The impact of occupant behaviour on the variation between the design and in-use energy consumption of non-domestic buildings: An experimental approach

R.M. Tetlow1*, C. P. Beaman2, A.A. Elmualim3 and K. Couling4
1 Technologies for Sustainable Built Environments, University of Reading, UK
2 School of Psychology & Clinical Language Sciences, University of Reading, UK
3 School of Construction Management and Engineering, University of Reading, UK
4 AECOM, Bristol, UK
* Corresponding author: r.m.tetlow@pgr.reading.ac.uk

ABSTRACT
There is an increasing demand on the construction industry to deliver energy efficient non-domestic buildings but there is evidence to suggest that, in practice, designs regularly fail to achieve the anticipated levels of in-use energy consumption. One of the key factors behind this discrepancy is the behaviour of the building occupants. Expanding on a previous paper which highlighted the need to target both “automatic” and deliberative action when attempting to influence behaviour, this paper explores how insights from experimental psychology can be used to reduce the gap between the predicted and actual energy performance of buildings. It reports on the findings of an experiment where normative prompts are used to encourage occupants to switch off the lights when leaving meeting rooms. Additionally, it outlines the development of a further experiment which incorporates aspects of prospect theory into real-time electricity feedback. The paper concludes that achieving energy efficiency in buildings is not solely a technological issue and that the construction industry needs to adopt a more user-centred approach to the design process.

Keywords: Occupant behaviour, user-centered design, normative prompts, feedback, electricity consumption

1. INTRODUCTION
The operation of non-domestic buildings in the UK is responsible for around 18% of total CO2 emissions (DUKES, 2009). As such, promoting energy efficiency is a key area of focus for the UK government as part of efforts to meet its ambitious CO2 reduction targets. The government’s strategy to achieve this is primarily through the introduction of gradually stricter CO2 emissions limits in Part L Building Regulations. These continuing changes to legislation are resulting in an increasing demand on the construction industry to supply energy efficient buildings. However, Building Performance Evaluations (where a building is closely monitored for a period after completion and occupation) routinely demonstrate that many of these buildings do not transfer this design intent to their operation. Indeed, the associated CO2 emissions of buildings are frequently up to three times the initial design calculations, a discrepancy which has been termed the ‘performance gap’ (Bordass et al., 2004).

The existence of a performance gap is unsurprising as current design approaches typically focus purely on compliance with Part L during the design process. Part L, however, does not provide a comprehensive overview of all the energy consumed within a building. While it does examine heating, cooling, ventilation and fixed lighting for particular levels of occupancy density, it crucially neglects the energy consumption of additional equipment such as ICT or plug loads. Furthermore, its inflexibility means that slight changes to operational
hours, occupant density or the way users operate building services, can have significant consequences for energy performance. These limitations of Part L regularly result in an underestimation of a building’s likely energy consumption as much occupant related energy use is not considered.

Although the majority of designers appreciate that the behaviour of building users can affect energy performance, it is usually considered of little importance compared to engineering solutions to this issue (Janda, 2011). This is despite growing evidence to suggest that the impact of behaviour can be extremely significant. Gill et al. (2010) investigated the impact of behaviour on energy consumption at a BREEAM Excellent housing estate in the UK. Using a psychological model of planned actions they discovered that deliberate energy efficient behaviours accounted for 51% and 31% of the variance in heating and electricity use respectively between homes. While the majority of studies on occupant behaviour are limited to the domestic sector, Menezes et al. (2012) demonstrated that the level of control occupants believe they possess over lighting and appliances in a commercial office building also accounted for variations in electricity consumption of up to 17%.

Approaches to promote energy efficiency among non-domestic building users typically involve awareness campaigns and the appointment of ‘green champions’ to disseminate information about inappropriate behaviour and the associated impact on the environment. This approach is based on the assumption that people will act rationally to the provision of information and modify their behaviour accordingly. This expectation is analogous with classical economics, where the predicted performance of markets is based upon the assumption that individuals will (on average) act rationally in order to maximise their potential gains; an approach exemplified by ‘Expected Utility Theory’ (EUT). However, behavioural economics has repeatedly demonstrated the deficiencies of EUT and has highlighted the fact that people often do not act as “rationally” as economists and others expect (Ariely, 2009). Instead, there is a growing realisation that delivering energy efficient buildings will require a greater appreciation of how occupants interact with their surrounding environments. To this end, obtaining evidence from psychological experiments of what factors and interventions affect energy-use within the built environment could prove extremely useful in helping to reduce the performance gap.

