Reducing User Influence On Energy Consumption Through Improved Building And Control Design

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ABSTRACT

Considerations of energy and CO₂ abatement by building designers currently focus heavily on compliance with Part L Building Regulations and rarely concern actual operational performance. Without this necessary focus, designs frequently fail to meet expectations in terms of in-use energy and the associated CO₂ emissions. In some cases this may be due to factors such as poor build quality or poor initial design assumptions; however, the behaviour of the building occupants is a critical factor in all cases. Current efforts to reduce this performance gap focus on the assumption that by providing information to occupants about their undesirable behaviour they will act rationally to reduce their energy usage. However, people’s attitudes and behaviours do not always coincide and, although this method may serve to raise awareness, addressing only this one aspect of human cognitive processing may merely result in short term and relatively small energy savings.

Dual-process models of cognition posit two modes of cognitive processing and behavioural control. One is conscious and deliberate and targeting interventions towards this system will improve knowledge and attitudes towards energy consumption. The other is unconscious and automatic. Targeting interventions towards this system should encourage energy efficient behaviour in situations where attention is not consciously focussed upon energy-saving.

This paper explores the potential of targeting the two different aspects of cognitive processing to influence building users into displaying energy efficient behaviour. It concentrates on incorporating these techniques into the design of building services and their control systems. It concludes that cognitive errors during user interaction with buildings can be responsible for inadvertent energy use, but corrective interventions for these need to be specifically targeted at the cognitive system from which they result. At present the provision of information is used for this purpose and while this may correct some errors it will not remove them all.

Keywords: Occupant behaviour, energy efficiency in buildings, building controls, user-centred design.

1. Introduction

Following global concerns over climate change the UK government has committed to an 80% reduction in CO₂ emissions by 2050, in relation to a 1990 baseline. As buildings are
responsible for as much as 50% of total UK CO₂ emissions (BIS, 2010) they represent an area where substantial reductions will need to be made if these targets are to be met. As a key element of the government’s strategy to achieve this target, recent alterations to Part L Building Regulations impose far stricter limits on estimated regulated CO₂ emissions. Additionally, planned changes to regulations will require all new residential buildings to be ‘zero carbon’ by 2016 and all new commercial buildings to be ‘zero carbon’ by 2019 (DCLG, 2007). These factors have led to a significant increase in the amount of buildings currently being designed and constructed with the objective of being energy efficient.

However, there is growing evidence to suggest that many supposedly energy efficient buildings do not, in practice, meet the intended levels of energy performance. In fact, CO₂ emissions of up to three times the design expectations have been documented (Bordass et al., 2004). This is because the current design methodology is not intended to predict actual energy consumption. Instead the main priority is to demonstrate compliance with Part L Building Regulations (Menezes et al., 2011) and as a result designs regularly fail to achieve the anticipated levels of in-use energy consumption.

There are various reasons for the gap between predicted and actual energy consumption. These may include poor build quality, such as gaps in insulation or thermal bridging, poor initial design parameters, such as assuming all systems are turned off when not in use, or ‘value engineering’ where inferior systems are substituted during the construction phase without prior consultation with the design team (Bordass et al., 2004). However, in all instances the behaviour of the building occupants is one of the most crucial factors that can lead to huge variations in a building’s energy consumption. The occupants can often compromise the complex systems that energy efficient buildings regularly employ for heating, cooling, ventilation, and lighting, leading to high levels of wasted energy (Demanuele et al., 2010). Unregulated loads, such as I.T. equipment and personal heaters, can also cause large and unanticipated increases in energy consumption. In an office building these unregulated loads can account for as much as 37% of the regulated associated emissions (DCLG, 2009).

Traditional efforts to reduce energy consumption in buildings have revolved around the ‘information deficit model’ which assumes that people will act rationally on any information provided to them and modify their behaviour accordingly (Owens & Driffill, 2008). The obvious example of this is with the use of signs urging building users to turn lighting or appliances off when they are not required. There is evidence to suggest that this type of intervention may influence attitudes but often has a negligible effect on behaviour (McKenzie-Mohr, 2000). Owens and Driffill (2008) point to examples from the domestic sector that show, despite constant information campaigns the adoption of energy efficiency measures has been relatively limited and in some instances behaviour has actually become more energy intensive.

