Evaluating Personalised Energy Feedback Information for Behaviour Change in Commercial Buildings

Dr. Michael Coleman, De Montfort University, Leicester, UK
Dr. Katherine Irvine, De Montfort University, Leicester, UK
Dr Mark Lemon, De Montfort University, Leicester, UK
Prof Li Shao De Montfort University, Leicester, UK

Abstract

A growing body of research indicates that the improved feedback of energy information to building users can encourage more efficient use of energy. However, the majority of previous research studies into energy feedback have focused on electricity use in homes, with little research undertaken in commercial buildings. This paper discusses the use of energy feedback in the commercial setting, in the context of a UK study that is currently investigating the development and application of wireless behaviour information (Wi-be) systems that utilise low power wireless sensors and networks for monitoring personal energy use, patterns of occupancy, and delivering personalised energy feedback information. Central to the "Wi-be" approach is the provision of accurate disaggregated feedback, so that individual energy users can assess the impact of their behaviour. The paper describes the study's methodology suggesting how behaviour change and energy savings can be evaluated. Both the positive and negative aspects of the technology are considered from technical and user perspectives. Results from initial interviews provide some support for the use of personalised feedback in commercial buildings. They also highlight the need to address the control of communal energy end-uses and the potentially counterproductive ethical issues associated with energy monitoring and tracking; including privacy, surveillance and the misuse of data.

Introduction

Buildings account for around 45% of overall UK energy consumption and it is estimated that improvements in occupants' behaviour could contribute significantly to the reduction of carbon dioxide emissions (Janda 2011). A growing body of literature points to the provision of better energy feedback information as an effective instrument to reduce energy use in buildings through behaviour change (Darby 2006; Ehrhardt-Martinez et al. 2010; Fischer 2008). Ehrhardt-Martinez et al. (2010) categorise two main types of feedback; indirect feedback consists of information about energy use after it has occurred (e.g., billing or reports) whereas direct feedback occurs in real time (e.g., in-home displays for electricity consumption). Such feedback can help to address two main types of behaviour; efficiency behaviours that relate to "one-shot" behaviours, such as investment in more energy efficient appliances; and curtailment behaviours that involve repetitive efforts to reduce energy use, such as regularly turning lights off (Gardner & Stern 2002).

At present, there is only limited information fed back to energy users within UK buildings. In homes, this is largely constrained to monthly or quarterly bills, which are often based on estimates and provide little information to householders about how the energy was used (Anderson & White 2009; Darby 2006). In commercial buildings, the majority of users rarely have access to bills and even when this information is available the energy use is often based on the activities of a group of people. As a result, energy use is still largely invisible to most building occupants (Carrico & Riemer 2011). In the UK, interest in the use of feedback has been heightened due to the increased opportunities to introduce more accurate and "real time" energy information into buildings through

the planned roll out of smart metering systems and the increased availability of home energy monitoring systems (e.g., in-home displays).

A number of extensive literature reviews have evaluated findings from research into the use of energy feedback information (e.g., Darby 2006, 2010; Ehrhardt-Martinez et al. 2010; Fischer 2008). These reviews have focused largely on electricity use in residential buildings and indicate that electricity reductions can be achieved – e.g. 4-14% (Ehrhardt-Martinez et al. 2010); 5-12% (Fischer 2008). However, many of the research studies in this field have small sample sizes, vary in the type of feedback, and usually include additional (and different) interventions to encourage energy saving (Fisher 2008). Some feedback studies may also overestimate potential savings due to short study periods, which can be influenced by seasonal variation (Ehrhardt-Martinez et al. 2010). Nevertheless, the aforementioned reviews provide clear direction for optimising feedback:

- Provide feedback based on accurate energy use
- Provide prolonged and frequent feedback
- Disaggregate energy consumption to specific energy end-uses (e.g., appliances)
- Make feedback interactive
- Present information in an understandable and appealing way
- Information needs to be tailored to the contexts of people's energy use