2. INSIGHTS FROM EXPERIMENTAL PSYCHOLOGY

Although people have a general perception that they are experiencing a consistent stream of events and continuously making conscious decisions, in fact much of our behaviour is carried out automatically and unconsciously (Nakicenovic et al., 2000). This ability to automate routine decisions is vital to allow us to operate effectively within information dense surroundings and is, for instance, what prevents us from spending hours in a supermarket deliberating over which brand of washing powder to purchase (Jager et al. 2000). Instead people form habitual behaviours where they repeat their original choice of action even when they may no longer provide the optimal outcome, e.g. particular routines or routes are followed in interacting with technology or making one’s way home, even though more efficient or shorter routes may have become available, a phenomenon known as “einstellung” or mechanization of thought (Luchins & Luchins, 1959). Consequently, our habitual behaviour can apparently be “irrational” with people leaving the heating on when not home and electrical appliances on stand-by, even though there is an associated financial penalty. (Nakicenovic et al., 2000).
2.1 Dual process model of cognition

Consistent with this, dual process models of cognition posit two cognitive systems that dictate actions; System I is automatic and intuitive, it responds directly to the external environment with no conscious consideration. Most habitual actions are guided by System I. System II is conscious, systematic and rational, but slow and effortful to deploy. Kahneman (2011) reviews repeated demonstrations of people defaulting to System I in many situations. Both Systems are prone to errors which can result in inappropriate actions. In terms of an occupant’s interaction with a building these errors can result in inadvertent energy use. In a previous paper Tetlow et al. (2012) suggested that many traditional energy efficiency engagement methods fail to produce any appreciable results because they assume that providing information will result in people rationally interpreting it and then acting upon it. As such, these engagement methods appeal only to System II cognitive processing. An alternative strategy which appeals to both cognitive systems should therefore reduce inadvertent energy use in a building. Through a comprehensive multi-disciplinary literature review, two aspects of behavioural economics governed largely by System I cognition have been identified as having the potential to be incorporated within non-domestic buildings to promote energy efficient behaviour amongst occupants; social norms and information framing.

2.2 Social Norms

Social norms are the implicit rules that govern behaviour in a group and to which there is a strong innate tendency for people to conform. This propensity is often unconscious and people regularly fail to realise the extent to which social norms have influenced their behaviour (Nolan et al., 2008). Goldstein et al. (2008) used prompts to encourage towel recycling in a hotel in the US. Specifically, they compared two different types of prompt; one containing a pro-environmental message, the other displaying the number of people in the hotel who had previously recycled their towels. The results showed that the social norm prompt produced a significantly higher towel re-use rate (44%) than the standard environmental message (35%).

3. EXPERIMENTAL PROGRAMME WITHIN THE BUILT ENVIRONMENT

Despite efforts to increase energy efficiency in the built environment, electricity consumption has been steadily increasing. Social norms have been shown to work in promoting pro-environmental behaviour in the hotel and catering sector (Goldstein et al., 2008) so one approach we have taken is to add social cues to reminders to switch off lights when leaving a meeting room. The aim of this experiment is to determine whether simply providing information about the behaviour of other groups is sufficient to increase compliance with the environmental message of the prompt, and if possible, to quantify any such increase. We also examine the effect of the number of people leaving the room at any one time. One possibility is that larger groups are more likely to switch off the lights: if there is a simple probability $o$ that any individual within the group switching off the lights, independent of the $n$ others within the group, then the probability of the lights being left on should be $1-(p(o)^n)$. Alternatively, the presence of others within the group might actively inhibit individuals from switching off the light, possibly to the extent that larger groups might be more likely to leave the light on. The effect of social norms within the hotel industry was observed in an environment where there were few alternative social cues available to influence behaviour. On leaving a room, the social cues of others in the groups not obviously switching off a light as they pass by might over-ride any positive benefit of the social cue reminder.
4. EXPERIMENT 1 – NORMATIVE PROMPTS

Two different prompts were created to encourage building users to turn off lights when exiting meeting rooms. One was a standard pictorial prompt, the other contained normative information. These were placed in meeting rooms and the effect on turning lights off was recorded. The expectation was that the normative prompt should be more effective than a straightforward injunction to turn off the lights.

