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## Analysing end-user energy rescheduling intentions using signal detection theory

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### Abstract

Two interfaces, co-created by designers and people living in eco-villages, were tested for their effects on end-user energy-use rescheduling intentions. When analysed with Signal Detection Theory both interfaces were implicated in biased user responses, but in opposite directions. Despite some favourable behavioural effects the majority of the 75 respondents chose not to reschedule their energy-use behaviours no matter what interface was displayed. The paper provides a demonstration of the role of behavioural factors in the apparently simple task of providing more information to energy-users on the assumption behaviour will change.

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*Keywords:* Interface design, signal detection theory, end-user energy use behaviours

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### 1. Introduction

There is a widespread assumption that if we increase the sophistication of our home energy controls then users will be able to perform more rationally and save energy. If domestic energy consumers are provided with more information, they will change their behaviour accordingly. Or will they? The ergonomics research is often far less optimistic than the widespread assumptions contained in government policy and the wider engineering community.

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In fact, the research in this area makes for a sobering read. Shipworth [1], for example, reports widespread misunderstanding of thermostat operation, most of which were selected and installed by previous owners or landlords. Indeed, almost 90% of respondents rarely or never adjusted the thermostat. An interesting commentary on industrial design is that the thermostat, with its circular dial, dates from 1953 and a product first released by Honeywell and called the T87 Round. Surely the situation must be better with the advent of programmable central heating controls? According to Peffer et al in [2], apparently not. In this study 20% of the surveyed programmers were showing the wrong time, 53% were not in automatic mode (and were switched on or off manually), indeed, 85% of people who said they did use the programmable features often didn't (45%). As a result, more sophisticated and information-rich central heating controllers can use more energy than manually controlled ones, something Revell and Stanton in [3] deal with using Kempton's [4] shared theories of thermostat function. Here the mental model of thermostat operation can be technically incorrect but functionally adept. Central heating programmer mental models seem to be neither. Given this paradoxical situation the question to ask is whether adding even more features and technology, and extending the ability of domestic heating controls to help users make better use of renewable energy sources, likely to make the situation better? The end-user energy behaviour aspect can no longer be ignored. As a result, Human Factors research finds itself participating in an increasing number of energy research projects. The current paper reports on a study undertaken within two such projects, the first funded by the EPSRC and called Aging Population Attitudes to Sensor Controlled Home Energy (APAtSCHE), the second an EU project called Orchestration of Renewable Integrated Generation in Neighbourhoods (ORIGIN). Both have an interest in the behavioural aspect of home energy use, and both contain a fascinating intersection of electrical engineering and Human Factors.

ORIGIN is a community-based Renewable Energy (RE) project working with three eco-villages in Scotland, Portugal and Italy to install an intelligent Information and Communication Technology (ICT) system for the management of energy use. The ORIGIN system will forecast time periods of RE availability to end-users with the aim they will schedule energy-use tasks to fit with such periods. As well as the accurate prediction of RE availability times, synchronisation also depends on influencing end-user energy demand. Or in other words, encouraging people to reschedule energy activities to a time when RE is available. ORIGIN and APAtSCHE are in some ways treading a familiar path in focussing on the provision of more information to users, but are unique in that the users are especially engaged with pro-environmental behaviours and in directly informing the design process.

Both ORIGIN's and APAtSCHE's primary method of interacting with end-users is via an energy interface. In the case of ORIGIN it will present RE forecasts. Extensive qualitative research has been performed to understand users and generate interface concepts. The interfaces to be tested in this study were co-created with ORIGIN users (see future paper) and the final concept is quite different to the norm. It reflects a desire to humanise the technology and ensure it blends with the home environment. The interfaces themselves are described in the sections below, but having 'co-created' these interfaces the question arises a) as to their effectiveness in terms of actually changing behaviour, and b), whether something co-created by a highly environmentally engaged community yields positive benefits within the population at large. The wider question to which this study speaks is fundamental to ORIGIN: the extent to which energy use behaviour among the eco-village populations falls within periods of forecast RE availability is the main determinate of success for the entire project.

