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MODELLING THE IMPACT OF USER BEHAVIOUR ON HEAT ENERGY CONSUMPTION

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Our behaviour in our homes can seriously affect the associated carbon dioxide (CO_2) emissions. In the UK, space-heating accounts for nearly 60% of domestic energy consumption and 27% of total CO_2 emissions come from our homes. Regrettably, low-energy building design does not guarantee low-energy performance. Controls systems, in particular heating controls, are often too complex for users to programme. This study uses real-world data from buildings, observational data from users and energy modelling to establish why people have difficulty using their control systems, and the potential resultant energy impacts.

Users were asked to programme an example heating profile for a week using three different control interfaces. Prior to attempting this task there was a preconception amongst users that they would be unable to complete it. Controls were found to exclude users due to the cognitive demands placed on them. A key observation was that five of the twenty-four users made a mistake in the programming process, which meant that the heating temperature was not reduced at the end of the heating period. This could potentially result in accidental heating throughout the day and night, unbeknown to the users.

Modelling this observation showed an increase in heating energy consumption of 14.5% compared to energy consumption associated with successfully programming the example heating profile. The modelling results showed that successful programming of the profile consumed less energy (in two of the three scenarios) than the default settings of the heating controls. Increasing the sense of perceived control users have over their environment may enable them to use less heat energy. By designing controls so that pro-environmental behaviour is, easily accomplished substantial energy savings could be made.

Keywords: *user behaviour, inclusive design, thermostats, housing, heat energy*

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1 Introduction

Occupant behaviour within homes can have a large impact on the associated carbon dioxide (CO_2) emissions. In the UK stringent reductions in CO_2 emissions are required by the Energy Act 2008 (Department of Energy and Climate Change, 2008), which demand an 80% reduction in emissions from 1990's levels by 2050. Currently housing contributes 27% of the UK's CO_2 emissions and 60% of these emissions come from space heating within homes (Boardman, 2007). If we are to achieve this deep decline in emissions then reducing the emissions associated with heating the home must be an imperative.

The amount of heat that homes consume depends on four factors; building fabric, outdoor temperature, indoor temperature and duration of heating. Two of these factors are controlled by the building occupants, highlighting the large impact users can have on their heat energy consumption. For example, heat energy consumption at one housing development varied by ±51% between homes (Gill et al. 2010). The importance of reducing the heating temperature has been highlighted by the Carbon Trust (2010) who suggest that reducing the temperature by 1^{o}C can result in energy savings of 8%. Relating this to carbon dioxide emissions, for every percentage increase of heating demand temperature there is a 1.55% rise in associated CO_2 emissions (Firth et al. cited in Shipworth et al., 2010). For each ^{o}C increase in temperature there was an increase of 520.2kWh in energy consumption annually (Moon & Han, 2011). They argued, "Unquestionably, proper thermostat setting would reduce energy consumption" (Moon & Han, 2011). Furthermore, Moon & Han (2011) highlighted that the largest reductions in energy consumption were correlated to reducing the night-time setback temperature.

Providing control over internal conditions (i.e. being able to open a window or adjust the heating) can increase occupant satisfaction with the building (Bordass & Leaman, 2001). Typically in the UK a domestic heating system will include a gas boiler, a central thermostat interface and thermostatic radiator valves (TRVs) at each radiator. This gives occupants control over how much heat energy is delivered, where in the house it is delivered, and when. If an occupant wishes to reduce their domestic consumption, their ability to do so will in a large part be dictated by the design of their heating control systems. However, these controls may be unnecessarily complex excluding users from operating them, especially older users (Combe et al. 2011a).

The usability issues of existing heating controls and programmable thermostats are well documented. The "Taking Control" report reviewed thermostat rating both visual and dexterity demands from one to five (Etchell et al., 2004). This report aimed to inform purchasing decisions, particularly amongst older users however did not assess the cognitive aspects of using the controls. The cognitive aspects of programming task was examined in Combe et al. (2011a) and was found to be extremely difficult for older users to complete. Meier et al. (2011) also found that time taken to complete a task using a similar programmable thermostat varied significantly between participants and not all participants were able to complete certain tasks. Furthermore, with the addition of new features thermostats are becoming increasingly complex which may increase barriers to effective use (Peffer et al. 2011).

