eViz – energy visualisation for carbon reduction in buildings

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Abstract

People play a key part in the energy performance of buildings, through design, operation control and management (Mahdavi, 2011). A building's energy use can be 40 % above expectations (Yu et al., 2011) due to occupant behaviour. Occupants might heat empty rooms, open windows rather than turn down heating, and forget to turn the heating down when they leave the building (Parker et al., 2006). The eViz project presented here is a multi-centre project between four UK Universities that takes an integrated interdisciplinary approach between behaviour and building scientists to reduce energy use and thus carbon in buildings.

Addressing the behavioural dimension allows for urgently required immediate responses, whereas many technological solutions have a time horizon of 10 years or more (Dietz et al., 2009). Additionally, behaviour change approaches do not require significant capital investments. A major obstacle in addressing the behavioural dimension is the abstractness and invisibility of energy (Darby, 2006; Fischer, 2008). If people see a tap running, they can turn it off to save water; but they cannot see heat escaping through a draughty door. If the problem is invisible, sustainable intentions are less likely to be translated into behaviour change of daily routines and habits. People feel psychologically distant from the problem (Pahl & Bauer, 2013). eViz uses energy visualisations to overcome this distance.

Pilot data from three early stages will be reported. First, a mental models approach will report on occupant perceptions of energy in the home. Second, pilot data and a feasibility analysis will focus on an in-depth case study of three residential homes. Third, progress on a visualisation intervention in a student hall of residence will be reported. We use both psychological measurement of energy understanding and attitudes and building monitoring data. The eViz project is designed to help influence the complex interaction between people and buildings to meet the carbon emission and energy efficiency targets needed to tackle climate change and ensure a sustainable future.

Introduction

Buildings have a range of characteristics that contribute to their energy use, for example the current heating system, the degree and quality of insulation, the number of occupants and what the building is used for. Buildings can be made more energy efficient by upgrading the building fabric and their systems, such as insulation and heating. Beyond these technical upgrades, the behaviour of occupants in buildings has an important influence on energy use (Mahdavi, 2011). For example, leaving windows open for long periods of time when the central heating is active could waste energy. If this energy loss can be made visible, this has the potential to change window opening behaviour. However energy efficient a building may be, the occupants can have a significant impact on its actual energy demand.

We see two important roles for people in this context. One is as decision makers in positions of power to upgrade and invest in technical improvements. For example, a building manager might decide to invest in a new heating system to replace an old inefficient one, or a householder might decide for or against adding insulation to his or her roof space. The other role is as actors in the complex building system. For example, office workers may make decisions throughout the day on opening doors and/or windows to cool their office space down or improve air quality. Similarly, householders may decide to turn up their thermostat based on subjective perceptions of comfort. These actions have a considerable impact on energy use (Gardner & Stern, 2008). We propose that energy visualisations can lead to sustainable change relating to both these roles.

A range of relevant approaches have been taken by previous researchers. Kempton (1987) described large differences between engineering models of home heating and folk models of home heating, pointing towards a considerable gap between those that design heating systems and those that operate these in the end. Kempton and Layne (1994) recorded how consumers attempt to make sense of their energy use by reading meters and analysing bills. These documented consumer efforts were remarkable because particularly at that time meters tended to be hidden away and bills tended to be infrequent and highly technical. From this early research, it was argued that better and more immediate links were needed between energy consumption and feedback to the householder. While utility companies have to some degree implemented such changes (e.g., comparative temporal feedback and online Energysmart™ access to data in the case of British Gas), the development of smart meters has perhaps been the most significant recent advance. Smart meters typically feed back real-time energy use in a range of 'currencies' including kWh, money or carbon and in the form of graphical representations such as bar charts. More sophisticated smart meter models offer comparison options and more in-depth data analytics.

Research on the reactions of people to smart meters in the homes has largely used small-scale qualitative/ethnographic methods (e.g., Hargreaves et al., 2010; 2013; Papantoniou et al., 2010). This research has found that after an initial period of excitement that is associated with self-reported behaviour change, householders use the device less frequently. Quantitative assessments of energy use after the introduction of smart meters has shown energy savings mostly in single digits, but results vary considerably (Darby, 2010; Faruqi et al., 2010).