## **2. Method**

### *2.1. Design*

Users' energy rescheduling intentions were tested against three energy interface types. Interfaces 1 and 2 employed a collaboratively designed clock interface showing the availability of renewable energy. Interface 2, in addition, presented users with suggestions on what energy-use tasks to undertake at a given time. These suggestions were communicated with icons showing different domestic appliances. Interface 3 was a 'no interface' control condition. The three interface types were paired with nine fictional energy use situations in which time of day (morning, afternoon, evening) and flexibility of rescheduling (laundry, washing-up, cooking) were defined. The trials were further divided into Signal and Noise types according to the rubric of Signal Detection Theory (SDT [5]; Table 1).

Table 1. Signal Detection Taxonomy.

	Signal Present	Signal Absent
<b>Yes, I will reschedule my energy use.</b>	<b>Hit</b> – renewable energy is available and the user correctly reschedules the energy use (i.e. uses the appliance during the time period in which renewable energy is displayed as being available)	<b>False alarm</b> – renewable energy is not available but the user still reschedules the energy use (any response other than “Do it now” is selected)
<b>No, I will use the appliance/energy now.</b>	<b>Miss</b> – renewable energy is available but the user does not reschedule the energy use (i.e. uses the appliance/energy now despite renewable energy being available during a different period)	<b>Correct rejection</b> – renewable energy is not available and the user correctly does not reschedule the energy use (the “Do it now” response is selected)

Within these categories every combination of interface and energy-use scenario was repeated in order to stabilise the responses and avoid bias. This led to a total of 135 user trials in which the dependent variable was user behaviour in terms of ‘number of energy-use reschedules’ and a characterisation of sensitivity and Decision Bias provided by SDT.

## 2.2. Participants

A total of 75 people were recruited using convenience sampling.

## 2.3. Materials

Interfaces 1 and 2 emerged from collaborative design workshops involving end-users taking part in the ORIGIN project. The interfaces took the form of clock faces split into three equal time periods: morning (8am till noon); afternoon (noon till 4pm); evening (4pm till 8pm). The clock border was split into three equal segments corresponding to the three time periods. When a particular segment was coloured green it was an indication to the user that renewable energy was available during that time period. The lack of renewable energy was indicated using a red colour. Interfaces 1 and 2 both had the coloured border, but Interface 2 provided users with an appliance specific usage suggestion via an icon on the clock face itself. Interface 3 was a control condition and represented the ‘absence of an interface’. In this condition participants were merely presented with the energy use scenarios with no support from an interface (Figure 1).

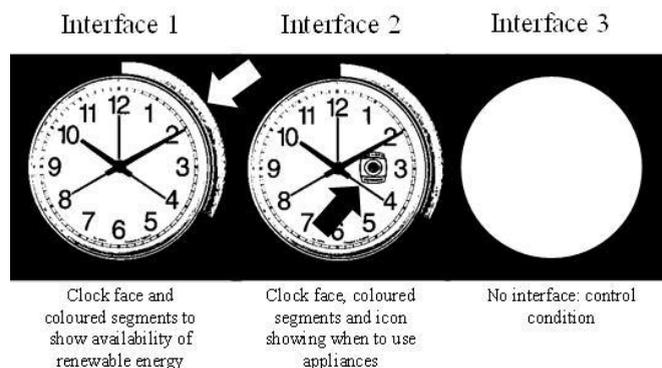


Fig. 1. The three interface types featured a co-designed clock display, with or without energy-use suggestions, and an ‘absence of interface’ control condition.

The study employed a web-based technique to gather participant responses. Stimuli for the experiment consisted of individual screens. The energy use scenario was shown on the right and an image of the interface on the left. The

energy use scenarios used a common syntax: “It is [time of day]. You have the [laundry/washing/cooking] ready to do. Would you:” The three response types were either “Do [the task] now”, “Leave it, do it in the afternoon (between noon and 4pm)” and “Leave it, and do it in the evening (after 4pm)”. There were no explicit incentives except those arising from an innate disposition towards greater use of RE. As soon as a participant response was received the software immediately progressed to the next set screen. A random number generator was used to mix the trial types, tasks and interfaces.