Despite policymakers assuming that enhancing control of central heating will reduce heat energy consumption Shipworth et al. (2010) echoed by Meier et al. (2010) conclude that simply providing control does not reduce energy consumption. It is suggested that new controls should be developed which are “intuitively usable...and make it easy for householders to reduce their heating energy use” (Shipworth et al., 2010). The results discussed in this paper support calls for improved controls which enable effectively programmed to help occupants reduce their energy consumption. By making simpler, more useable control systems a double- dividend may be provided: greater thermal comfort and reduced energy consumption (Bordass & Leaman, 2001). Gupta, Intille & Larson (2009) agree that when programmed effectively controls can save substantial amounts of energy. Miller concurs that one of the best ways of reducing domestic energy consumption is encouraging proper use of heating controls by users (cited in Lomas et al. 2009). Simplification of these interfaces may encourage proper usage, in particular by focusing on levels of comfort rather than temperature (Gupta, Intille & Larson, 2009). Thus, control systems should to be designed such that “environmentally-preferred behaviour is also the most logical and easiest accomplished” (Derijcke & Uitzinger, 2006).

This study aims to estimate the scale of excess energy consumption of a particular user error identified previously. From the earlier user testing of controls (published in Combe et al. 2011a), it was observed that setting the on and off times for a period of heating was problematic for users. This confusion surrounding on/off times could have a negative impact on energy consumption in reality. When programming the control two of the three controls tested provide six intervals that can be programmed individually. Users frequently did not understand that the second fourth and sixth time periods are essentially the finish or off times, where the temperature should be reduced. Five of the users did not turn the temperature down at this point when using the Honeywell control (approximately 20% of the sample). This resulted in the controls being programmed to heating throughout the day at 19°C (66°F) and through the night to 21°C (70°F) unintentionally.

The study compares a variety of possible heating profiles and the associated heat energy consumption of a two-bed end of terrace house at a specific housing development. These homes were designed to be particularly well insulated and therefore should not require excessive heating. Furthermore using these homes allows for a particularly accurate model to be used as measured values can be used regarding the insultation properties of the building fabric and homes abilities to retain heat. The results have then been compared to the real-world thermostat settings and heat energy consumption of the dwellings on site. In reality this could result in accidental heating throughout the day and/or night, unbeknown to the users. The results present in this paper help suggest the scale of any energy savings possible by eliminating this particular user error. This could provide an estimate of the environmental impact eliminating this error may have and inform the design of future control systems. By removing this potential error or providing the user with feedback to avoid this scenario could enable efficient use of heating controls.

2 Developing the Model

Six possible scenarios were modelled in the Integrated Environment Solutions' (IES) Virtual Environment 6.0 software. The energy modelling was based on a two-bedroom end of terrace home at the Elmswell 'Clay Fields' development in Suffolk, designed by Buro Happold. Using an existing house as the model allowed the development of an accurate and realistic model, which is vital to elicit valid energy consumption results.

To allow comparison between the energy consumption of the different scenarios six heating profiles were modelled, all shown in figure 1:

- The default settings of the controls tested (Control A, B & C)
- The settings the participants were asked to programme as the exam heating profile (Task)
- The settings of the profile when the controls were not turned down at the end of the heating period (i.e. when the controls were left on through the day and night, Misuse)
- The default settings of the controls installed at the Elmswell development (Control D)

