Householder Experiences with Resource Monitoring Technology in Sustainable Homes

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ABSTRACT
The use of feedback technologies, in the form of products such as Smart Meters, is increasingly seen as the means by which ‘consumers’ can be made aware of their patterns of resource consumption, and to then use this enhanced awareness to change their behaviour to reduce the environmental impacts of their consumption. These technologies tend to be single-resource focused (e.g. on electricity consumption only) and their functionality defined by persons other than end-users (e.g. electricity utilities). This paper presents initial findings of end-users’ experiences with a multi-resource feedback technology, within the context of sustainable housing. It proposes that an understanding of user context, supply chain management and market diffusion issues are important design considerations that contribute to technology ‘success’.

Author Keywords
Behaviour change, feedback, residential, resource monitoring, smart meters, technology interface.

ACM Classification Keywords
H.5 Information Interfaces and presentation; H5.2 User Interfaces; user-centred design.

INTRODUCTION
Climate change, resource depletion and increasing urbanisation are converging global issues that are challenging the way we design, construct and operate buildings. The housing sector is a significant contributor to these global issues through consumption of limited resources, waste (solid/liquid/atmospheric) disposal and negative human health impacts (Senick, 2006). To reverse the negative environmental impacts of human activity, a number of approaches are being adopted globally, including policy change, market reform, technology development and the active engagement of citizens in the change processes required (Sachs, 2008; Seymour, 2008). Increasingly technology, specifically eco-feedback technology (Froehlich, Findlater, & Landay, 2010) has been seen as a major means of driving behaviour change towards sustainability. A key example of this is a group of products that are collectively labelled “Smart Meters” which focus on changing and controlling electricity consumption. The assumption of these feedback technologies is that if occupants are able to see real time consumption, they will make informed decisions about their consumption choices and practices (Rosta, Hurt, Boehm, & Hale, 2008). Electricity Smart Meters are driven primarily by energy utilities who wish to implement two way communications and control capabilities between their networks and end customers, enabling better utilisation of network assets as well as the potential for greater integration of distributed renewable energy technologies (collectively referred to as a “Smart Grid”). Most feedback technologies to date have focused on one particular resource, typically electricity. The purpose of this paper is to present preliminary findings of end-user experiences with a specific multi-resource feedback technology and to discuss their experiences in the context of implications for product design.

METHOD
This paper, utilising an extended case study, adopts a qualitative approach to evaluate participant experiences of a specific eco-feedback technology and to propose the implications of their experiences on the design of such technologies.

Housing Context
The physical context of the case study is an ecovillage in sub-tropical Queensland, Australia. The estate’s extensive and prescriptive building code encompasses the triple bottom line of environment protection, resource management and social cohesion. An Intelligent Metering and Control System (IMCS) is required to be installed in each house in order to measure and display usage of resources involved in each utility service (electricity, water, gas) and provide real time and historic display of the resource consumption within each residence. Additional purposes of the IMCS are to a) enable the aggregation of end use data at a community level, allowing benchmarking both within the community and with other communities; b) enable the community to optimize its utility infrastructure with a view to future self sufficiency at an estate level; and c) use the data to inform policy and regulation. EcoVision is the specific IMCS product adopted in the ecovillage. Its specifications, categorized according to key eco-feedback characteristics (Fischer, 2008; Froehlich, 2009), are shown in Table 1.
Figure 1 depicts the home page. At the time of the study (January – June 2010) there were 50 constructed and occupied homes in the ecovillage, just over 1/3 of planned residences. Approximately 40 of these houses had an EcoVision system installed.

Table 1: IMCS/eco-technology feedback characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>EcoVision characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>Continuous</td>
</tr>
<tr>
<td>Duration</td>
<td>Continuous</td>
</tr>
<tr>
<td>Content</td>
<td>Electricity/gas/water consumption; electricity generation; thermal comfort; water tank levels; cost; carbon emissions</td>
</tr>
<tr>
<td>Breakdown</td>
<td>Electricity: plug in appliances, lighting, water pumping; Water: potable, recycled, hot water; comfort: temperature/humidity</td>
</tr>
<tr>
<td>Data granularity, reporting units</td>
<td>Electricity (0.3125Wh; kWh); Water (1 litre; litres); Gas (10 litres; litres); Thermal comfort 5sec. sampling</td>
</tr>
<tr>
<td>Presentation medium</td>
<td>Interactive touch screen; service and time specific break downs on request</td>
</tr>
<tr>
<td>Presentation mode</td>
<td>Pragmatic visualization: Bar and line graphs: slight differences for each service</td>
</tr>
<tr>
<td>Comparisons</td>
<td>Historical (hour, day, week, month) No normative yet (planned)</td>
</tr>
<tr>
<td>Other instruments</td>
<td>Social networking (Intra-community benchmarking not yet functioning)</td>
</tr>
<tr>
<td>Additional information</td>
<td>No prompting strategies / messages</td>
</tr>
</tbody>
</table>

Figure 1: Ecovision home screen for weekly data

Participants
Participants for this case study were seven volunteer families (13 adults), representing 14% of the completed residences in the Ecovillage at the time of the study. Each family had had EcoVision installed in a new home in the period 2007 – 2010. All families live in detached off-ground dwellings (1-3 bedrooms), and household occupancy rates range from 1-3 people. Quotations from families are indicated by F1, F2 etc after each quotation.