Notably, the literature suggests that it is unlikely that the provision of feedback alone will result in energy reduction unless viewed as part of a wider approach that aims to improve people's knowledge and motivate them to take action (Darby 2010). Thus, many feedback studies include additional interventions such as the provision of additional information and advice, competitions, goals-setting, formal commitment and rewards (Ehrhardt-Martinez et al. 2010; Fischer 2008). There is still some uncertainty regarding the effectiveness of feedback; particularly in respect to commercial buildings. Energy use in commercial buildings is more complex than the residential sector (Carrico & Riemer 2011). This complexity is reflected in the wide range of built forms, sizes, and the mix of activities that can take place (Bruhns 2008). At home, an individual has full command over building energy controls, whereas energy use in commercial buildings is more likely to be subject to building systems and characteristics, and management structures (e.g., facilities managers) (Lehrer 2009). There are also differences in social contexts, such as roles, rules of conduct, and normative expectations (Nye & Hargreaves 2009). Importantly, employees often do not have a vested interest in reducing energy use, because they are not paying the bill (Siero et al. 1989).

These differences raise questions of how applicable findings from residential energy feedback studies are to the commercial setting. Furthermore, many of these studies have largely focused on the effectiveness of the feedback (Hargreaves et al. 2010). Nye and Hargreaves (2009) suggest that behavioural studies could improve policy initiatives and outputs by giving more importance to understanding the processes of behaviour change in different contexts. Also, little attention has been given to wider social effects of introducing energy monitoring technologies into buildings.

This paper explores some of these issues by focusing on the Wireless Behaviour Information Systems (Wi-be) project[1] an ongoing UK study that is evaluating the use of wireless technologies to provide personal energy feedback to building occupants. The next section outlines the project and the methodology employed; the former focusing on the more qualitative aspects of the research which has been carried out through a preliminary set of in-depth interviews with occupants of commercial buildings. The subsequent sections will be thematically presented and will be structured

1 The project's full title is 'Reduction of Energy Demand in Buildings through Optimal Use of Wireless Behaviour Information (Wi-be) Systems' – the study is part of the 'Transforming Energy Demand through Digital Innovation (TEDDI) programme', which is funded by the Engineering and Physical Sciences Research Council (EPSRC) – EP/I000259/1

through a synthesis of literature and primary data collected from the interviews. This is felt to be more appropriate due to the exploratory nature of the work to date. This interpretation is also considered more suited to developing an initial understanding of issues relevant to energy use and the delivery of personal energy feedback in commercial buildings.

Overview of the study

The Wi-be project is a multidisciplinary research study being undertaken by a consortium of three UK universities; De Montfort University (DMU), University of Nottingham (UoN), and Queen Mary, University of London (QMUL). The project aims to evaluate the feasibility of using low power wireless sensors, networks and communication devices to provide personal energy information to building occupants. Wi-be systems use wireless sensors to monitor people's energy use (e.g., heating, lighting, electrical appliances) and patterns of occupancy in buildings, along with environmental conditions, such as temperature and air quality. These data are used to give personal energy feedback that is disaggregated to specific end-uses (e.g., individual appliances), locations (e.g., rooms) and people.

The use of wireless sensors has a number of advantages over other "wired" forms of monitoring systems. The energy monitoring equipment can be installed and relocated relatively easily and there is usually no need for mains power supplies. The location tracking system being used by this study utilises a building's existing wireless infrastructures (Wi-Fi) to track individuals' patterns of occupancy through the use of wearable radio-frequency identification (RFID) badges (Ekahau 2012). By integrating tracking and energy use data, there is the potential to provide more detailed feedback that relates energy use to individuals and specific causes of wasted energy (e.g., if someone has left their computer on when they have left their workstation). The study is evaluating the use of Wi-be systems in a number of ways. From a technical perspective it is assessing the feasibility of developing Wi-be systems for real world use by investigating equipment configurations (e.g., location, power levels) and the practical limitations of using wireless sensor networks in buildings. Other work is exploring signal propagation and RF capabilities to inform future wireless sensor deployment. Behavioural research is evaluating people's responses to the systems. This has required the development of a multi-disciplinary methodology that integrates the expertise of partners from ICT, behavioural sciences and building engineering. Figure 1 summaries key elements of the multi-disciplinary approach and the main roles of the consortium partners.