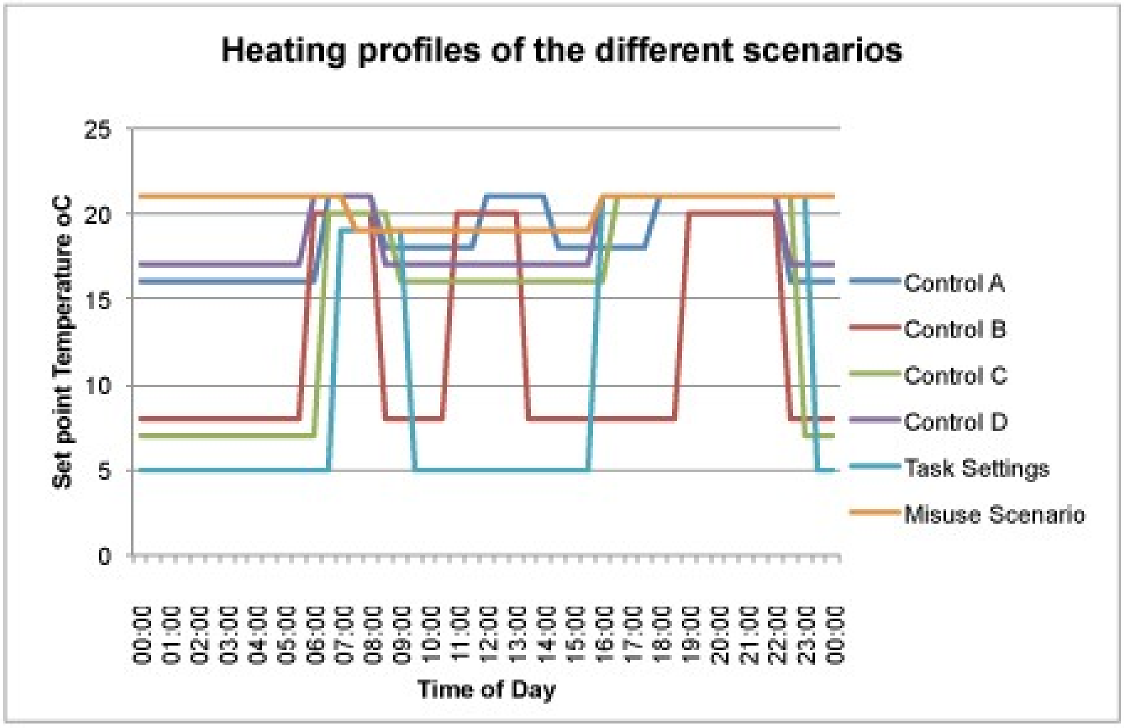

Figure 1. Heating profiles for the different scenarios modelled

The parameters in the model represent the actual building where the U-values have been measured in-situ. Such a property has an internal floor area of 69.1m^2 and a glazed area of 11.7m^2. This is consistent with the average size of a two-bedroom house from the CABE Dwelling Size Survey with a gross internal area of 69.2m^2 (Scott Wilson, 2010). The walls have a U-value of 0.25 W/m^{2}K performing better than the target U-value of 0.35 W/m^{2}K specified in the Building Regulations (2006). Similarly, the windows have a U-value of 1.4 W/m^{2}K with 2.2W/m^{2}K the requirement of the building regulations.

Occupancy is based on 25m^2 per person giving occupancy of 2.58 people per household, close to the average occupancy of 2.36 (National Statistics, 2011). It was assumed the house is unoccupied for the majority of the daytime when residents are at work. Air infiltration is kept constant at 0.168ach as it was the average measured on site post-construction. The simulation is then run for an entire year to establish the annual energy consumption of each profile in kilowatt-hours (kWh) and the results reported.

3 Energy Modelling Results

Firstly, the energy consumption of the default settings of the heating controls was compared to the task settings. These settings can then be compared to establish annual energy consumed in each scenario (shown in figure 2). Only the default settings of Control B were more efficient than the task set, this was due to an automatic set back temperature of 7^{o}C. Controls A & C consumed more energy annually than the task settings, therefore leaving those controls on the default setting is not the most energy efficient behaviour. In figure 2. Control D represents the actual heating control installed on site at the development.

