Personalized Energy Priorities: A User-Centric Application for Energy Advice

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Abstract. This research presents a new web-based application, called Personalised Energy Priorities (PEP), that provides households with personalised and tailored advice on practices or technologies they might adopt to improve the energy efficiency of their home. PEP proceeds in a manner similar to an online energy audit, but combines a user centric design approach with relatively new choice modelling software that allows recommendations to be tailored to individual preferences. The tool also provides links to further information about each energy recommendation, creating a more successful, one-stop-shop for persuasion.

Keywords: energy demand management, personalised advice, energy efficiency, choice modelling

1 Introduction

This paper describes Personalized Energy Priorities (PEP), a user-centric web-based application that provides households with personalized advice to help tailor their practices and technologies to improve the energy efficiency of their home. The motivation for developing this tool is twofold: (1) the growing need for more efficient use of energy; and (2) the difficulty for households in obtaining personal advice that they both want and trust, to support and facilitate energy efficient behaviour.

The first motivation stems from resource consumption. On the basis of current trends, global demand for energy is expected to increase by more than 50% by 2030 [1]. Given our current dependency on fossil fuels for electricity, transport, and industry, this implies an increasing pollution of greenhouse gases into the atmosphere. Thus the need to use energy more efficiently is more pressing than ever, and will require consumers, as well as energy suppliers, to take action [2]. Households have potential to reduce their overall energy consumption significantly by implementing more energy efficient behaviour in the home and car [3]. Dietz et al. [4] report, for example, that energy savings of approximately 20% could be achieved in the U.S. through changes to 17 different typical household actions using readily available technology (e.g. stopping draughts, applying thermostat setbacks, making changes to driver behaviour, etc.). These relatively easy changes could improve energy efficiency relatively quickly, with most savings occurring within a 5-year timescale.

The second motivation for the development of this tool is due to the slow rate of uptake of energy efficiency improvements; opportunities like these have been available for decades, which raises the question of why these savings have not yet been realised. One explanation is that people typically have limited information about the energy savings potential of different actions [5]. They may express a desire to reduce expenditure on energy or improve environmental outcomes, but the cost of obtaining reliable information, that is specific to their own needs and that they can trust, prevents action. Gardner and Stern [3] conclude; "crucially households lack accurate, accessible, and actionable information on how best to achieve potential savings through their own steps." General information programmes are rarely effective, and better results are seen when the information is made personal to the user, that is, when it is based on the specific characteristics of their own circumstances [6]. This makes it more appealing to users, and helps to reduce information overload by removing anything not relevant.

A home energy audit provides a starting point for personalization. Energy is an input into a wide variety of services in the home, and while householders see the total energy bill for all of those services, they often have little idea of how much each service contributes to that total [5]. An energy audit provides that critical information. The process involves an in-depth assessment of household energy use and, given the services that householders currently demand, an auditor can recommend physical improvements that would deliver the same or similar services at lower energy cost, i.e., more energy efficiently.

Despite the practical approach taken during an energy audit, research findings are mixed regarding its effectiveness in helping consumers to make changes and reduce their energy bills [7]. We suggest that this is due to several shortcomings in the information provided during an energy audit, which are examined in the following section. The remainder of this paper then goes on to describe the design elements of PEP, outline the identification of energy efficiency actions and their characteristics that are used to develop a prototype, discuss findings from initial testing, and suggest and discuss options for further development.

2 Going Beyond Energy Audits

Although the approach taken by most energy audits is fairly systematic and inclusive of all physical elements of the dwelling, they tend not to incorporate either users' perspectives or user behaviour, potentially limiting the effectiveness of the information provided [8]. The following sections explore the elements of user behaviour, user preference, and communicating recommendations to users.

2.1 User Behaviour Matters

The way in which energy is consumed is the result of the users' house characteristics, the energy related technologies they own, and the way in which they use those technologies. However, conventional energy audits tend to focus only on energy efficiency improvements that can be made to the building envelope and appliances in the home, and ignore behavioural changes that may be implemented [9]. This may be problematic, as residential demand is affected by more than just dwelling form, technology, and climate; indeed patterns of occupancy and household behaviour may determine up to two-thirds of the energy demand in homes [10]. Furthermore, there are limits to the gains from retrofits. If done well, each additional increment of energy efficiency comes at a successively higher cost. At some point, it may make more sense to change the way in which we use energy technology than to keep buying more energy efficient technology.