The study is using a mixed methods design to collect qualitative and quantitative data with preliminary interviews being conducted to assess people's perceptions of Wi-be systems and energy use in buildings. At the heart of the study is the evaluation of these in two case study buildings; one commercial and one residential. Around ten people will be using the Wi-be system in the commercial building, which is located on the De Montfort University campus. The case study participants will be subject to energy and occupancy monitoring, and feedback interventions designed to encourage behaviour change. Regular interviews with case study participants will evaluate respondents' experiences of using the system (both positive and negative), the type of feedback they receive, and the process of behaviour change. These methods of data collection will be iterative whereby responses from participants will be used to optimise the system and the feedback that they receive. The energy use data will also be used to assess the effectiveness of the feedback delivered. At the end of the study further interviews and focus groups will be conducted to explore the results with a larger sample size.

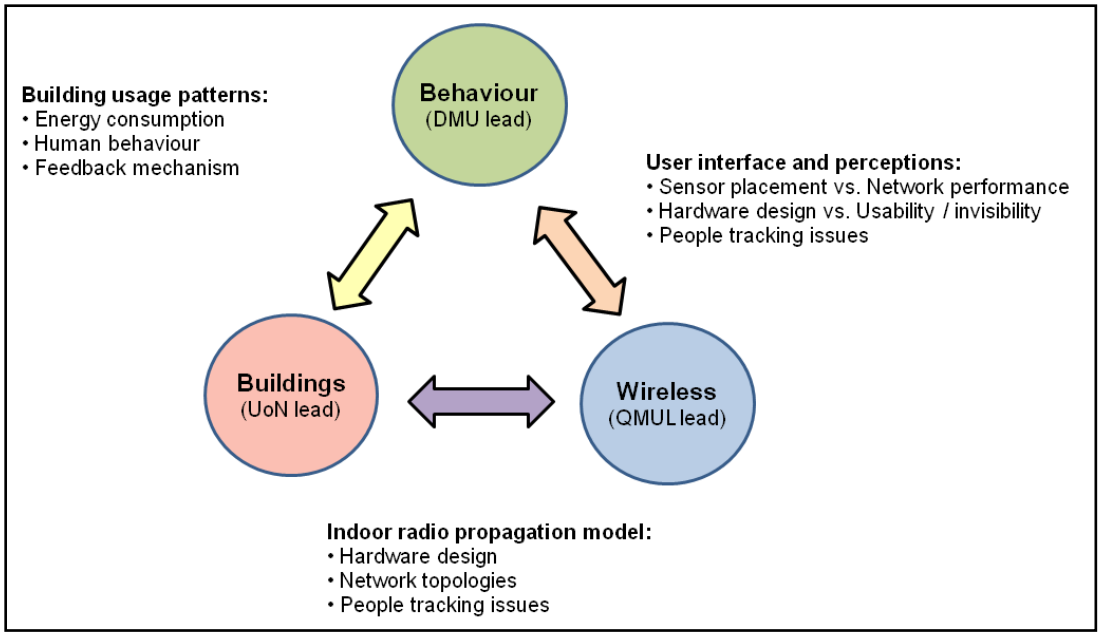

Figure 1. Overview of the integration of key roles and research areas of the Wi-be project consortium partners.

The following sections will integrate contemporary research on energy feedback with the initial findings from seven preliminary in-depth interviews that have been conducted with employees from the commercial case study organisation. These participants will not use the Wi-be system, but have been interviewed to explore people's perceptions of energy use and Wi-be systems from a larger sample. The four male and three female respondents were selected through a combination of purposive and "snowball sampling" to gain participants with a range of responsibilities for energy use in commercial buildings and consisted of: (i) two energy managers; (ii) one participant involved in the organisation's voluntary "environmental champions" initiative (established to develop an employee network to disseminate information and encourage environmentally responsible behaviour); (iii) four employees (including a fulltime research student) with no defined energy related responsibilities. The interviews were documented through hand-written notes and a voice recorder. They have been transcribed and an initial thematic analysis was undertaken and considered alongside the review of the current literature.