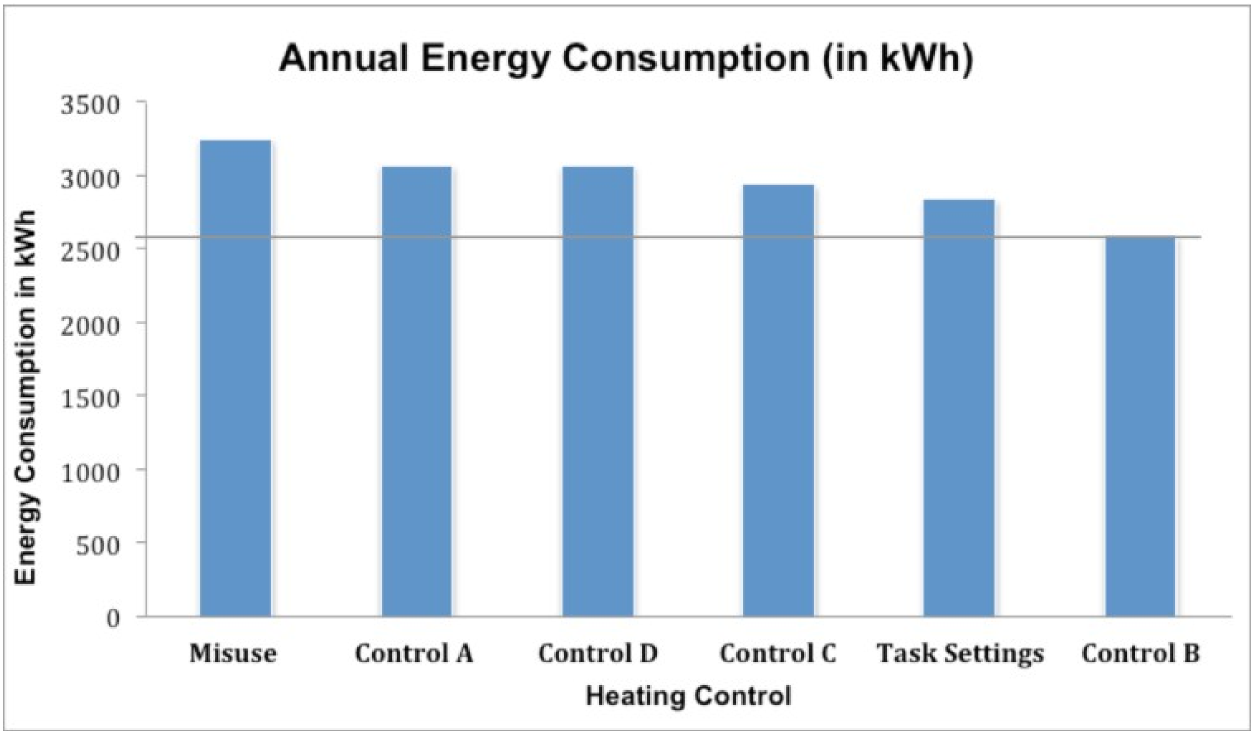

Figure 2. Annual energy consumption of the heating control settings

The second point of interest to research was modelling the excess energy consumption of the user error observed. By accidentally programming each of the controls to heat through the day and the night energy consumption was found to be 411.3 kWh higher annually than if the user completed the task successfully. This user error could theoretically result in an increase of 14.5% in heat energy consumption and the production of an extra 81.4kg of CO_2 emissions annually per household.

4 Comparisons with Real-World Data

To put the modelled results in context the recorded thermostat settings from the eleven houses studied at Elmswell were analysed. The initial modelling results suggest that the defaults of the controls available to users at the Elmswell development consume a comparable amount of energy annually to Control A on the default settings. Compared to the example profile settings the default settings of Control D have an energy consumption of 8% higher annually.

However, it is unlikely that the default setting will be used outside of the lab conditions and in the initial study at the Elmswell 'Clay Fields' development only one of the eleven houses used the default settings of the controls. The thermostat setting recorded during the initial study (Combe et al. 2011b) indicated that five of the eleven surveyed heated their homes at 20^{o}C or above through the night (after 2300 hours).

As is consistent with the modelling of the misuse scenario, the real world data indicates that the houses heated during the night had higher annual heat energy consumption. The data shown in figure 3 shows actual on-site energy consumption for heating and hot water. The modelling can be tentatively verified as those who heat through the night appear predominantly at the right hand side of the graph, shown as red bars. However, it is unclear at this stage if other factors such as work patterns or user preference may be responsible for this night-time heating. It would be wrong to assume that usability issues of the control system are fully responsible for this excessive heating, however it may be a contributing factor.

