Making it obvious: designing feedback into energy consumption

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ABSTRACT

The process of giving feedback on consumption motivates consumers to save energy through reduced waste, yet the body of evidence testifying to this is rarely acted upon in any systematic way. The paper reviews the literature on the effectiveness of three types of feedback to domestic consumers: direct feedback in the home, indirect feedback via billing and 'inadvertent' feedback (a by-product of technical, household or social changes). The lessons learned on the importance of clear, immediate and user-specific information are then applied in a survey of the opportunities for better feedback to consumers in terms of technology, design and location of meters and display panels, energy billing and services such as audits and advice programmes.

The paper concludes that feedback has a significant role to play in raising energy awareness and in bringing about reduced consumption of the order of 10%; and that opportunities exist for designing it into energy-related systems which have yet to be realised.

INTRODUCTION

While some aspects of energy usage may be highly visible, domestic energy consumption as such is largely hidden from view. This 'invisibility' hampers our ability to learn about how to use energy more intelligently and less wastefully. Evidence from the survey of implementation of the EU directive on labelling of cold appliances in the EU indicates that 'the message about energy saving and the environment has been noted by consumers in every country', but that few actually link the importance of energy saving to their own personal behaviour (Winward et al, 1998). 'Noting' a message is clearly not enough to spur people to action: much work remains to be done to build on a low level of awareness of a need to save energy, by developing peoples' ability to identify what can be done in *specific* terms to improve the situation.

This paper begins an investigation into *the extent to which householders can teach themselves* about energy usage in the way in which they teach themselves about so many other things: by using feedback signals from their own actions and their own consumption.

CONCEPTUALISING ENERGY

How do we think of energy? At the level of the individual consumer, in three main ways:

as a commodity, a social necessity and an ecological resource (though see Sheldrick and Macgill, 1988, for a fuller account). All of these suggest ways of making consumption more visible, while pointing to shortcomings in policy and practice aimed at carbon reductions.

.1 1. Energy is a *commodity*: much policy is based on this conception. With the liberalisation of utilities, customers have become more aware of fuel price, but most only have fleeting contact with the financial cost of their energy services, when they receive a bill or bank statement or if they change their fuel supplier. Those who are constantly reminded of their usage because they rely on solid or 'packaged' fuel, or because they pay in advance for energy, are in a minority. For the rest, individual metering and prepayment send stronger signals about usage than group metering and payment in arrears (Birka Teknik og Miljo, 1999). For the majority who pay in arrears for their energy, billing can be developed in ways which send more frequent and clearer messages to customers (Kempton, 1995; Wilhite and Ling, 1992).

.2 2. Energy is a *basic human need*: in that sense, it is most noticeable when in short supply. Users of modern energy systems, and especially those living in poverty, need to be able to understand how to control their energy to best effect and to have access to help when it is needed. Feedback and information systems must be as accessible, clear and simple as possible in order to allow for this.

.3 3. Energy is an *ecological resource* – that is, energy use never occurs without side-effects. Production of energy for human use requires mining, tree felling, the growing of fuel crops, gas and oil extraction, the construction of dams, pipelines, power lines and power stations. Some of this production may be highly visible in a localised way, so that there is a vague awareness of the ecological dimension of energy; but electricity and gas, along with carbon dioxide and other waste gases, are largely invisible in consumption. This invisibility comes about in a number of ways: through connection to huge hidden distribution networks; through lack of thought about energy unless it becomes expensive or suddenly scarce; through design for convenience or utility rather than for visibility and learning; and through obscure metering and billing systems.

These conceptions of energy show consumption to have extensive financial, social, ecological and cultural aspects that are inadequately recognised, not least because they are often obscured. It is becoming more and more clear that existing policies aimed at increased efficiency, fuel switching and development of renewables cannot bring about savings in carbon in the timescale necessary to stave off significant climate change. The recent UK study of *Lower Carbon Futures*, for example, concludes that a scenario which does not involve any change to lifestyle, behaviour or standards of service 'will not achieve, by 2020, the reductions in carbon emissions needed to achieve sustainability by 2100. To do so requires behavioural change. Some of this can be encouraged through policy changes, particularly provision of information and feedback to consumers' (Fawcett et al, 2000).