Results and discussion

Accuracy, disaggregation and personal feedback

Accurate feedback about energy use is a key requirement for both residential and commercial buildings and employees must perceive it "as reliable and contingent on their own behaviour" (Siero et al. 1996, 245). Research within non-residential buildings, as with residential ones, suggests the need for detailed and disaggregated feedback. For example, Komor, Kempton and Haberl (1989) found that store managers/workers could link specific patterns of behaviour (e.g., the use of particular appliances) more easily to feedback which showed hourly energy use. Schwartz et al. (2010) provided feedback in a German case study organisation in which office level feedback was initially provided but, following employees' requests for more detailed information, appliance monitoring equipment was introduced to provide disaggregated feedback. This allowed participants to link the information to more specific behaviours, to identify standby power consumption, and to

change their behaviour accordingly. The authors also contend that direct feedback could be an effective means to elicit energy reductions because it helps people to reflect more deeply on their energy using behaviour. Furthermore, the potential advantage of using occupancy tracking is suggested by the authors, who comment that an "option to support change of habits is to capture and track the personal activities and integrate this information with energy consumption data" (Schwartz et al. 2010, 460). Thus, individuals can evaluate, more accurately, energy use that is not directly attributable to the performance of their work activities.

Within the Wi-be interviews, the majority of participants indicated that the provision of personal energy feedback information would be useful. At present, feedback information (overall monthly gas and electricity use) is disseminated through the organisation, through quarterly reports, which shows historical energy use for each building. One energy manager respondent explained that the results of a "Christmas shut off" campaign were also fed back to employees. The campaign reduced electricity consumption by around 20%, in comparison to the previous year, saving the organisation around £6000. This information was being used to encourage employees to switch off unused equipment at weekends and in evenings. An energy manager respondent also highlighted that opportunities for the provision of more detailed feedback were being explored (including monthly feedback, and energy use disaggregated to the floor level in some of the buildings).

Both energy manager respondents indicated that the extra detail from the system could be a potentially useful tool to alter employees' behaviour. Other participants also stated that personal and disaggregated feedback would be useful. For example, one employee described a limitation of building level information:

> *...each individual intervention of turning a PC off every night doesn't show up on the building energy consumption because it's just too small.*

Similarly another employee said:

> *That would be interesting... because that would personalise it, because I think at the moment, it's quite difficult for us to actually see what our personal input is in that...*

Although the interviews suggest that most people would find personalised feedback of interest, this does not mean that it would always result in energy saving. For instance, an energy manager respondent highlighted that such feedback would be of little use in departments where employees rarely wasted energy. However, an employee respondent, an "environmental champion", indicated that personalised feedback could still be useful to someone already motivated to reduce energy use.

> *...it'd be one of those things where you'd think, oh, I never do turn that radiator down do I? You know, like I think I turn it down most of the time, er, but possibly I don't.*

Overall, the initial results suggest that the provision of personal, and disaggregated, feedback information would be of use to employees in this case study organisation. We will now consider how it might be delivered.

Medium and content

The effectiveness of feedback can be linked to how feedback is presented to users (Karjalainen 2011; Wood & Newborough 2007). Anderson and White (2009) investigated preferences concerning the functionality of residential feedback displays. Their findings reflect the wider psychology literature, which indicates the importance of balancing quantitative (e.g.,

numerical) and qualitative (e.g., analogue display) information and the balance between simplicity and extended functionality (Anderson & White 2009). Such characteristics would appear to be applicable to people whether in residential or commercial buildings. Unless an employee can make sense of, and be stimulated by, the information that they receive, the feedback is unlikely to be effective. This is apparent in recent studies in commercial buildings, which are exploiting information and communication technologies, such as interactive on line (serious) games, visualisation software, social network sites, and Web 2.0 products (e.g., Cowley et al. 2011; Lehrer 2009; Leher & Vasudev 2010).

Fischer's (2008) review found it difficult to draw conclusions concerning the expression of energy use in monitory terms, kWh or in environmental terms (e.g., CO_2). This was due to most of the reviewed studies combining electricity consumption and cost information. However, cost appears to be the most easily understood, and an often preferred unit of display (Raw & Ross 2011). Participants in Anderson and White's (2009) study made it clear that displays should "focus on money, on the cost of energy use, and not on power" (30). However, cost may not be easily transferable to the workplace due to most users not having a vested interest in paying energy bills. Cost may also be ineffective for motivating energy saving due to the relatively small financial savings that can be made from tackling some end-uses (Wood & Newborough 2007), different energy tariffs and tracking changes in the price of energy over time (Raw & Ross 2011). Crompton and Thøgersen (2009) suggest that framing feedback in economic terms may "crowd-out" moral motivations to save energy and reduce the potential for "positive spillover" (i.e. the adoption of one pro-environmental behaviour, may motivate the adoption of another). In order to optimise energy feedback it may be important to consider how elicited behaviour change can influence other energy related behaviours (e.g., transport, recycling, etc).