This phenomenon parallels the situation in classical economics, in which the predicted behaviour of markets is based upon the assumption that individuals will respond rationally to maximise their expected gains; yet in many cases they demonstrably fail to do so (Ariely, 2009). This and other, deficiencies in classical economics have led to the foundation of behavioural economics, incorporating insights from psychology into human deviations from ‘rational’ behaviour (Kahneman, Slovic & Tversky, 1982). These revelations demonstrate that behaviour is often influenced by a myriad of factors with lack of knowledge being only one of these (McKenzie-Mohr, 2000).
Consistent with this, dual process models of cognition state that there are two cognitive systems governing judgements of choice; System I which is automatic and responds directly to the external environment with little conscious intervention, and System II which is conscious and reflective (Evans, 2008). Current efforts to reduce occupant energy consumption, such as information posters or email prompts operate on System II. This is because these interventions rely on the user consciously assimilating the information for later use. Although there has been some research into how targeting the automatic system of human cognition can be used to engender energy efficient behaviour (Schultz et al., 2007; Thaler & Sunstein, 2008), there has been little into its potential implementation within buildings and the consequential impacts on energy consumption. This paper will look at some of the ways these two aspects of cognitive processing can be incorporated into the building service design and the control design in buildings.

2. Dual Process Models of Cognitive Processing & Behavioural Control

Dual process models of cognition have become increasingly popular over the previous decade. Although they can be criticised (Evans, 2008) as over-simplistic, they provide a useful framework for which to consider various methods of influencing user behaviour. The model makes a distinction between two cognitive systems that govern automatic and deliberative decision-making. Both of these systems are prone to errors of various types. When considered in the context of an occupant’s interaction with a building and its systems, these errors can often cause behaviours that result in inadvertent energy use. It is important to emphasise that although the root cause of the error may be different the resulting behaviour can often be the same. It is therefore imperative to understand what cognitive error is producing the observed behaviour so corrective interventions can be successfully targeted.

To consider how errors of the different cognitive systems directly lead to behaviour that increases energy use an example where a building user operates a heating system and a window concurrently will be presented for each situation. For the system to function efficiently the user must first switch the heating system on and subsequently close the window.

2.1 System I

System I is characterised as non-conscious, automatic, heuristic and irrational. It is highly influenced by the individual’s surrounding environment. For instance, the order and position that foodstuffs are presented to customers at a cafeteria has long been known to influence their choices (Thaler & Sunstein, 2008).

Heuristics are mental short cuts which people employ unintentionally during the decision making process. Our surrounding environments are complex and to function properly within them requires constant decision making. Analysing all this information before making decisions would be time-intensive so instead people routinely employ rules of thumb to quickly and efficiently make choices. However, this process is prone to biases and mistakes. In terms of interactions with building there are two main types of errors that can cause inadvertent energy usage; action slips and post-completion errors. The theories behind these types of errors were designed to account for human error in operating complex systems as well as everyday errors in mundane situations.

Action slips refer to the performance of an action which was unintended (Norman, 1981). They often occur when the intended action and the unintended action have similar initial
stages, such as when driving to the shops on a weekend you inexplicably arrive at your place of work (Norman, 2002). For the heating system example, an action capture would occur when the user engages the heating control, but then instead of closing the window, they turn the lights off instead.

Post-completion errors occur when the primary goal of an activity is achieved, but a terminal step is forgotten (Byrne, 2008). A common example of this is failing to attach an aforementioned document to an email message, or leaving the filling cap open after refuelling a vehicle. For the heating system example, a post-completion error would occur when the heating control is operated, but the user subsequently fails to close the window.

### 2.2 System II

System II is characterised as conscious, controlled, systematic, and rational. It allows for a more systematic and reflective analysis of information during the decision making process. Errors and subsequent inadvertent energy use of this system can result from two main sources. Firstly, the user may have inappropriate attitudes or intentions regarding energy consumption in buildings and may consequently operate systems with little regard for the amount of energy that they consume. This situation is especially common in non-domestic buildings where the user is not usually financially penalised for wasting energy. For the heating system example, the heating controls are operated, but the user leaves the window open as they do not care that energy is being wasted.