Interviews
These families were interviewed in their homes regarding their broad experiences of the design, construction and operation of their ‘sustainable homes’. These recorded semi-structured interviews incorporated global environmental issues, overall goals for their home, and their design and construct experiences. The recorded interviews were transcribed and coded to condense and categorise the data into key themes. The IMCS emerged as a recurring topic under several themes, but especially arose in discussions of water and energy systems performance, in the context of a common major household sustainability goal of low running costs. Follow-up interviews, focusing solely on IMCS issues, were conducted where necessary to clarify and explore in more depth issues raised in the initial interviews. Broader community views of the IMCS were noted from adhoc comments, by way of casual conversations, as well as from conversation threads on the community’s intranet. Ecovillage resident experiences were compared with preliminary findings (unpublished) from an estate in South Australia (involving 10 households, 16 individuals) that deploys the same technology.

RESULTS
Resource consumption goals and management
The seven families shared a long term approach to their homes: they designed homes to meet both immediate and long term family needs, and immediate and life-time sustainability goals. Another commonality was the need to ensure that the resultant home had low operational costs, particularly in terms of energy and water. The driving motivations for low resource consumption were financial (minimizing monthly operational costs in the long term) and/or ethical (i.e. a value decision based on sustainability goals). Three key themes relating to the specific resource management technology emerged: product comprehension; product utilisation; and product development, support and reliability.

Product comprehension
Generally the level of knowledge about the technology, in terms of its purpose, the extent of its functions, and how to interrogate it to extract the desired information, was quite low. This was true for the seven households and appears to be reflective of the general community. This was revealed through lack of end-user knowledge about what features their particular model of the product had or lack of knowledge about how to use the product:

I don’t know what to do. Can you show me? (F7)

This lack of knowledge about how to use the product did not apply to the whole product, but rather different ‘screen views’ relating to different resources. No household could explain the information contained in each of the screens. Most families appeared to be able to interpret the electricity consumption and generation screen, the most utilised screen for all households.

It’s easy. You look at the diagram, and see what we are using in orange and what we are earning in yellow (F6).

The ‘cost’ and ‘greenhouse gas’ screens did not appear to be used by any household. The extent to which individuals interacted with other screens (e.g. water, gas, temperature, tank levels) , seemed to be dependent on individual interests and knowledge of particular resources and the importance of that resource to the household at that time. In the broader community, household knowledge of the system was often not sufficient to enable them, without assistance from other people within
the community, to identify any anomalies in their resource consumption or to identify any system failures (e.g. if an individual meter had stopped transmitting.)

**Product utilisation**

Interview data, casual conversations with residents and intranet discussion threads revealed five categories of household use of the IMCS: low/no use, specific behavior change, self-awareness, fault detection and extended applications.

**Low-use**

A small group of residents had either not installed an IMCS or had not utilised their installed system. Their motivations for non-use were not explored as part of this study, although issues of cost versus real or perceived benefit were mentioned on the intranet discussion threads. Preliminary findings from a current South Australian study of the same technology reveals that less likely to make much use of the EcoVision system. Attitudes such as ‘already sufficiently responsible and prudent’ were expressed, and the non-users, as a group, were considered to be less likely to be ‘motivated to actively monitor their use and modify their behavior in relation to feedback from smart meters’ (Edwards, 25/8/2010).

**Specific behaviour change**

Developers of the IMCS did not specify what behaviours were expected to change, nor how. Two specific behavior changes were mentioned by end-users. Firstly, EcoVision was the catalyst for developing and implementing a household level resource management plan (for water).

> We have a personal thing now. We have now as long a shower as we want when we have plenty of water, but when we hit 75% we go straight into [your own water management strategy]? Yes, exactly the same as for town water people, only we monitor it through EcoVision, which is why we love it. (F5)

Secondly, EcoVision was the catalyst for tracking resource consumption goals and taking action:

> I’ve now got a quote on my desk to add an extra .5 or 1Kw [photovoltaic panels] because our information on EcoVision shows that we are using more than we are generating. And that’s embarrassing and I’m going to do something about that. (F6)

Interestingly households elaborated on a range of other uses of the technology that may be pre-cursors to change.

**Convenience and self-awareness**

The convenience of having readily accessible (in the house) information was acknowledged:

> We could go outside and tap on the tanks, but we just go and press the button and see where we are (F5).