The eViz approach

eViz stands for energy visualisation for carbon reduction and addresses one of the key gaps that have been observed: Energy flows in buildings are invisible and cannot be observed directly (Darby, 2006; Fischer, 2008). This lack of direct and intuitive information about the energy system in a building is thought to contribute to an apparent reluctance on the part of occupants to make upgrades and change their habitual behaviour (e.g., Yates & Aronson, 1983). While smart meter approaches have, to some degree, attempted to address this gap, they have tended to focus on electricity rather than heating, and many still rely on abstract figures and graphs rather than more intuitive visual representations (Darby, 2006; 2010). Abstract graphs or figures represent energy but do not provide more intuitive visualisations that are immediately meaningful; occupants still have to translate this information and make it meaningful. Our project takes a critical look at prior conceptualisations of visualising energy and explores how visualisations can be made even more intuitive and compelling for use in daily life. In addition, we embed our approach in the psychological literature on risk perception and behaviour change. Far from following an information-deficit model (Hargreaves et al., 2010; 2013) we propose that communicating energy has to be based on a thorough understanding of mental models of energy flows, memory processes, and theoretical models of behaviour change.

First, understanding the mental models in detail will highlight those aspects of an energy system that requires visualisation (e.g., heat flows in the home). Second, if energy-relevant behaviour is determined largely by habits, designing visualisations that are highly memorable and have the power to interrupt habitual behaviour is vital (e.g., through using thermal images that directly show heat escaping through a window). Third, behaviour change approaches are needed that distinguish between information or skills deficits, lack of motivation or perceived control (e.g., Fisher & Fisher, 1992). Our research will allow us to delineate principles for energy visualisations that have maximum potential for behaviour change.

The research is embedded in the multidisciplinary eViz team between four collaborating universities in the United Kingdom, which started in September 2012. eViz integrates approaches from psychology, human factors and the behavioural sciences with architecture, building engineering and simulation. The United Kingdom has one of the poorest and least well insulated housing stocks in Europe and policy efforts are increasingly directed at improving this situation (Department of Energy and Climate Change, 2011). Overall, our aim in eViz is to change occupant decisions and behaviour through providing intuitive knowledge and supporting decision making by using the latest developments in smartphones, ICT, visualisation and social media. We are developing tools that make 'the invisible visible' and transform building users into smart occupants who are in control of energy demand. The eViz project is thus aiming for energy reductions that are beyond the scope of the building fabric, building services design and energy management, or Facilities Management.

In this paper, three aspects of our early research will be reported. First, we have adopted a mental models approach from the risk perception literature. The results from interviews with both experts and non-experts will be described. Second, we study three residential homes where we combine an in-depth metering approach with a diary study to investigate occupant behaviour amongst homeowners in different buildings and occupant structures. Third, collaborating with a university accommodation provider, we focus on students in a hall of residence. The students do not pay energy bills directly and thus have a different motivational structure when it comes to reducing energy use.

Mental Models of Energy Flows

Experts and non-experts alike have mental representations of a variety of complex systems. Energy in the home can be described as such a system, and we argue that it is important to understand people's conceptions of energy and energy flows in order to communicate with occupants and users and effect attitude and behaviour change. Mental models have been used for that purpose for many years, particularly in interdisciplinary contexts (Morgan, Fischhoff, Bostrom & Atman, 2002). While the approach has been used in a variety of risk perception and communication contexts, there is to date little work on energy directly (see Kempton, 1987, for an exception). The mental models approach is based on the observation that people develop their own models based on perceptions of issues such as energy even if they do not have the relevant expert knowledge. They may have heard about the workings of heating systems from a neighbour or read about it in a newspaper, and these bits of information form a mental model of the system in their minds. Often, mental models that have been constructed in such a way are not 'accurate' in the sense that they would differ from the mental model of a building engineer. However, occupants make decisions on the basis of their personal mental models. Hence, understanding such non-expert models and comparing them with expert models provides the first step in developing a suite of communication tools for behaviour change.

In our first study, experts and non-experts took part in structured qualitative interviews about energy flows in the home. Each interview took about one hour and was complemented by a drawing task that asked participants to draw a representation, for example of how they thought a radiator worked in terms of heating a room. Interviews were then transcribed and analysed thematically. Data show differences between expert and non expert mental models, for example around how heat flows around the home. However, even the experts expressed some uncertainties when it came to specific details. The drawings provide further illustration of these differences. For example, non-experts generally thought heat from wall-mounted radiators was emitted at a ninety degree angle away from the radiator and wall. However, expert drawings showed convection effects of heat rising up from the radiator towards the ceiling. These mental models have the potential to influence how occupants control their heating system or take action to conserve energy such as closing curtains. This type of interaction is the subject of further exploration to inform communications for energy conservation. Non-experts in particular expressed that they have no direct access to heat flows, as these are invisible, and that this was a barrier to using heating systems in an efficient manner. This indicates the need for visualisations that demonstrate heat flows in an intuitive observable manner. Working with 3D virtual reality modellers, this is something we are currently developing.