HOW FEEDBACK WORKS

Feedback is defined as *The modification, adjustment or control of a process or system … by a result/effect of the process, especially by a difference between a desired and an actual result; information about the result of a process, experiment etc; a response.* Oxford English Dictionary, 2000

This definition is here applied to the process of learning. Observation of a young child quickly shows how fundamental feedback is as an element in early learning, but we tend to forget that it remains crucial throughout life:

> *We are obliged to act…as intelligently as possible in a world in which…we know very little, in which, even if the experts know more than we do, we have no way of knowing which expert knows the most. In other words, we are obliged to live out our lives thinking, acting, judging on the basis of the most fragmentary and uncertain and temporary information. The point of all this is that this is what very young children are good at doing…The young child is continually building what I like to call a mental model of the world, the universe, and then checking it against reality as it presents itself to him, and then tearing it down and rebuilding it as necessary…We have got to learn…this business of continually comparing our mental model against reality and being willing to check it, modify it, change it, in order to take account of circumstances.* - Holt, 1970

Such an approach to learning helps to explain why environmental information and education do not necessarily lead to behavioural change. Learning is an active process and learning about practical issues is related to 'reality as it presents itself'. Environmental policy aimed at reducing energy use has failed so far to recognise adequately the crucial link between our (generalised) sense of our environment and our (specific) daily needs and actions: there is a need to extend expertise much more widely and to do so by focusing on how people *connect* their lives to the environment (Eden, 1996)

Policymakers have a major contribution to make in providing a 'toolkit' for householders that enables them to learn how to do this. Such a toolkit can be immediate and tangible – as with better direct displays of energy use – but the concept can also be extended to the cultural context (see, for example, Bruner, 1996). Opportunities for learning about energy from the daily usage in homes could connect with learning in the local community, or from interactions with utilities, government and government agencies.

Two general approaches to cutting carbon can be observed. The first begins with identification of carbon reduction targets and aims to meet them in the most efficient way by identifying promising areas for reduction in the hope of persuading or ordering people to implement the necessary actions. The second begins from existing patterns of energy use in their cultural context and looks at needs and aspirations, aiming to identify processes by which people might come to use energy in more environmentally-friendly ways. This paper is concerned more with the second approach: with the processes by which people may learn, by trial and error, to use energy in an ecological fashion.

FORMS OF FEEDBACK

The literature on feedback on domestic energy use is limited, but it does supply some pointers as to the approaches most likely to be successful in bringing about energy conservation. A typology, with some examples, provides an outline of what is possible:

A. Direct feedback: available on demand. Learning by looking or paying.

.1 (a) *Direct displays*, such as those tested in Canada and Japan (Dobson and Griffin, 1992; Tanabe, 2000). Customers who have their supply metered in the standard way are unlikely to consult their meter: it will probably be hidden away and difficult to understand. Some more attractive and user-friendly displays of energy usage have now been tested, and the indications are that these do lead to energy savings as well as to increased awareness (eg Tanabe, 2000; Mansouri and Newborough, 1999). An additional benefit is likely to be that better-designed meters will have an appeal because of they will be seen as high quality products: this appears to be the case with high-efficiency cold appliances (Winward et al, ibid).

.2 (b) *Interactive feedback* via a PC has shown promise and is an obvious candidate for further development (Brandon and Lewis, 1999). Some utilities (eg Scottish and Southern Energy) already offer this service to large business customers.

.3 (c) *Smart meters*. Possibilities include meters operated by smart cards (Birka Teknik & Miljo, 1999) and two-way (automatic) metering (Sidler and Waide, 1999; Kennedy, 1999).

.4 (d) *Trigger devices/consumption limiters*. These are contentious because they can cut the supply of low-income consumers. However, there are possible solutions to this, such as that in use by EdF for providing such customers with help from social services (Ranninger, pers comm.)

.5 (e) *Prepayment meters.* The continued usage of these meters by consumers on low incomes in the UK - in spite of the extra cost - is an indication of the high importance attached to debt avoidance and the value of direct feedback to people with limited resources (Doble, 1999).

.6 (f) *Self-meter-reading*. The review below shows the value of this as part of an effective feedback programme.

.7 (g) *Meter reading with an adviser,* as a tool in energy advice programmes (see LEEP, 1996; Harrigan, 1992).

.8 (h) *Cost plugs* or similar devices on appliances (though they tend to be complicated to operate and can be unreliable).

B. Indirect feedback – raw data processed by the utility and sent out to customers. Learning by reading and reflecting.

.1 (a) *More frequent bills*, based on meter readings rather than estimates (Wilhite and Ling, 1992; Arvola et al, 1994).

.2 (b) *Frequent bills based on readings plus historical feedback* - comparison with the same period of the previous year, weather-adjusted. (Wilhite and Ling, 1995).

.3 (c) *Frequent bills based on readings plus normative feedback* - comparison with similar households. (Kempton and Layne, 1994; Wilhite et al, 1999).