Benchmarking of actual consumption and comfort levels compared to goals and expectations, occurred at a household level. A level of informal community benchmarking was also evidenced.

I have used it to compare the outputs of my PV system with other 1Kw systems and discovered, to my chagrin, that mine is underperforming. It’s consistent but it’s the lowest 1Kw system in the village. (F3)

Additionally, the in-house monitoring of solar power, solar hot water, rainwater collection, recycled water use and internal comfort levels appeared to be nurturing a deeper understanding of the households’ relationship with, and reliance on, the natural elements.

**Equipment performance and fault detection**

Because energy, water and gas meter data was displayed on the one screen, it was possible, for individuals who understood and could interpret the data on the screens, to use the system as a means of determining if the connected technologies were working properly. To this extent, the EcoVision system has been used to identify the impact of shading on photovoltaic systems; the breakdown of inverters; water leaks; faulty hot water systems and gas burners unintentionally left on.

**Extended application**

One resident identified that he could extend the functionality of the EcoVision system to control the performance of his solar water heater, eliminating the need to purchase additional hardware to perform this task.

> I’ve had to develop my own control mechanism, so the ICMS gets the data from the photovoltaics meter in the box...puts the pump on in proportion to how much sun there is... It’s great.

**Product development, support and reliability**

Three general product diffusion issues arose. Firstly, the cost of the system was a major issue for residents who actively engaged with the product and those who felt they had no need for such a product. Secondly, the lack of product support was a common complaint (no in-house training at the point of installation, limited on-screen help functionality, and delayed publication of a user manual). This perhaps reflects little understanding or tolerance of technology diffusion stages. Thirdly, there were recurring problems with the reliability of the front end meters and sensors, and on the poor practices of tradespersons who install the meters and wiring required for interconnection to the IMCS. These problems are attributed, by end users, directly to the IMCS.

**DISCUSSION**

These findings raise three key issues that conceivably impact on designers of feedback technologies.

**Product Design Intent: End-user focus**

Understanding the user context is essential prior to the development of feedback technologies. One design intent of EcoVision’s designers, that of enabling occupants to offer demand side capacity back to electricity utilities (Maddox, 2008), is of little use in the ecovillage, as high energy use appliances such as air conditioners are not permitted and electricity demand is already 70% below the regional average household consumption (Hood, Gardner, Beal, Gardiner, & Walton, 2010). Arguably, environmentally aware consumers want a technology that
helps them to understand, control and manage their household metabolism, requiring different design approaches (Goldblatt, Hartmann, & Durrenberger, 2005). Additional features (beyond behaviour change) suggested by end-users could alter the ‘value proposition’ that the technology currently offers: a) the capability to display important community notices; b) the capability to enter other resource consumption data, such as vehicle fuel and food; c) enabling input of household details and goals; and d) extending to full internet capabilities to enable use for activities such as social networking.

**Importance of managing the supply chain**

The design of feedback technologies requires more than identifying device and interaction design characteristics and programming and delivering the device. Designers need to understand and consider the whole product supply chain: the accuracy and robustness of the meters and sensors, the reliability and installation ease of any interconnectors, and the professionalism of installers of these components. A failure in any part of this supply chain is seen as a product failure by end users. This carries reputational risks for product designers and suppliers, and financial risk for suppliers and end-users.

**Managing market diffusion**

This particular eco-feedback technology is in the early stages of both technology development and market diffusion. One of the difficulties of such an innovative and complex product is that it is difficult to fully development before deployment in the market, but this presents risks to both the technology developer and the end user. The opposing views of those who did and did not use the technology could be explained through market diffusion theory: end-users as early adopters (conceivably the 7 case study families) and the early majority. These market segments have different motivations and expectations, with the latter of these segments being less tolerant of ‘early stage’ imperfections in technology performance, and more sensitive to the high price of new technologies, when compared with early adopters (Caird, Roy, & Herring, 2008; McCoy, Thabet, & Badinelli, 2009). One could argue that mandating the technology forced the early majority group into a situation they would not normally place themselves. Conversely, if the technology had not been mandated at the estate development stage, the opportunity for such inclusive resource monitoring would have been lost. An understanding of market diffusion could have assisted both the technology developer, and the estate developer, to minimize risks and implement strategies to provide for the needs of both groups of end-users. One such strategy may have been to provide financial incentives for the early adopters to inform further product development and marketing (Faiers & Neame, 2006) that would enhance the reliability and reduce costs for the early majority.

**CONCLUSIONS**

Feedback technologies are considered instrumental in changing consumer behaviour in terms of sustainable resource consumption, however the developers and designers of such technologies can make assumptions about end users that results in designs being too focused on one particular resource or on the particularities of screen representations. These end user experiences provide insights that suggest that the framework of designing feedback technologies needs to be expanded to include greater emphasis on user context, supply chain management and market diffusion strategies.

**REFERENCES**