In-depth analysis of residential buildings

The main aim of the second study was to develop a methodology that would allow a matching and comparison of monitoring data and behaviour data. The aims here were two-fold. First we wanted to obtain fine-grained data on specific aspects of the home and/or the behaviour that could then be visualised at a later step. Second, we wanted to test a more sophisticated diary approach, in addition to the more common log sheet method of recording behaviours. The diary allowed us to obtain additional measures of energy perceptions and motivations. We equipped three residential homes with a suite of monitoring equipment including temperature and relative humidity sensors, PIR motion sensors (occupancy), window contact sensors as well as smart meters. The outdoor environmental factors (temperature, relative humidity, wind speed, wind direction and rain) were monitored using a weather station deployed at each home. A paper based log sheet for the manual recording of specific occupant behaviours (occupancy, window opening, temperature and TRV settings) was also deployed to validate the automated methods of data collection. In addition, we programmed an iPad diary (see Figure 1) for the occupants that asked them to select energy-relevant actions (e.g., having a shower, adjusting thermostat settings) they had engaged in during the day and rate these actions in terms of importance in their daily life and perceived energy use. The diary was filled in twice a day after peak periods.

Figure 1. iPad Diary.

A diary approach was chosen because other research has shown that this provides reasonably accurate data when collected quite closely to the actions but is not as intrusive as requiring occupants to record actions immediately or sending prompts throughout the day (Kahneman et al., 2004). Data collection is ongoing for this study. The three homes are a) a modern detached house occupied by a couple and their teenage son, b) a Georgian city house occupied by a mother and daughter and c) an old traditional cottage occupied by a couple and their two young sons.

Addressing Energy saving in student accommodation

Finally, we collaborate with an accommodation provider that offers student flats and houses across the UK. Their challenge is that with rising energy prices they absorb costs because these are included in the students' rent and not added on in response to use. This alternative test bed allows us to examine what determines energy use for individuals who are not responsible for paying their own energy bills, and how feedback on energy use needs to be communicated in this setting. The building we selected consists of four floors with eight flats of either five or eight en-suite student bedrooms with a shared communal kitchen. The study consists of two phases, a) measuring energy understanding and barriers to as well as motivations for energy saving behaviour in the shared flats, and b) providing a visual feedback tool in the shared kitchen space (that can also be accessed online and via smartphones) with varying messages. The underlying data for the visual feedback will be provided from a range of embedded monitoring sensors in the student accommodation building, including, overall electricity, gas and water use for the building; electricity, gas and water use for individual flats; electrical end-uses (cooking, lights, and appliances); as well as the indoor environmental conditions.

Preliminary data showed that students in shared accommodation have generally positive beliefs about energy saving. For example, on average, they did not think energy saving was a hassle or would reduce their quality of life. Further, they thought saving energy would not restrict their freedom and would help combat climate change. This seems to be a good starting point for an energy saving intervention. However, we found only a small and non-significant correlation between these energy beliefs and self-reported energy saving behaviour, and, on the whole, the students only felt moderately responsible for problems resulting from energy use (such as depletion of energy resources). In turn, feeling responsible was associated with awareness of consequences and a strong personal norm to save energy. Further, a strong personal norm was associated with strong shared norms in housemates. When directly asked about potential motives for saving energy, the students stated that saving money was the most powerful motive, followed by helping the environment. The least important motive was if their friends and housemates also engaged in energy saving behaviours. However, ratings for all motives were relatively high (above the neutral midpoint of the scale), indicating that a range of motives was important.

The next step will be to introduce visible energy feedback in the flats and test the effect this has on energy understanding, attitudes and actual energy use. Overall, these data show that students are interesting in saving energy but it remains a challenge to implement an effective motivational structure if they are not paying their own energy bills. The intervention data will show if visualising energy and thereby improving energy understanding and direct access to the system has the capacity to overcome this challenge.