4.1 Participants

Employees leaving meeting rooms in AECOM offices in Bristol between the standard working hours of 9am – 5.30pm were observed on 149 occasions.

4.2 Materials & Design

Prompts were sized at 120x120 mm. The first prompt was a standard pictorial prompt, common in many offices. The second prompt had the same format with the only alteration being that the picture of a light bulb was substituted for a representation of a smiling person with a percentage indicating the amount of people who have previously turned off the lights when leaving the meeting room (see Figure 1). This percentage was an arbitrary value based around the 75% value utilised in Goldstein et al. (2008). It was altered slightly between the 4 meeting rooms.

![Figure 1. Example of the two different types of prompt used](image)

4.3 Procedure

A baseline was established by observing the frequency that lights were turned off when employees left meeting rooms prior to any intervention. Each meeting room contained an existing text-based prompt located above light switches stating ‘Please turn off the lights when you leave, thanks’. Initial monitoring was carried out for a ten work day period from the researcher’s desk which provided a good view of all meeting rooms. Employees were unaware that they were being monitored. After a baseline was established the new prompts were introduced. These were positioned on the glass walls adjacent to the opening side of the door, between eye level and the door handle. Employees were given no information about the meaning of the new prompts. Two normative prompts and two pictorial prompts were placed in the four different meeting rooms. Incidences of turning off the lights were again recorded. After 5 days the prompts were swapped between rooms.

4.4 Results

The results for the three different conditions are shown in Figure 2. There was a statistically significant effect of the prompts, $\chi^2 (2) = 6.79$, $p < .03$, indicating that the association between prompting and switching the lights off was unlikely to have arisen by chance.
However, further analysis showed no statistically reliable effect of normative prompts over standard prompts ($p = .24$, Fisher’s exact test, 1-tailed), so the numerical advantage enjoyed by the normative prompts may be the result of random factors. Figure 3 shows that when larger groups are within the room, the proportion of time the lights are switched off goes down, the opposite pattern from that predicted by the independent responsibility assumption. Thus, social cues to act from within the group may run counter to the social cue displayed on the prompt.

It is possible that the influence of group size is more powerful than the social cue on the prompts and as such reduces its effect. Distributed responsibility increases as group size increases which reduces the likelihood of an individual turning off the lights, however, the last person may fail to turn off the lights as they have just witnessed everyone else leave without doing so.

5. FRAMING

Alongside the possibility of utilising social cues, we also aim to examine how informed feedback can influence energy use, and whether particular framings of feedback might maximise energy-saving. A key barrier to reducing energy consumption is that it is not readily apparent to the majority of people due to its relative invisibility. As a result building users often receive little if any information about their consumption patterns and hence have little opportunity to learn how to be more efficient. Providing feedback on consumption, specifically the associated financial cost and environmental impact, is often cited as an effective way to reduce consumption with savings of up to 20% (Darby, 2008). However, how information is framed can have a large influence on decision-making. Framing refers to
the fact that people often reverse their preference when exactly the same information is presented to them in a different way. Perceived losses are reacted to differently from perceived gains, even when – objectively (using System II) – there is no difference in the situation described. Losses are felt more acutely than gains by System I, and action is taken to try and recover from them. For example, Tversky and Kahneman (1981) presented two groups with two seemingly different solutions to an outbreak of a fatal disease. The crucial difference was whether the solution was framed in terms of the number of people saved or (an equal proportion) of people dying. Choices informed by expected outcomes expressed as losses (people dying) resulted in 75% opting for a high-risk treatment programme whereas the same outcomes expressed as gains (people saved) produced risk-averse behaviour with around 75% opting for the “safer” of the two options. In general – when losses are plotted against gains – people value losses twice as much as a gain of an equivalent amount (Ariely, 2009).