Participants in this study also suggest a need for appealing, accessible and meaningful feedback. One energy manager respondent had found that people generally wanted feedback "that would be bite-size and visual". An employee respondent explained that she was a "visual" person and that a reason for her losing interest in her home energy monitor was that it just showed numerical information. Also, for another employee respondent, information presented in technical terms (e.g., W, kWh, CO_2) was described as "over my head". Similarly, when asked about kWh information, another employee respondent said "I'm afraid that doesn't mean anything to me". However, for two employee respondents, more technical information did not appear to be an issue with one explaining that this reflected his "scientific" background.

The interviews also suggest that the use of monitory terms may have pros and cons. Although some participants related financial savings from energy conservation to job security, an energy manager and an employee highlighted that using monetary terms may have limitations, saying, respectively:

> *…one of the things I've always found is that if you don't pay for the energy, then it doesn't matter*.

> *…it's not coming out of my wage packet, it bothers me from an environmental point of view and it being a waste*.

An employee respondent also explained:

> *…I think part of the problem will be that if you try and cost it out per hour, people will look at it and say it's such a piffling amount, why is it worth doing? Why is it worth turning it off? Erm, rather than just engendering the habit of, just turn it off.*

Thus, using cost as a non-technical method to explain energy use as a mechanism for engendering behaviour change may not always be the most appropriate method in commercial

buildings. One approach, being considered by this study, is to simply feedback information about durations of use (i.e. "hours of use" information) – i.e. your computer was used for 8 hours today, but you were only at your desk for 6 of them. This approach is consistent with some responses from the interviews, because hours of use were often mentioned by participants. Nevertheless, in order to support the development of employees' energy literacy it may be beneficial to include other terms, such as kWhs.

Comparative feedback

Historical information appears to be an essential element of any feedback approach because it allows people to compare recent energy use to past levels of consumption (Darby 2006). Thus, people can see the effects of their behaviour change. Normative feedback (i.e. comparison to other energy users) has been used successfully in the workplace to motivate energy saving behaviour and has the potential to encourage competition (Siero et al. 1996). However, normative comparisons showing low energy consumption can indicate room for improved comfort levels, a feature which has been found to motivate increased energy use in homes (Brandon & Lewis 1999; Schultz et al. 2007). In response to this Schultz et al. (2007) found that the addition of an injunctive message (i.e. a happy face) led to continued lower energy consumption. It therefore appears that communicating good performance is vital to encourage continued energy saving.

There was some evidence from this study that both historical and normative comparison could help employees to reduce their consumption. An energy manager made the following comment when discussing comparisons to the average energy use of other building occupants;

> *I think people like to be able to compare themselves with others, but they also really like to compare themselves to past times, so, they know what they've done themselves, and that makes it easier for them to make sense of the figures.*

An employee also thought that normative comparisons could be useful:

> *...I think that would just make me think, well what am I doing that the others aren't? You know, why is my energy consumption more? So that doesn't bother me, I could only see that as a good thing.*

Other comments however, suggest that normative comparison must be treated with a degree of caution. While discussing the potential use of Wi-be systems in buildings, an employee said:

> *...I think it would be important to present it as part of the, er, sort of, overall, team effort. Rather than, we're going to point out how you're wasting De Montfort's money... Because I think that wouldn't go down very well.*

Although the above comment was describing the system as a whole, rather than comparative feedback directly, it highlights the need to consider people's perceptions of the underlying motive when providing comparisons to other employees. This is an issue explored in more detail in following sections.