In addition, the rebound effect [11] means that changes in how technology is used can counteract energy savings made by technology changes: more energy efficient appliances mean lower costs, which householders may take advantage of by demanding more services. In short, householder behaviour becomes a key determinant of energy consumption. And there are as a practical matter a large proportion of people, such as renters or those on low incomes, who are unable to make significant investments in energy-efficient appliances. Thus is it important to provide advice about changes in user behaviour that complements changes to the house and contents.

2.2 Preference Matters

There are usually multiple ways to tackle each problem identified in an audit, and each of these options typically varies along multiple dimensions (e.g. cost to implement, efficiency gains, skills level required to implement, impact on house value, etc.). The appropriateness of each of these options depends both on the characteristics of the house *and* household members, yet audits tend to account only for cost and efficiency impacts of each option as determined by the house characteristics. However, the additional dimensions of energy efficient retrofits and impact of these on household members is important to consider as this may affect the likelihood of a particular action being considered [12].

In an evaluation of home energy audits from a consumer perspective, Ingle et al. [8] found that the main driver for households making upgrades to their home was the extent to which the change addressed “specific aspects of their own experience in the house”. Consumer preferences for the characteristics of the energy saving measures themselves, in addition to their cost-effectiveness, influenced choices. These findings have been mirrored in other research, which have shown that users express concern about different attributes of energy efficient products, e.g. risks associated with the reliability of heating systems [13], or express preference for different aspects of heating and hot water systems, e.g. the aesthetics of the technology or the level of independence from the national power grid it provided [14].

These studies illustrate the importance of consumer preferences for different characteristics of energy saving measures at an aggregated level, however, underlying this there is often a significant variation in people’s individual preferences, which is also important to account for [12].

2.3 Communication Matters

Variations to the way in which energy related information is communicated to users can have an impact on subsequent behaviour change. Recommendations following an audit-based process are typically provided to users as a long list of actions, and simply changing the order of recommended actions can have a significant impact [15]. Actions are typically presented in order of net financial benefit, but non-financial preferences, such as ease of use, aesthetics or reliability, may outweigh financial implications for many households [16], and this should be customized to each user.

Although home energy audits do tend to result in positive savings for those who implement changes [7], not all households go on to make changes [8]. This may be because users have trouble finding information about the recommended changes or how to actually implement them, and thus information programs that provide users with a one-stop shop where they can access a full set of energy advice information tailored to their context, incentives for action (e.g., better energy efficiency means lower power bills, a better lifestyle and less damage to the environment) and links to information about implementing changes are relatively more successful [16, 17].

2.4 Personalised Energy Priorities (PEP)

In order to overcome the shortcomings of existing audit-based approaches, the design of PEP introduces three novel elements. Firstly, PEP provides advice for households in terms of changes to the way in which they use energy technologies, as well as the physical retrofits that could be implemented in their homes; advice about changes in user behaviour is designed to complement changes to the house and contents.

Secondly, PEP takes a user centric approach, putting householders, not their homes, in the centre of the decision making process. PEP enables the various characteristics of energy-efficiency actions to be accounted for through the use of an innovative choice-modelling platform. In this way householder preferences can be incorporated into the advice provided to the householder, and used to structure the order in which recommendations are provided.

Finally, PEP represents a significant step toward a one-stop on-line information shop customized for each user's context and motivations. For each of the actions recommended, web-links are provided to users to enable easy access to more detailed information about the recommendations most attractive to them, as well as any contacts needed to implement the actions.

3 Developing PEP

In developing PEP we identified the following key steps: (1) identify the set of energy efficiency actions to be used in the tool and the attributes that can be used to describe them, (2) elicit information from users so that their preferences toward different attributes can be determined, and (3) communicate information about energy efficiency actions to users in an appropriate manner.