#### 2.4. Procedure

The experiment took place in compliance with the host institution’s ethical guidelines and were approved by a formal ethics committee. It was publicised widely on mailing lists and via group emails. Participants logged on to the experiment website and before commencing were briefed on the aims of the study and their consent to participate was gathered. Demographic data was also collected. The experiment started with three practice trials, followed by the main experiment comprising 135 trials. Participants were encouraged to give their first impression and to move swiftly through the stimuli. The stimuli remained on screen for a maximum of 15 seconds, but would move to the next one sooner if the participant gave a response. At the conclusion of the trial participants were further debriefed on-line and given contact details should they wish to ask questions and find out more. All responses were collected anonymously.

### 3. Results and Discussion

Seventy five participants each provided 135 responses reflecting their energy-use intentions when faced with the different interfaces, amounting to 10,125 responses in total. Analysis of this data is divided into two parts. The first examines the number of reschedule intentions and compares them across interfaces. The second part provides a more sophisticated analysis using Signal Detection Theory to disentangle the separate effects of sensitivity and decision bias, focussing on the two more complex ORIGIN derived interfaces.

#### 3.1. Reschedules

A response was considered a reschedule if the participant selected any response other than “do it now”. The question being answered is to what extent energy-users are intrinsically willing to reschedule, and the role of different interfaces in influencing this intention. Figure 2 shows the percentage of reschedules for each interface.

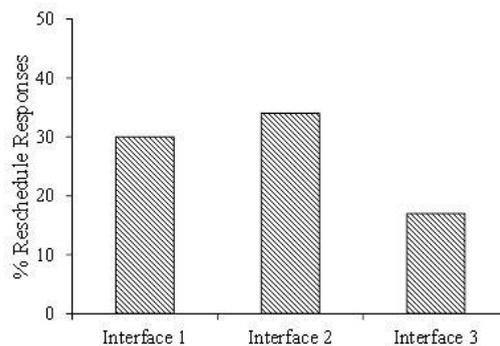


Fig. 2. The percentage of responses indicating an intention to reschedule energy-use across the three interface conditions

The control condition is the ‘absence of an interface’ condition and 17% of responses were ‘reschedule’ energy-use. This proportion increased markedly to 30% for Interface 1 and 34% for Interface 2. An analysis of variance shows a main effect for interface type ( $F(2,225) = 826.3$ ;  $p < 0.01$ ) and pairwise comparisons using a Bonferroni correction reveal significant ( $p < 0.01$ ) differences between each condition. Collectively, the findings illustrate a low

residual level of willingness to reschedule, but a beneficial effect of the novel interfaces in helping to change user intentions. Despite these encouraging changes, even under the most favourable interface conditions over 60% of responses were to not reschedule. Part 2 of the results explores these decisions in more detail.

### 3.2. Sensitivity and Decision Bias

Responding to the ORIGIN interfaces is not merely a perceptual one of seeing the different interface indications, it is also cognitive: users not only have to discriminate a ‘stimulus’ from within a ‘noisy’ decision environment, but correctly classify it and choose to respond in a certain way. Secondly, there are different strategies energy-users employ to perform this apparently simple task. Signal detection Theory (SDT) helps to untangle these different aspects by separating out a person’s sensitivity to stimuli (how easy it is to detect what the interface is saying) and their response bias (their preference for responding one way or another to the information given). SDT helps us to understand why a particular ‘stimulus’, which might to engineering eyes seem abundantly clear and unambiguous, is not always responded to in the ways we expect (or vice versa). Table 2 shows the sensitivity ( $d'$ ) and response bias ( $C$ ) results for Interfaces 1 and 2.

Table 2. SDT Analysis.

Trial type	Interface 1		Interface 2	
	Signal	Noise	Signal	Noise
<b>No. of trials</b>	1975	1990	1958	1779
<b>Response Type</b>				
“Yes”	780	741	578	462
“No”	1195	1249	1380	1317
<b>Proportions</b>	<b>p(Hits)</b>	<b>p(False Alarms)</b>	<b>p(Hit)</b>	<b>p(False Alarms)</b>
	0.39	0.37	0.30	0.26
<b>Z-Scores</b>	<b>Z(Hit)</b>	<b>Z(False Alarm)</b>	<b>Z(Hit)</b>	<b>Z(False Alarm)</b>
	-0.27	-0.33	-0.54	-0.64
<b>Sensitivity (<math>d'</math>)*</b>	0.06		0.11	* SD units
<b>Criterion (c)*</b>	0.30		0.59	* SD units

The  $d'$ -prime figure measures the strength of the stimulus, which in this case is the information being conveyed by the ORIGIN interfaces. Values of 0.06 for Interface 1 and 0.11 for Interface 2 are low. Energy users are not highly sensitive to the information being presented to them. It is somewhat ambiguous and difficult to discriminate this information from the wider background of informational ‘noise’, conflicting information, and other contextual factors. Expressed more formally, the responses energy-users are providing when information from an ORIGIN interface is overlain on top of the ‘contextual noise’ is only 0.06 (Interface 1) or 0.11 (Interface 2) standard deviations ‘different’ from the responses they give when the signal is absent and only the ‘contextual noise’ is present.