Motivation

While normative comparison is one way to present feedback information to motivate behaviour change there are also additional levers to consider – e.g. goal setting, commitments and

competition. The use of rewards is an approach that appears to have a positive effect on energy saving, but their effect is often short lived (Abrahamse et al. 2005). While noneconomic factors could provide a source of motivation in residential buildings "relatively few feedback projects currently incorporate noneconomic levers such as goal setting, competitions, modelling, and social norms" (Ehrhardt-Martinez et al. 2010, 49). Work by Carrico and Riemer (2011) provides a recent example where energy savings were achieved in commercial buildings through feedback and peer education; the combination resulted in a reduction of around 8%. The authors note that their findings add to the literature which suggests that social support and peer influence can stimulate behaviour change when economic incentives are not present.

The potential benefit of such levers was also apparent, to a degree, in the Wi-be interview data. One employee mentioned that targets would help motivate the use of the feedback and another two employees suggested that tackling energy use as a team may help to motivate energy saving. The potential for peer support and education to motivate energy saving was also described by an employee who explained that the "green team" in the building had not only provided information, but helped to develop an office culture where "it's alright to turn things off".

Knowledge and control

A key theme throughout recent feedback literature is that energy feedback must be viewed as a tool to assist wider learning. Janda (2011) highlights that people generally have poor energy literacy and that when seen "in this context, the idea of relying primarily on energy feedback to deliver changes in behaviour seems rather peculiar" (Janda 2011, 19). This issue is apparent in previous examples relating to the limited understanding of energy units (e.g., kWh, W) and suggests that energy users need to be given broader support to improve their understanding of their energy use, how to reduce it, and why they should take action in the first place.

Data from the interviews also suggests that additional information is important. Most participants explained that they would need to know how to act on the feedback they were given. For example, one employee suggested how the lack of controls and knowledge of the building's heating system could sometimes result in occupants opening a window.

> *We'll that's annoying, because you think, well what's the point then? You need the information to make an informed decision of how to change your behaviour, to do something about it… if we don't know how things work or who controls those, you know, and then its, if we knew that, then we'd know which managers should be in charge of reducing, you know, its information.*

Control over energy end-uses was a common theme and participants often felt that the only energy end-uses that were in their full control were the equipment on their desks (e.g., computers, monitors, desk lamps, etc). Most participants viewed space and water heating, communal lighting, printers, photocopiers and kitchen equipment, as being subject to group dynamics and other external considerations. For instance, one employee had no control over the space heating in her work area and another employee made the following comment about it:

> *…apart from giving feedback to building management, there's no real control over the energy consumption of the heating system, I can say, oh it's too hot, or oh it's too cold, and hope for an adjustment on it, but that doesn't just depend upon me, because it has to work in with the other people using the same large space...*

In contrast to dwellings, occupants of commercial buildings are not fully in control of significant energy end-uses, such as space and water heating. This is an important issue for the use of Wi-be systems and raises the question of whether to disaggregate and feedback energy use when

an individual has no way to reduce it; a potentially frustrating position for the user. For example, Hargreaves et al. (2010) found that participants using home energy monitoring systems became frustrated at the lack of information to support purchase decisions. However, the following response by an energy manager highlights how additional feedback loops could improve the feedback systems' ability to address such situations.

> *Heating might not be under their control, but if somebody's feeling hot in a room, rather than opening the windows, if they can raise a ticket, ask somebody to come and check why, is the valve stuck in an open position, or is it too much heating... that sort of thing.*

It follows that to optimise energy feedback in commercial buildings it may be important not only to empower people through improved knowledge and information, but to improve their ability to control energy use, directly or indirectly through energy managers.

Privacy and ethics

One of the most important themes to emerge from the Wi-be interviews related to ethical implications of undertaking detailed energy monitoring and tracking of building occupants. Although the majority of participants said that they would be potentially willing to use the system all of them expressed varying degrees of concern about the potential invasion of privacy or that other colleagues would be concerned about being tracked at work. For example, when discussing the use of tracking sensors one employee said:

> *Part of me wants to say, well what's the problem with it, genuinely, you know, I'm not doing anything wrong so why does it matter if someone knows I've been into that building at that time, but then another part of me thinks, well why would somebody need to know all that? So, I'm a little erm, I'm torn with that one really…*

Another employee expressed a willingness to use the system, but said that this would depend on whether the information remained confidential. He went on to explain that some colleagues would probably have concerns about information being used to assess work performance:

> *…I think if people thought that the information might get back to someone who'll say, well you know, I see you were out of the office for an hour and 15 minutes, you know, at lunch time, what happened there? I mean that would, some people might worry about that.*

Similarly, a third employee suspected that some work colleagues would be worried that they might be reprimanded for the way they worked. Both the energy managers expressed concern that some employees would be reticent about being tracked at work and how that information would be used. One energy manager suggested that the system could be an interesting tool to help raise awareness, but believed people should not be monitored continuously. For one employee, the notion of using tracking was an unacceptable invasion of privacy. She explained:

> *…I think it's absolutely shocking, I think it's a level of surveillance that is encroaching on civil liberties... I think it's one thing to be providing feedback to individuals about their appliances, I think it's quite another [to track occupancy] …*

Although the ethical issues evident in this study are likely to have been heightened by the inclusion of occupancy tracking, the potential to use appliance level monitoring for surveillance purposes must not be overlooked. Schwartz et al. (2010) found that employees were concerned over

the misuse of energy monitoring data to track and assess work performance. As a result, they emphasise that it is:

> "*essential for employees to remain owners of their energy consumption information and to be made able to govern the flow of this information, as its interpretation can be very ambiguous and motivate misuse*" (Schwartz et al. 2010, 461).

Privacy concerns for household smart meters have been highlighted by Darby (2011) and Hargreaves et al. (2010) also emphasise that there is clear potential for in-home displays to enable new types of surveillance to occur within households. The authors contend that such ethical issues must not be ignored in the evaluation of the effectiveness of energy monitoring systems that provide real-time feedback (Hargreaves et al. 2010). Initial findings from this study support this notion and highlight the importance of ensuring that monitoring information remains confidential and is only used for energy reduction purposes. This implies that Wi-be systems should only be used with the full and voluntary commitment of users. Furthermore, it highlights that there must be a strong degree of trust between the people using the system and individuals managing the data. Without this, the use of Wi-be systems may be counterproductive and, in common with other aspects of organisational change, potentially damaging to other aspects of organisational dynamics (Lemon, Graig, & Cook 2011).

Conclusions

It is misleading to suggest firm conclusions from the preliminary results presented. Nevertheless a number of issues have emerged that are of value to research in this field. The literature suggests that many of the approaches used to deliver energy feedback information in residential buildings are applicable to commercial settings. These include the provision of direct and disaggregated feedback, combined with interactive, tailored, understandable and appealing content. The delivery of feedback information must also be seen as part of a wider approach that provides motivation, "know how", and improved energy literacy. The use of technical terms, such as kWh and Watts, may also be inhibited by people's limited technical knowledge. In contrast to residential buildings, presenting feedback in terms of cost may be less appropriate in non-residential contexts due to building occupants not paying energy bills. Initial findings from the interviews for this project suggest that the effectiveness of personal feedback in commercial buildings may be inhibited by the level of occupant control over communal energy end-uses, including space and water heating. However, empowering employees to indirectly control energy use, through an additional feedback loop to energy managers, may help to address this issue. Importantly, the ethical issues associated with the expansion of energy monitoring and occupancy tracking must be addressed. These issues have received relatively little attention in many previous studies, but it is apparent that concerns over confidentiality, surveillance and the misuse of data (e.g., to assess employees work performance) could undermine the potential energy reductions associated with feedback information. These are issues that this project will continue to explore as the research progresses.

References

Abrahamse, W., Steg, L., Vlek, C., and Rothengatter, T. 2005. "A review of intervention studies aimed at household energy conservation". *Journal of Environmental Psychology* 25: 273-291.

Anderson, W., and White, V. 2009. *The smart way to display.* London: Energy Savings Trust.

Brandon, G., and Lewis, A. 1999. "Reducing Household Energy Consumption: A Qualitative and Quantitative Field Study". *Journal of Environmental Psychology* 19: 75-85.

Bruhns, H. 2008. "Identifying Determinants of Energy Use in the UK nondomestic Stock". In *Proceedings of the 5th International Conference on Improving Energy Efficiency in Commercial Buildings: IEECB Focus 2008* 2: 389-400.

Carrico, A. R., and Riemer, M. 2011. "Motivating energy conservation in the workplace: An evaluation of the use of group-level feedback and peer education". *Journal of Environmental Psychology* 31: 1-13.