Conclusions

Pilot data from three early stages of the eViz project highlights important issues in addressing energy saving in different occupant samples. The mental models study found differences in perceptions of experts and non-experts that can directly inform visualisation tools for occupants. The in-depth case studies allow us to target the most energy-intensive behaviours while validating metering and self-report behaviours in a mix of owner-occupiers and tenants. Finally the student accommodation study explored psychological factors in occupants who do not pay their own bills. The visualisation tool in the last case needs to be conceptualised so that it increases energy understanding and motivates energy saving behaviour in the absence of direct financial savings.

Even though it is early days, some key challenges have already been identified in our work for eViz. For example, there are conflicts between an engineering perspective (in the technical sciences in our multi-disciplinary team) and an occupant perspective (in the social sciences). The former tends to focus on measuring specific aspects to a very high resolution (e.g., window opening) whereas the latter thinks of such specific behaviours as a function of a general understanding of the building system, which are essentially interchangeable. Integrating these top-down and bottom-up approaches at a meaningful level of resolution will be on our task list. Another challenge is to identify meaningful sample sizes with still adequate technical data, and implement robust research designs including control groups.

Overall, the data highlight that people find energy flows difficult to understand and relate to their daily lives. This suggests that more intuitive, online representations of energy are required. The eViz project will develop and test these from a multi-disciplinary perspective over the next three years.

References

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. Journal of Environmental Psychology, 25(3), 273–291.

Darby, S. (2006). The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering, Billing and direct Displays, 486.

Darby, S. (2010). Smart metering: what potential for householder engagement? Building Research & Information, 38(5), 442–457.

Department of Energy and Climate Change. (2011). Energy trends March 2011. http:/www.decc.gov.uk/assets/decc/Statistics/publications/trends/1511-trendsmarch11.pdf (accessed 2nd June 2011).

Dietz, T., Gardner, G.T., Gilligan, J., Stern, P.C., Vandenbergh, M.P. (2009). Household actions can provide a behavioural wedge to rapidly reduce U.S. carbon emissions. PNAS, 106, 18452–18456.

Faruqui, A., Sergici, S. & Sharif, A. (2010). The impact of informational feedback on energy consumption – a survey of the experimental evidence. Energy, 35, 1598–1608.

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? Energy Efficiency, 1(1), 79–104.

Fisher, J. D., & Fisher, W. A. (1992). Changing AIDS-risk behavior. Psychological Bulletin, 111(3), 455–474.

Gardner, G.T., & Stern, P.C. (2008). The Short List: The most effective Actions U.S. Households Can Take to Curb Climate Change Environment, 50, 12–23.

Hargreaves, T., Nye, M. & Burgess, J. (2010). Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy, 36, 6111–6119.

Hargreaves, T., Nye, M. & Burgess, J. (2013). Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. Energy Policy, 52, 126–134.

Kahneman, D., Krueger, A. B., Schkade, D. A., Schwarz, N., & Stone, A. A. (2004). A survey method for characterizing daily life experience: The day reconstruction method. Science, 306(5702), 1776–1780.

Kempton, W. (1987). Variation in folk models and consequent behaviour. American Behavioral Scientist, 31 (2), 203–218.

Kempton, W., & Layne, L.L. (1994). The consumer's energy analysis environment. Energy Policy, 22 (10), 857–866.

Morgan, M. G., Fischhoff, B., Bostrom, A., & Atman, C. J. (2001). Risk communication: A mental models approach. Cambridge University Press.

Mahdavi, A. (2011). People in building performance simulation. In: J. Hensen and R. Lamberts (eds), Building Per-

formance Simulation for Design and Operation. Sponn Press.
Pahl, S. & Bauer, J. (2013). Overcoming the Distance: Perspective Taking With Future Humans Improves Environmental Engagement. Environment and Behavior, 45(2), 155–169.
Papantoniou, L., De Jong, A., Crul, M., Geelen, D., & van Lieshout, M. (2010). A Social Approach to Energy Metering: The Energy Mentor. Knowledge Collaboration & Learning for Sustainable Innovation, ERSCP-EMSU conference, Delft, The Netherlands, October 25–29, 2010.
Parker, D., Hoak, D., Meijer, A., & Brown, R. (2006). How much energy are we using? Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings, Asilomar, California.
Steg, L. (2008). Promoting household energy conservation. Energy policy, 36(12), 4449–4453.
Yates, S. M., & Aronson, E. (1983). A social psychological perspective on energy conservation in residential buildings. American Psychologist, 38(4), 435.
Yu, Z., Fung, B., Haghighat, F., Yoshino, M., & Morofsky, E. (2011). A systematic procedure to study the influence of occupant behavior on building energy consumption. Energy and Buildings, 43, 1409–1417.

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