Secondly, if a user possesses a poor mental model of how a system operates then they are likely to use it incorrectly. The poor mental model can be due to inexperience of the user or due to an inadequately designed system. The latter situation arises because designers and users often possess very different conceptual models of a system. Figure 1 shows the flow of information between the designer and the user. Communication between the two actually takes place at the system image, which is created from a combination of the system’s physical structure as well as other pertinent information, such as instruction manuals or labels. The user’s mental model is formed through their interaction with the system image without direct input from the designer. Designers often assume that the users will have exactly the same conceptual model that they do and it is this discrepancy which can lead to the user operating the system incorrectly and inefficiently (Norman, 2002).

![Figure 1. Conceptual models of designers and users and how communication flows between them (Norman, 2002).](image-url)

This is particularly relevant to building control systems as incorrect and inefficient use of controls is a major cause of energy consumption in buildings. Controls which are easy to use
and intuitive tend to be energy efficient as the users only operate them as and when needed (Bordass et al., 2007). During a post occupancy evaluation for a UK EcoHomes site rated ‘excellent’, it was discovered that 67% of surveyed residents could not properly program their thermostats (Combe et al., 2010). For the heating system example, the heating controls are operated incorrectly as the user does not adequately understand them and the controls fail to give any accurate feedback. However, the window is successfully closed.

3. Corrective interventions

It can be seen from the errors described that although their root cause is different the actual observable behaviour is often the same, in this case the heating is often on while the window is left open. Understanding the cause of the behaviour is critical in designing and targeting effective interventions to eradicate them. Figure 2 shows what corrective interventions can be used to mitigate errors caused from the different systems. These interventions will be expanded on and their use for the heating example will be explored.

System | Cause of Error | Possible Corrective Interventions
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System 1: Non-conscious, automatic, heuristic, irrational | Action not as intended | Affordances, Defaults, Forcing Functions, Social Norms
System 2: Conscious, controlled, systematic, rational | Inappropriate Attitude/Intentions | Education & training
 | Poor Mental Model of System | Affordances, Education & training, Transparent design & feedback

Figure 2. The corrective interventions for the different cognitive systems.

3.1 Affordances

Affordances provide intuitive signs to the user of how the object or system should be operated. Norman (2002) describes the affordances of doors; with plates for pushing and handles for pulling, and demonstrates how easily even these basic design features can be implemented incorrectly resulting in frustration for the user. Used properly affordances can indicate to the user the correct, and in this case, the most energy efficient way of operating the system. If there is little or no obvious affordance the system is prone to incorrect use and inadvertent energy consumption. For the heating system example, better affordance on the heating control increases the likelihood that the user will operate the control properly.

3.2 Defaults
When confronted with several options for a situation with which they are unfamiliar many people will not make an explicit choice and will instead settle for the default option. Johnson and Goldstein (2003) show how levels of participation in an organ donation program can be drastically affected by whether the box on the requisite form requires the individual to tick it to opt in or tick it to opt out of the program.

The default settings for building services and their control systems can have a large impact on the amount of energy consumed. During the post-occupancy evaluation of the Heelis building, Swindon, it was discovered that the kitchen extract fans were continually operating on a much higher level than was actually required (Fordham, 2007). Defaults are often utilised in building services to return a system to a particular low-energy setting after a pre-set period of time. For the heating system example, defaults could be used to restore the heating control to its original level when the building is un-occupied, such as during the night or at the weekend.

3.3 Forcing functions

Forcing functions constrain actions by making one stage impossible without first completing a prior stage. Requiring keys to be in the ignition before a car can be started is a good example of this (Norman, 2002). Forcing functions can be an effective way of ensuring that users operate the system as the designer intended, but can prove unpopular as they are often inconvenient for the user. For the heating system example, the user would be unable to activate the heating system unless the window is first closed.

