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ENABLING SUSTAINABLE USER INTERACTION WITH DOMESTIC HEATING CONTROLS

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The way we live greatly effects the carbon emissions of our homes; heating accounts for nearly 60% of domestic energy consumption in the UK. This consumption is directly influenced by occupants through the use of their control systems. Using real-world data from buildings and observational data from users this research proposes guidelines for the design of more inclusive domestic heating controls. Two user-centred studies have been completed to date; one using controls under lab conditions and the other in a low-carbon housing development. In both studies controls were found to exclude users due to the cognitive demands placed on them, therefore creating an unnecessary barrier to reducing heat energy consumption in the home. The design principles proposed aim to help designers consider user needs when designing the interfaces of heating controls and energy management systems. By designing more inclusive and usable controls considerable energy savings could be made in the domestic context.

Keywords: *user behaviour, inclusive design, heating controls, domestic buildings, design guidelines.*

1 Introduction

The poor design of domestic heating controls can not only exclude users from using the product successfully but could result in excess energy consumption. Currently the emissions of our homes in the UK account for over a quarter of all carbon dioxide emissions (Boardman, 2007). Of this, 60% comes from emissions relating to space heating which users have a direct influence over through their control systems. Improved efficiency of both the building fabric and the heating system can help reduce heat consumption. However, designing a building in a sustainable manner does not ensure it will perform as expected as energy

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consumption is heavily influenced by the behaviour of the building's occupants (Derijcke & Uitzinger 2006). Gill et al. (2010) found a variance of 51% in heat consumption at a low-carbon housing development due to the occupant's behaviour. One contributing factor to these emissions is the trend of increasing average internal temperatures from 13^{o}C in 1970 to 18^{o}C in 2000 (Department of Trade and Industry, 2008). Partially this variance may be to do with the complexity of the heating control system; a study on the same low-carbon site found 66% of users could not program their controls to an example heating schedule (Combe et al., 2010). Although nearly a third of homes in the US have programmable thermostats 44% of people with this level of control do not reduce the temperature of their home when they are away during the day, wasting a significant amount of energy (Gupta, Intille & Larson, 2009). Moon & Han (2011) found that reducing the heating system set back temperature overnight had the greatest impact on energy consumption. For each ^{o}C increase in temperature there was an increase of 520 kWh in energy consumption annually for the typical building modelled (Moon & Han, 2011).

Informing users of their resource usage has proven successful in reducing consumption. The use of indirect feedback in reducing energy consumption has been linked to savings of around 10% (Wilhite and Ling, 1995 cited in Darby, 2008) whilst improved billing and direct feedback, resulted in greater reductions of up to 15% (Darby, 2008). Predictive feedback displays were found to led to improved ecological performance over any other display types as they help lower working memory load by reducing the need to plan in advance (Sauer, Wastel & Schmeink, 2009). Sustaining these changes in behaviour can be difficult, although initial energy savings of 7.8% were reported by van Dam, Bakker and van Hal (2010) the savings were not maintained in the medium to long-term. The initial trail lasted four months after which savings were not maintained despite users developing habits to check their energy monitors regularly during the trial (total length 15-months: van Dam, Bakker & van Hal, 2010).

To help users sustain reductions in energy consumption the influence other people have on our behaviours should be considered as it has a powerful effect on behaviour (Nolan et al., 2008). Schultz et al. (2006) showed by utilising the power of the social norm reductions in domestic electrical energy consumption could be made. Their study showed that giving comparative feedback meant highest consuming users reduced their consumption but also that lowest consumers could be encouraged to remain low by providing positive reinforcement (Schultz et al., 2006). Combining personal and comparative feedback may help to sustain the reductions in energy consumption in the medium to long term.

The literature comprehensively suggests that the feedback, comparison and advice given to users undoubtedly plays a role in reducing domestic energy consumption. However if the user is unable to act upon the information provided due to the complexity of their control systems then reductions may not be achieved. Simpler, more useable control systems could provide a double-dividend of greater thermal comfort and reduced energy consumption according to Bordass & Leaman (2001). The results, observations and insights gained through this research provide the basis for the design principles for energy management systems. By designing more inclusive and usable heating controls could enable users to make energy savings the domestic context.