3.1 Energy Efficiency Actions and Attributes

Data collection began by compiling a list of energy efficient or pro-environmental behaviours and their attributes mentioned in key known academic literature [3, 4, 5, 18, 19, 20]. Further actions and attributes were identified via forward citations from these articles and keyword searches in academic databases (e.g. Scopus), and non-academic databases (e.g. Google) using terms such as home energy efficiency, home energy behaviours, home energy savings, home energy audits, energy-saving measures, and so on. Contacts from industry and government (e.g. Building Research Association New Zealand, and the New Zealand Energy Efficiency and Conservation Authority) provided data on various energy efficiency actions that they had previously compiled, which we incorporated. Finally, we sent our compiled list of energy behaviours and their attributes to industry experts from Beacon Pathway and the Energy Efficiency and Conservation Authority for review.

In total 60 different actions including changes to the building envelope and technology as well as changes to energy practices (i.e. how users interact with those technologies) were identified. These are presented in Table 1.

Table 1: Alternative energy efficient actions available to householders

Actions to improve residential energy efficiency	
• Install more energy-efficient dishwasher	• Turn off lights in unused rooms
• Install more energy efficient refrigerator	• Install a more energy-efficient water heater
• Install more energy efficient clothes washer	• Install a heat recovery unit on shower system
• Install more energy-efficient clothes dryer	• Install a shower dome
• Duct clothes-dryer exhaust outside	• Install low-flow showerheads
• Install/upgrade ceiling insulation	• Cut shower time in half
• Install/upgrade under-floor insulation	• Set hot water cylinder to 60°C
• Install/upgrade wall insulation	• Shut off any unused hot water cylinders
• Fill the sink with hot water rather than leaving the hot water running	• Turn hot water cylinder off when you go away for more than a week
• Install secondary glazing to windows	• Wrap hot water cylinder and pipes
• Apply DIY window insulation film	• Fix leaky pipes and taps
• Install thermal-lined curtains and pelmets	• Install double-glazed windows
• Replace/upgrade windows	• Line-dry laundry outside
• Draught stop around doors and windows	• Use lower temperature settings on the washing machine
• Seal gaps around window frames, skirting boards and cornices with sealant	• Wait for a full load before you use the washing machine
• Seal wall, floor and ceiling penetrations for electrical and plumbing services	• Remove unused food from refrigerator and freezer
• Block unused open fireplaces	• Fill kettle appropriately
• Fit and draught-stop ceiling hatch	• De-ice the refrigerator
• Install more energy efficient space heating	• Cover pots with lids when cooking
• Avoid using unflued gas heaters	• Check under house for dampness issues
• Thermostat setbacks	• Install an on-ground vapour barrier

Due to the nature of the data collection and our intended audience, there are some actions that are fairly specific to the New Zealand housing context. On the whole New Zealand houses have low levels of insulation, poor air-tightness, and persistent under-heating, resulting in many homes failing to reach the World Health Organizations healthy indoor temperature range of 18-24°C [21], which often leads to dampness and mould growth. Thus there may be a higher proportion of actions focussing on improvements to insulation, heating and dampness than is necessary in other contexts.

Each action listed in Table 1 can be described in terms of its attributes, which were identified through an iterative process; the authors first reviewed the literature and developed an initial list of 31 attributes in an attempt to construct an exhaustive set of characteristics by which the energy efficiency actions could be described. The attributes were then tested to check for orthogonality (the final attributes must be mutually exclusive) and attributes found redundant were removed. Several additional attributes not found in the literature but of apparent relevance to local homeowners were added, resulting in the list of 25 attributes presented in Table 2 along with two examples of actions that have been rated on each attribute.