Decision Bias should be independent of sensitivity and relates not to the discriminability of the ‘signal’ but to the payoffs involved in making one response in favour of another. Regardless of how easy it is to discriminate a stimulus a counter intuitive response may still be favoured. This is because the real-world consequences of signal detection tasks may vary with the context. For example, frequent false alarms may get ignored, yet potentially a missed signal could be extremely hazardous. Psychological research shows that Decision Bias is more unstable and situationally dependent than sensitivity, and could be a potentially important factor in behaviour-change

interventions. It may be that sensitivity is primarily facilitated by perceptual or physiological factors, while bias is more driven by cognition.

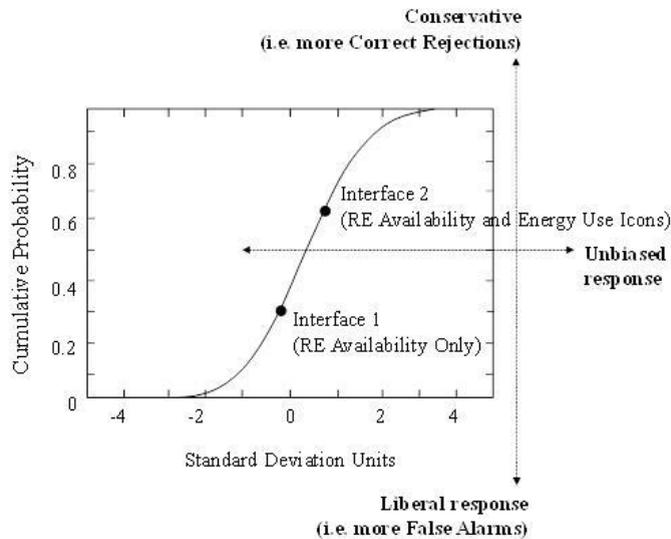


Fig. 3. Cumulative probability plot showing the extent to which the two ORIGIN interfaces bias energy-user reschedule responses

The Decision Bias metric (c) reached 0.3 for Interface 1 and 0.59 for Interface 2. The fact these two values straddle the 0.5 point is important as can be seen in Figure 3. Interfaces 1 and 2 both elicit biased responses, but in the opposite direction to each other. Interface 1 is implicated in a more liberal response bias, with the same participants intending to make more unnecessary energy-reschedules than were strictly needed. With Interface 2, participants cross the ‘unbiased response’ line and exhibit more correct rejections. In other words, they will not reschedule if they don’t have to but their ‘miss-rate’ also increases slightly. Clearly the effect of additional, more prescriptive energy-use advice in Interface 2 is eliciting a quantitatively different response type, albeit one that is similarly biased.

#### 4. Conclusions

Contrary to received wisdom about the need to provide more information in order to improve end-user energy demand, this study illustrates some of the complexities involved. Using Signal Detection Theory, specifically the Decision Bias data, Interface 1 led to more unnecessary energy-reschedules (false alarms) while Interface 2 led to fewer false alarms but more missed opportunities for using Renewable Energy. The former showed users when Renewable Energy was available, while the latter combined this with more explicit energy-use suggestions via icons. Two key points need to be highlighted. Firstly, despite the fact a user-group ‘co-created’ the interface responses were still biased. Secondly, these findings need to be set in a wider context in which the majority of people did not intend to reschedule their energy use regardless of the interface. While it is true to say even small gains in efficiency brought about by interfaces like those tested are very worthwhile when scaled up to entire populations, it is clear the issue of end-user energy behaviours is more complex than engineers might assume. That being said, it is also out of this complexity and non-linearity that novel user-centred interventions wait to be discovered.

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