6. EXPERIMENT 2 – FRAMING ELECTRICITY FEEDBACK IN SCHOOLS

Energy feedback in non-domestic buildings is usually delivered through ‘Energy Dashboards’ which are often displayed in communal areas and entrance lobbies. Noble et al. (2012) suggested that the potential for these dashboards to promote energy savings is being greatly overstated and recommended a re-conceptualising of energy as a ‘common resource pool’ which would gradually reduce over time. This idea could conceivably alter people’s concept of energy into a physical resource which needs to be sustainably managed. Combining this with framing has the potential to improve how feedback is presented to building occupants; the traditional method of which is through a bar chart of weekly consumption in kWh, CO₂ emissions, or cost, all of which focus on System II. Instead, presenting electricity use as a common resource pool that is gradually depleted over time could motivate savings by appealing to a sense of “loss” rather than “gain”.

This experiment is due to commence June 2012. Electricity consumption feedback will be displayed to primary school teachers and pupils on a monitor in their classroom. The form that this energy feedback takes will be varied over three conditions. The feedback will show the electrical appliances that the participants have control over. The expectation is that showing consumption as a communal “loss” rather than a communal “gain” will engender a higher level of saving.

6.1 Materials & Design

A weekly baseline for electricity consumption of the participating classrooms will be established using a data logger connected to the classroom’s distribution board before any feedback conditions are implemented. Current transformers (CTs) will be connected to the various circuits serving the classroom. Electricity consumption will be monitored over two weeks to establish the typical weekly baseline. Once the baseline has been established the graphical feedback intervention will be introduced. The data logger will send a CSV file to a computer every 10 minutes and this will then be used to update the feedback visualisation. The display will also show the electricity being consumed by the specific devices the classroom occupants have control over. Three different conditions of electricity consumption feedback will be displayed to classroom occupants (see Figure 4):

*Condition 1* - weekly feedback presented as a bar chart with kilowatt-hours (kWh) as the units. There will be a bar for total consumption for every day of the week which will run one day behind. This is currently how electricity consumption data is usually presented to building occupants.
Condition 2 - a ‘communal energy pot’ which gradually decreases over the course of a week depending on the classrooms consumption. The total amount of represented energy in the pot will initially be slightly larger than the typical baseline consumption. The graphic showing the pot will be updated every 10 minutes resulting in a visible reduction of the pot over the course of the week. We predict that this will be perceived as a “loss”.

Condition 3 - a ‘communal energy pot’ which shows a gradual increase in energy used over the week in the same manner as Condition 2. This condition will show how presenting communal energy use is affected when not perceived as a “loss”.

Figure 4. Examples of graphical displays for Conditions 1, 2 and 3 respectively.

7. GENERAL DISCUSSION AND CONCLUSIONS

The results of Experiment 1 demonstrate that designing prompts to appeal to System I (by increasing salience and improved location) can have a significant effect on their success. However, although there was an apparent increase in effectiveness of the normative prompt over the pictorial prompt, this effect was not statistically significant. It is possible that the effect size was smaller than originally anticipated so a greater sample size would be needed to detect any difference. The results also indicate that there is a stronger social influence produced by the group’s visible actions (in that the last person observes people leaving without turning off the lights) than is generated from the normative prompt. Probability dictates that the more people in the room the greater the chance that one of them will turn the lights off upon exiting the room. In reality we observed the opposite occurring with the greater the number of people in the room reducing this likelihood. One explanation for this could be that responsibility for building controls becomes distributed as group size increases without conscious realisation from the occupants and that shared responsibility is far weaker than individual responsibility. This has potential implications for building design and management in that the smaller the number of people given responsibility for a building control the more likely it is to be operated in line with the initial design intent. However, further research is needed in this area to determine if there is a similar effect in different building sectors and for other types of building service control.

Current methods to engage with building users, such as green champions and informative posters are based on the assumption that people will behave rationally to information presented to them. As a result they are disproportionally targeted towards System II decision making. This assumption is flawed and although it is undeniably important to educate users
on efficient energy use it is not by itself a comprehensive strategy to achieve discernible and long term energy savings. Experiment 1 has provided some evidence to support the approach of targeting both Systems when designing interventions to modify building user behaviour. It is anticipated that Experiment 2 will contribute further weight to this methodology as well as demonstrating how aspects of behavioural economics can be successfully integrated into the built environment to help reduce energy consumption. Delivering energy efficient buildings is not exclusively a technological issue and the construction industry needs to develop a more sophisticated understanding of how building occupants behave and adopt a more user-centred approach if they are to successfully increase energy efficiency and decrease the performance gap.

REFERENCES