.4 (d) *Frequent bills plus disaggregated feedback.* This is relatively expensive, though popular when tested (Wilhite et al, 1999). The NIALMS and DIACE systems allow for automatic end-use breakdown by pattern recognition (Sidler and Waide, 1999).

.5 (e) *Frequent bills plus offers of audits or discounts on efficiency measures*. Frequent, informative bills can stimulate a demand for audits by raising awareness (see Lord et al, 1996).

.6 (f) *Frequent bills plus detailed annual or quarterly energy reports.* See Wilhite et al (1999) and Kempton (1995).

C. Inadvertent feedback – learning by association

There is little in the way of literature on this, but there are pointers to the potential for such feedback.

.1 (a) *New energy-using equipment* in the home, when a person moves house or when there are changes in the physical fabric of the dwelling, provides an opening for effective 'opportunistic' advice (Green et al, 1998).

.2 (b) With the advent of solar water heaters and photovoltaic arrays, the home can become a site for *generation* as well as consumption of power and it is highly likely that this causes increased observation of energy use and a shift in thinking.

.3 (c) A further possibility for inadvertent feedback is the development of community energy conservation projects, with their potential for *social learning* (see, for example, Sharpe and Watts, 1992).

Two further types are worth noting in passing. They are:

D. Utility-controlled feedback – learning about the customer

Utility-controlled feedback is not designed with householders' learning in mind, but it is rapidly being developed and debated with a view to better load management.

E. Energy audits

Audits are included here because they provide vital baseline information on the 'energy capital' of a dwelling as well as giving guidance on how to improve it. Audits may be

.1 *(a) undertaken by a surveyor on the client's initiative*

.2 *(b) undertaken as part of a mortgage or other mandatory survey*

.3 (c) *carried out on an informal basis by the consumer* using freely available software such as HESTIA or the UK 'EcoCal'. A series of audits can give a stream of feedback, guiding a motivated consumer towards a target consumption. More formal audits are likely to be infrequent, but can still indicate degrees of progress.

The diagram in Figure 1 shows some of the types on two axes, approximately related to the level of immediacy and the extent to which the energy user is in control of finding and using the information:

Immediate/frequent

Smart- card metering prompts from utility bills from utility

other-directed

annual energy report

homebuyer's audit

in-house display prepayment metering self-meter-reading meter reading with

adviser

user-directed

installation of new equipment

self-audit questionnaires audit on demand

Single event

Figure 1: feedback in terms of immediacy and control

If feedback is to promote learning, the discussion above would suggest that immediacy and control of the process by the user would tend to lead to the most effective feedback. What does the literature show?

FEEDBACK EFFECTIVENESS – A REVIEW

A review of 38 feedback studies carried out over a period of 25 years demonstrated the possibilities of some types of feedback and also some of the issues which affect interpretation of the results. A number of difficulties arise in comparing, and even categorising, these studies: all contain a different mix of elements such as sample size (from three to 2,000), housing type, additional interventions such as insulation or the provision of financial incentives to save, and feedback frequency and duration. The timing of the study itself may also be significant in relation to the energy politics and research paradigms of the period. In spite of these areas of uncertainty, though, some lessons can be learned from the review.

First, feedback has a significant part to play in bringing about energy awareness and conservation. Savings achieved by the 38 projects were as follows:

Table 1: savings demonstrated by the feedback studies

Savings	**Direct feedback studies** (n=21)	**Indirect feedback studies** (n=13)	**Studies 1987-2000** (n=21)	**Studies 1975-2000** (n=38)
20%	3		3	3
20% of peak			1	1
15-19%	1	1	1	3
10-14%	7	6	5	13
5-9%	8		6	9
0-4%	2	3	4	6
unknown		3	1	3

Awareness is more difficult to assess, but an increase in awareness was noted in half of the studies and some continuing or additional effect in 11.

While it is not possible here to go into the detail of each study, it appears that *direct feedback*, alone or in combination with other factors, is the most promising single type, with almost all of the projects involving direct feedback producing savings of 5% or more. The highest savings – in the region of 20% - were achieved by using a table-top interactive cost- and power- display unit; a smart-card meter for prepayment of electricity (coinciding with a change from group to individual metering); and an indicator showing the cumulative cost of operating an electric cooker. In the absence of a special display or a PC display, the feedback was supplied by the reading of standard household meters, sometimes accompanied by the keeping of a chart or diary of energy use. The implication that this meter-reading was a factor in reducing consumption demonstrates how seldom people normally consult their meters (probably hidden away) and/or convert their readings into useful information.

Direct feedback in conjunction with some form of advice or information gave savings in the region of 10% in four programmes aimed at low-income households (with constant or improved levels of comfort), indicating the potential for feedback to be incorporated into advice programmes on a regular basis.