2 Research Methods

A combination of research methods have been used in the research to date, these include; observations, usability testing and exclusion calculations. In human factors research observations are extensively used to gather information regarding physical or verbal aspects of a task (Stanton et al., 2005). These are most commonly direct and structured observations where the participants know they are being observed (Stanton et al., 2005). This may mean the observations are subject to the reactivity of participants and compromise their completeness (Robson, 2002). However, Robson (2002) argues that formal, structured observations can provide higher validity and reliability than informal approaches and is a way of quantifying user behaviour.

The study process described by Stanton et al. (2005) involves the observation design stage, the observation application stage and the data analysis stage. In the design stage defining the scenario is particularly important, therefore users were observed completing a typical yet specific programming task using a variety of control types. This task was consistent across the user groups and different control types to allow the comparison of results. The data elicited from users came from observing their interaction with controls both within the home and in the lab. In the field study users were observed using the controls installed in their homes which they had occupied for one year. In the laboratory setting two different user groups were observed using three types of controls with identical functionality. The comments users made both during and after attempting the task were audio recorded.

Observational research was used as a supportive method to exclusion calculations, a method used in the field of Inclusive Design. The Exclusion Calculator is a publicly available software tool used to estimate the number of people currently excluded by a product (http://www.inclusivedesigntoolkit.com). It considers how challenging each task is and rating it for each of the six capability demands (Goodman, Waller 2007). User capability is defined as “an individual’s level of functioning, along a given dimension from very high ability to extreme impairment, which has implications for the extent to which they can interact with products” (Johnson, Clarkson & Huppert, 2010). The capabilities assessed in the calculation are vision, hearing, dexterity, thinking, locomotion and reach & stretch. The level of demand required is correlated to the number of people who would find the task impossible due to a disability, giving an overall percentage of the population excluded.

The exclusion calculation highlights the areas of user exclusion and estimates the scale of this exclusion. Direct user involvement is strongly advised when trying to asses specific usability issues (Nielsen, 1993) and in this case when trying to understand the reasons for the user exclusion occurring. Involving users directly in the research requires consideration of ethical issues of observing users, hence the need for the participants to sign an informed consent form prior to completing the task. The laboratory based study included two age ranges of users, younger users (aged 24-44, n=14) and older users (aged 62-75, n=10).

3 Results

The Exclusion Calculations revealed the primary sources of user exclusion were the vision, dexterity and thinking demands of the heating controls. In the design of a more inclusive set of controls the demands placed on these capabilities should be reduced. The calculation results suggest a priority order for reducing the capability demands, which, from highest to lowest priority, should be; thinking, vision then dexterity. Furthermore, the exclusion calculator suggested that there would be higher frequency of exclusion amongst older users, which was confirmed in the observations (see Figure 1).