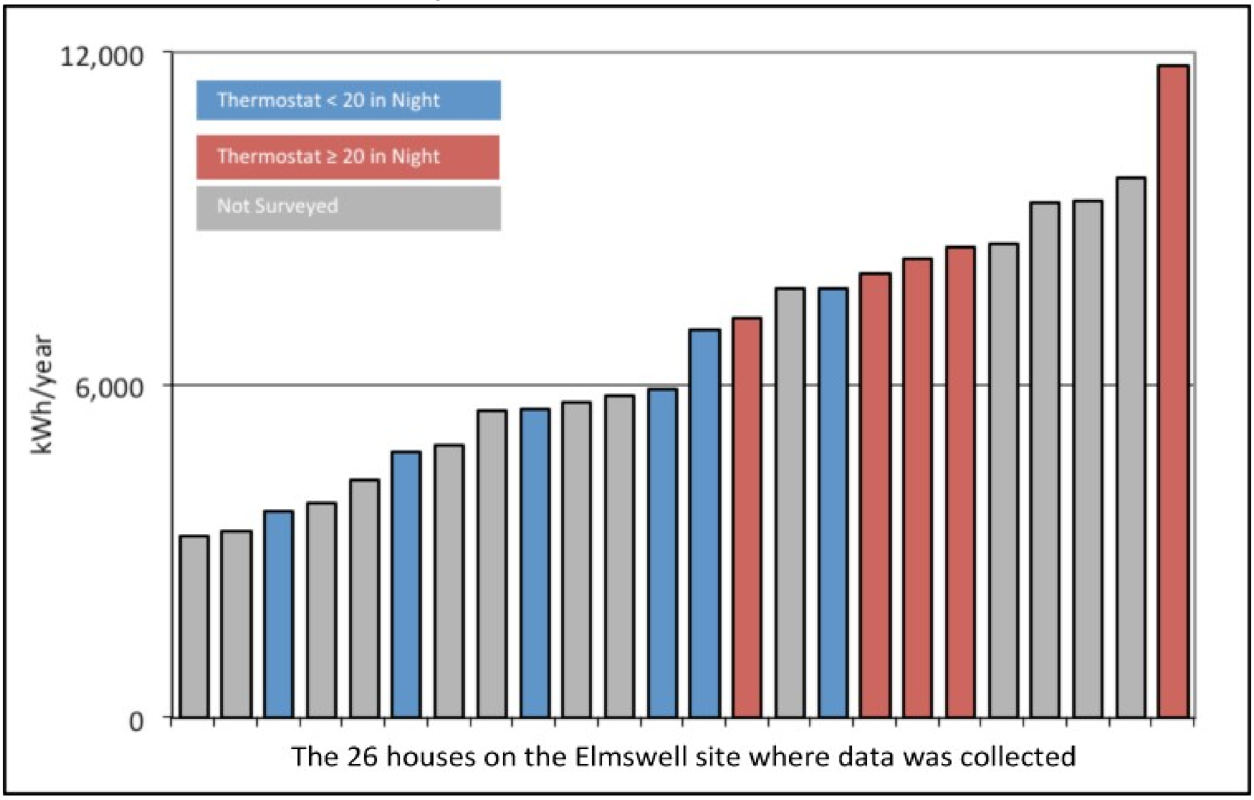

Figure 3. Actual heating and hot water energy consumption of the homes (Zack Gill, personal communication 2011)

5 Conclusions

The energy modelling demonstrates that the user error observed can result in increased energy consumption. Relating the energy modelling to the recorded thermostat settings indicate that the issues observed in the user testing may translate to real-world behaviours. The actual energy consumption goes some way towards verifying that the houses that heated through the night did in reality consume more energy.

The study is limited to the behaviour observed in the 24 participants of the user testing and again at the 11 dwellings surveyed on site. Therefore, the conclusions can only be tentative due to the small sample sizes of the two groups. Future work should examine other building types, constructions and model a larger number of homes. The type of building, fabric efficiency, occupancy and local climate will all influence the scale of the savings achievable.

However, the fact that savings could be made at the Elmswell ‘Clay Fields’ development, in what are particularly well insulated homes, through proper programming of controls is encouraging. The default settings in any future control system should be carefully selected as the default set back temperature has been shown to have a considerable impact on the associated energy consumption. The verification of the modelled results adds credibility to the observed behaviours in the user testing. If periods of unintentional heating could be eliminated through the improved design of controls then the energy savings made could be considerable.

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