human-Computer Interface Design. Ergonomics, 30(3), 491-502.