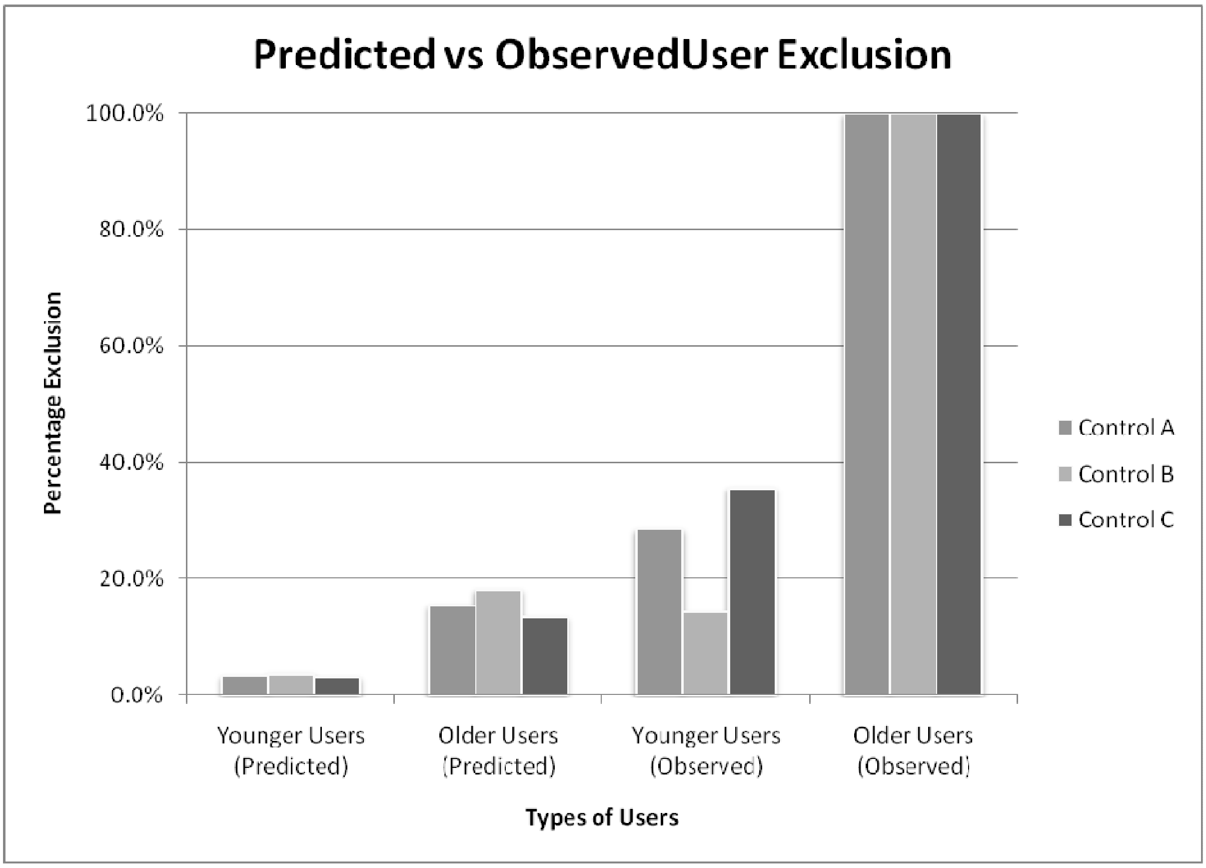

Figure 1: A comparison of predicted and observed user exclusion

Themes extracted from the analysis of the audio transcripts were overall system complexity, the lack of a confirm or enter button and the use of unfamiliar and inconsistent symbols between interfaces. This resulted in severe user frustration and some users being unable to complete the task successfully. The usability problems users' encountered are reported fully in the paper Combe et al. (2011). With one control in particular users commented on the high levels of dexterity required to use the system. Older users specifically commented on the size of the text on the interfaces and in the instruction manuals which caused them difficulties. A final theme was a lack of feedback from the systems of the settings entered. The frequency of the occurrence of the themes is shown in Figure 2.