Providing direct financial incentives for consumers to save energy (a method tested during the late 1970s) made little lasting impact: consumption reverted to what it had been once the incentive was removed. Cost signals need to be long-term to have a durable effect.

Where *indirect feedback* is concerned, the range of savings achieved does not go so high, although significant levels are still achievable at relatively low cost (eg Wilhite and Ling, 1995). There was also agreement between most of the studies that interest and awareness levels of consumers were raised as a result of supplying informative bills. One study (Garay and Lindholm, 1995) found no savings at all (but increased customer satisfaction) after providing bills for electricity and water with historical and normative feedback over a period of 18 months. This was an unusual outcome but interesting in that it pointed to at least one possible reason for the lack of change: many of the customers were users of district heating and it could be that they feel less incentive to save than others because of a perception that the heat would be available whether or not they made use of it.

Only three of the studies might be thought of as *inadvertent feedback*, as defined above, but they give an idea of the possibilities for learning using novel technology or situations. The first involved a cable service to over 600 electricity customers which combined energy information to the householder with automatic meter reading, load control by the utility and time-of-use pricing This produced average bill savings (not necessarily energy savings) of 7-10% along with a 2kW peak demand reduction per household (Goldman et al, 1998). The second and third, both unpublished small-scale projects reviewed by Ellis and Gaskell (1978) contained 'trigger' signals which went on when the outside temperature dropped below 68F or when the electricity load went above a specified amount. They achieved a 16% reduction in air-conditioning consumption and a 'moderate' reduction in peak load respectively.

Finally, one community programme involved energy audits for 1,600 households followed by subsidised retrofitting according to customer choice (Sharpe and Watts, ibid). The whole programme was estimated to have achieved a reduction of 20% in peak demand: it could be argued that this was solely due to physical measures, but the strong emphasis on participation and learning suggests a contribution from inadvertent feedback.

In general, there does not seem to be any correlation between the scale of a project and the outcome in terms of reported savings and awareness: the spread of results for the 12 larger-scale projects, with experimental samples of 200-2000, mirrors that for the whole range of studies. Similarly, the best-documented studies show a spread of outcomes which parallels that of the whole range. When the more recent studies are compared with those carried out over the whole 25-year period, the ratio of 'successful' ones (5%+ or 10%+ savings) to the whole is almost exactly the same (although the four most effective projects in terms of savings were all carried out from 1992 onwards).

The implication is that all those studies which demonstrated some effectiveness had enough of a common element (or elements) to succeed; or that they compensated for lack of one element with another. It could be, as a minimal explanation, that *any* intervention helps if it triggers householders into examining their consumption. It could also be that the personal attention of the experimenters motivated the householders into action. However, the documentation of these feedback projects points strongly to other factors at work, of which immediacy or accessibility of feedback data - allowing the householder to be in control - are highly important, accompanied by clear information that is specific to the household in question. Provision of such data is coming well within reach in terms of the technical possibilities for metering, appliance and heating system design. It also requires political determination if it is to be implemented soon.

Feedback is a necessary but not always a sufficient condition for savings and awareness. It should not be treated in isolation: this is also a clear lesson from this review. The range of savings, as well as the accompanying detail, shows the importance of factors such as the condition of housing, personal contact with a trustworthy advisor when needed, and the support from utilities and government which can provide the technical, training and social infrastructure to make learning and change possible.

CONCLUSION

Feedback is an essential element in effective learning: this is as true of domestic energy use as of anything else. A variety of feedback types can be identified and the literature on three – direct, indirect and inadvertent – indicates that they have a significant role to play in raising energy awareness and in bringing about reduced consumption of the order of 10%.

A number of lessons emerge from the literature. Metering displays should be provided for each individual household in a form that is accessible, attractive and clear. Signals which are activated when a given load is exceeded may have potential – though not in isolation, without the means to learn from them - but need testing with great caution, especially where low-income households are concerned. Informative billing, designed and tested on customers before becoming widely available, shows promise as a means of raising awareness. Audits can provide baseline information on each dwelling and are increasingly used to assess the quality of the housing stock. The language of the audit should fit with that of the utility and the householder: there should be a common language for maximum clarity.

Feedback implies monitoring, which can be used at an individual or at a collective level: design for feedback should take this into account, as debate on whether energy-saving initiatives are reaching their goals is often ill-informed. Finally, new technologies are making possible generation of power at a household level, automatic and highly sophisticated metering and more detailed communication between utilities and customers. All these developments hold out the possibility for improved learning and control of energy use, if handled with attention to the principles of immediacy, clarity and specificity.

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