3.4 Social norms

Social norms are the behavioural expectations that are present within a specific group. Individuals are highly influenced by those around them and will often take behavioural cues from what other people are doing in the same situation. Schultz et al. (2007) carried out an experiment to measure the effect social norms could have on domestic energy consumption. They informed around 300 households in California about how much energy they were using relative to the average of households in their neighbourhood. As a direct result households who were above the average consistently lowered their energy consumption. However, a ‘boomerang’ effect occurred where households that were using much less than the average actually increased their usage towards the average. This effect was reduced by the inclusion of emoticons indicating whether the current energy usage was socially approved or disapproved. For the heating system example, the user has repeated witnessed other users operating the heating controls and then shutting the window. To avoid any social ramifications they too carry out this behaviour in the observed order.

3.5 Education and training

This is currently the intervention most often employed to influence building user behaviour. It includes user manuals, staff training, and informative signs and posters. Although it is undeniably important to educate users about energy efficient behaviour it is not in isolation an effective measure. This type of intervention is often used as it is perceived being relatively cheap and easy to implement. Evidence suggests that while it may have an initial effect, users will often revert to their old behaviours after a short period of time (McKenzie-Mohr, 2000).

Education and training can be an effective intervention where they are used to improve the user’s mental model of a particular system. If errors are occurring due to the user’s erroneous
conception of how the system functions then training can be provided to ensure that they can use it correctly and efficiently. For the heating system example, prior training for the user could allow them to operate the heating control correctly due to a more appropriate mental model of the system.

3.6 Transparent design and feedback

Errors made by a user due to a poor mental model of the system can be greatly reduced by making the design much more transparent and intuitive. Natural mapping between control systems and the results of their operation can be an extremely effective way of achieving this. Norman (2002) highlights examples of how a four ring cooker hob and its control knobs can be simply laid out taking advantage of natural mapping and removing the need for any labelling.

Feedback is an important consideration for building services and their controls. It is essentially sending the user information about what effect their action has had. To be at its most effective feedback needs to be salient, close in time, and specific to the conducted action (Byrne, 2008). Without adequate feedback the user is unlikely to form a sufficient mental model of how the system operates further perpetuating errors. An example of effective feedback within building can occasionally be seen in mixed mode ventilated buildings. Users in these buildings can often compromise the carefully controlled ventilation settings by opening and closing windows at inappropriate times. This can inadvertently lead to unacceptable levels of thermal comfort as well as high energy consumption. Mixed mode ventilation systems occasionally use a traffic light LED displays to indicate to the user when it is appropriate to operate the windows without compromising the system. For the heating system example, feedback could be incorporated into the design so that when the user operates the heating system a warning light and sound would result from the window if it was open.

4. Conclusions

This paper has discussed how dual process models of cognition may be used as a framework to consider how to influence building user behaviour. Both systems are prone to different types of error and in the context of user interaction with buildings these errors can result in inadvertent energy use. Although the resulting energy use behaviour from these errors can be the same they can have different sources which need to be addressed in different ways.

Currently, the vast majority of attempts to influence user behaviour revolve around the ‘information deficit model’ and as a result are primarily targeted at System II cognitive processing. The assumptions of this model; that there is a direct link between attitudes and behaviour and that the user will necessarily act rationally on information that they receive is flawed (McKenzie-Mohr, 2000). Although it is important to educate users about how to properly use control systems it is not by itself an effective comprehensive strategy to achieve discernable and long term energy saving. Instead, the errors stemming from System I cognitive processing need to be appreciated. The interventions for targeting this system, such as affordances, defaults, forcing functions and social norms can provide effective and long term energy efficient behaviour regardless of the knowledge and attitudes of the user.
However, there has been little research into this topic and corrective interventions of this type will need careful consideration and testing. Some interventions can produce quite different results from what was initially intended, as with the ‘boomerang effect’ during social norm interventions (Schultz et al., 2007).

It is clear that if the UK is to meet its ambitious emissions targets then building designers cannot continue to marginalise the building users during the design process. It is futile to integrate ever more complex energy efficient technology into buildings if the users will be incapable of using them. Designers often claim that the problem is not with the design of the systems, but with people operating them incorrectly. However, it is important to emphasise that systems are created with the implicit purpose of allowing users to perform necessary functions; they are not designed as entities themselves. If the majority of users cannot operate the system easily and consistently to achieve their desired purpose then the design has failed.
References