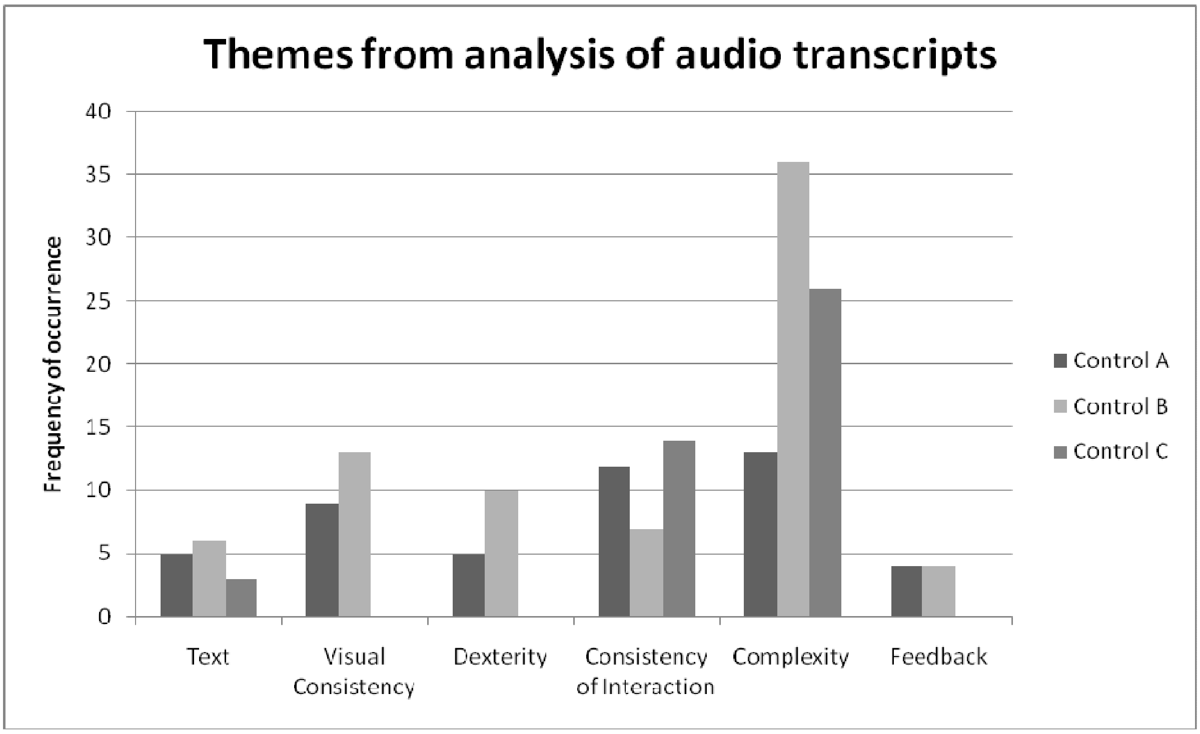

Figure 2: Frequency of theme occurrence from transcripts of observations

4 Research Outcomes

In order to help counter exclusion and reduce the demands placed upon users a set of design principles have been formulated based on the user observations. These consist of ten points relating to the three main areas of user exclusion; thinking, vision and dexterity. Six of the ten directly relate to the themes elicited from the observation data. The principles of advice and comparison are drawn from the literature review and could be incorporated into feedback provided by the system. Despite none of the current systems having audible feedback currently, incorporating this may help reduce the visual demand placed on users. Any audio features incorporated should be optional as not to irritate users and of variable volume.

The Principles for the Design of Energy Management Systems are:

- **Text** - consider the size of text, fonts and contrast between colours used to reduce visual demands.
- **Visual Consistency** - visual consistency, especially in the use of icons or symbols, between interfaces can reduce the load on the user

Audio - consider the provision of audio feedback to confirm settings as it would reduce reliance on the users' visual requirements and include a wider range of users.

- **Dexterity** - the size of any buttons should be suitable for use by people with limited dexterity. The force used to operate these buttons/controls should not exclude users. Feedback that a button press has been recognised could also assist users.
- **Consistency of Interaction** – using styles of interaction that are familiar to the user such as mobile phones, computers or ATM systems may help reduce cognitive and dexterity loads.
- **Complexity** - avoid unnecessary complexity of the interface wherever possible.
- **Feedback** - give the user feedback on the settings programmes, their energy consumption and positively reinforcement of energy reductions achieved. Ensure that any feedback provided is easy to understand, relevant and meaningful to the user.
- **Advice** - provide the user with some advice to help them change behaviour and nudge them in a more sustainable direction.
- **Comparison** - where possible relate their energy consumption to a peer group, such as a neighbourhood, to put their energy consumption in context.
- **Metrics** - keep the quantity of different numerical units to a minimum as not to intimidate or confuse the user.

5 Discussion and Conclusions

Future work on the design principles should include presentation as a meaningful and usable resource for designers. As Nickpour & Dong (2011) found when assessing a range of ergonomic tools, designers, as users of these tools, had a preference for less volume of text, more imagery and increased use of colour. Other key preferences elicited from those interviewed were simplicity and interactivity (Nickpour & Dong, 2011). With a similar target audience these design principles could be converted into a simple, interactive website to engage and encourage designer to apply them.

Tentative conclusions can be drawn that the application of the design principles would help reduce the high levels of user exclusion found through the use of current heating controls. These are initial design principles based on the observational research to date. The consideration of these design principles at the start of the design process may help the design of more usable and inclusive interfaces.

The application of these principles in the design of a heating control interface is the ultimate aim of the research. This interface would include heat energy consumption data consistent with the requirements of the UK smart meter rollout, which requires both heat and electricity energy consumption feedback. Although the application of the principles is thought have the double dividend of both a reduction in user exclusion and in the associated energy consumption, there is little substitute for involving users directly in the design process.

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