Cowley, B., Moutinho J. L., Bateman, C., and Oliveira, A. 2011. "Learning principles and interaction design for 'Green My Place': A massively multiplayer serious game". *Entertainment Computing* 2: 103-113.

Crompton, T., and Thøgersen, J. 2009. *Simple & painless? The limitations of spillover in environmental campaigning*. Godalming: WWF-UK.

Darby, S. 2006. "The Effectiveness of Feedback on Energy Consumption". Report for DEFRA. Environmental Change Institute, University of Oxford.

Darby, S. 2010. *Literature review for the Energy Demand Research Project*. http://www.ofgem.gov.uk. Environmental Change Institute, University of Oxford.

Darby, S. J. 2011. "Metering: EU policy and implications for fuel poor households". *Energy Policy* doi:10.1016/j.enpol.2011.11.065.

Ehrhardt-Martinez, K., Donnelly, K. A., and Laitner, J. A. 2010. *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities*. Report No. E105 for American Council for an Energy Efficient Economy.

Ekahau, 2012. *Solutions overview*. http://www.ekahau.com/solutions/solutions-overview.html. Ekahau, Inc.

Fischer, C. 2008. "Feedback on household electricity consumption: a tool for saving energy?" *Energy Efficiency* 1: 79-104.

Gardener, G. T., and Stern, P. C. 2002. *Environmental Problems and Human Behaviour, 2nd edition*. Boston: Pearson Custom Publishing.

Hargreaves, T., Nye, M., and Burgess, J. 2010. "Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors". *Energy Policy* 38: 6111-6119.

Janda, K. B. 2011. "Buildings Don't Use Energy: People Do". *Architectural Science Review* 54: 15-22.

Karjalainen, S. 2011. "Consumer preferences for feedback on household electricity consumption". *Energy and Buildings* 43: 458-467.

Komor, P., Kempton, W., and Haberl, J. 1989. *Energy Use, Information, and Behavior in Small Commercial Buildings – PU/CEES Report No. 240*. Princeton: Princeton University.

Lehrer, D., 2009. *Research Scoping Report: Visualizing Information in Commercial Buildings*. Interim Report to the California Energy Commission PIER Program, September. http://cbe.berkeley.edu/research/pdf_files/Lehrer2009-IR-Visualizing.pdf.

Leher, D. and Vasudev, J. 2010. "Visualizing Information to Improve Building Performance: A Study of Expert Users". In *2010 ACEEE Summer Study on Energy Efficiency in Buildings*, Washington D.C. 7: 141-153.

Lemon, M., Craig, J., and Cook, M. 2011. "Looking In or Looking Out? Top-down Change and Operational Capability". *Historical Social Research* 36 (1): 143-159.

Nye, M., and Hargreaves, T. 2009. "Exploring the Social Dynamics of Proenvironmental Behavior Change – A Comparative Study of Intervention Processes at Home and Work". *Journal of Industrial Ecology* 14 (1): 137-149.

Raw, G., and Ross, D. 2011. *Energy Demand Research Project: Final Analysis – Appendix C: Review of the Literature on Interventions used in EDRP*. Ofgem, AECOM Limited.

Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., and Griskevicius, V. 2007. "The Constructive, Destructive, and Reconstructive Power of Social Norms". *Psychological Science* 18 (5): 429-434.

Schwartz, T., Betz, M., Ramirez, L., and Stevens, G. 2010. "Sustainable Energy Practices at Work: Understanding the Role of Workers in Energy Conservation". In *Proceedings of NordiCHI 2010, October 16-20, 452-462.*

Siero, S., Boon, M., Kok, G., and Siero, F. 1989. "Modification of Driving Behavior in a Large Transport Organization: A Field Experiment". *Journal of Applied Psychology* 74 (3) 417-423.

Siero, F. W., Bakker, A. B., Dekker, G. B., and van den Burg, M. T.C. 1996. "Changing Organizational Energy Consumption Behaviour through Comparative Feedback". *Journal of Environmental Psychology* 16: 235-246.

Wood, G., and Newborough, M. 2007. "Energy-use information transfer for intelligent homes: Enabling energy conservation with central and local displays". *Energy and Buildings* 39: 495-503.