Table 2: Attributes of energy efficiency actions

Attribute	Example 1: Efficient wood burner	Example 2: Shower time in half
Upfront monetary cost	Moderately high	No or low
Upfront time cost	Low	No or low
DIY installation?	No	NA
Structural alterations required	Moderate	None
Capitalisation into home value	Full	NA
Try before buying	Limited	Yes
Energy efficiency	Moderate	High
Ongoing $ maintenance costs	Moderate	Nil
Ongoing time costs	Low	Moderate
Ongoing energy savings	Moderate	Low
Reliability	High	High
Confident will work as advertised	High	High
Ease of use	Moderate	High
Skills required to operate	Moderate	Moderate
Requires changes in habits	Yes	Yes
Lifespan	Long	Long
Transferrable to another dwelling?	Limited	Yes
Effect on comfort	Positive	Negative
Effect on aesthetics	Positive	None
Effect on safety	Negative	None
Effect on damp/mould	Positive	Positive
Impact on the Environment	Neutral	Nil
Impact on household members	None	Positive
Impact on neighbours	Some	Nil
Provides independence from the grid	Yes	NA

The first example provided in Table 2, "efficient wood burner", is a specific example of the action "Install an energy-efficient heating system" in Table 1. Installing a wood burner has what might be considered a moderately-high purchase cost, is only moderately energy efficient, but is reliable, generates comfort and aesthetic appeal, and provides users with some independence from the distribution (i.e., gas or electricity) grid. The second example provided "shower time in half" provides a contrast; this action has no upfront cost and is highly energy efficient, but has a negative impact on comfort and requires users to change their habits. The appeal of each of these actions (and of the other 58 actions identified and shown in Table 1) depends on the degree to which users value one attribute over another; for example, a householder may value comfort, aesthetics, and energy efficiency more highly than saving money from the installation of an energy-efficient space heating system. Thus preference for one action over another may be predicted for individual users by eliciting information about the degree to which they value one attribute over another.

3.2 Determining User Preferences

To determine user preferences for one energy-efficient action over another, PEP elicits householder preferences toward their attributes, and uses this to generate a personalised list of suggestions for change. This elicitation process can be carried out in a variety of ways. A simple and effective method is to ask the householder about their willingness to trade off each attribute against each of the others one at a time. For example, we could ask the householder to choose between a heating system that costs more upfront and is easy to operate and another that costs less but requires more effort day-to-day, assuming all else the same. The choice directly provides information about the householder's relative preference for these two attributes. The process carries on by presenting other pairs of alternatives, each of which requires a trade-off. This general method of 'paired comparison' has been used widely in various contexts to elicit preferences for multi-attribute goods [22].

The disadvantage of this approach is tedium. Working through all pairs takes time and may seem repetitive, and the time and concentrated effort needed increases with the number of levels each attribute is defined on. For example, the upfront cost of purchase and installation of an action alternative can vary considerably. The more levels of each attribute, the more potential paired comparisons to consider. With a large number of attributes, the number of comparisons can become unrealistic.

We deal with this problem in several ways. First, we use web-based decision software called 1000minds[1], which reduces the number of paired comparisons the householder must respond to by eliminating from consideration all pairs implied by each choice via transitivity [23]. This often reduces the number of choices by two-thirds without loss of information (assuming that the choices are accurate).

Though smaller, the number of choices can still be large. To reduce the burden further requires its own trade-offs. First, elimination of some of the levels of an attribute reduces the number of choices, while interpolation provides estimates of the weights on intermediate levels. Second, we allow the householder to choose the

[1] www.1000minds.com

subset of attributes that matter most to his or her household, eliminating consideration of attributes that have little value (by assuming they have no value). Finally, the software recalculates weights and updates the prioritised list of action alternatives immediately after each paired comparison so that the householder can skip to the personalised list of actions when boredom sets in (and he or she can go back to the choice survey if the ordering in the list seems to need more work).

3.3 Communicating Energy Advice

Having elicited user preference by evaluating the relative weights the householder places on each attribute, the energy-efficient actions can be sorted so that those with the most desirable combination of attributes to that user are presented first. The next major step in the PEP process is to provide information about the action alternatives that fit the householder's preferences. To access this information, the householder clicks on an action alternative that seems of interest (and is presumably high on the personalised list of actions), which takes them to a webpage with further information.

This page is designed to provide several types of information to users in one easy to access place. To compile this information we relied primarily on several sources widely regarded as independent and reliable in New Zealand: the NZ Energy Efficiency and Conservation Authority Energywise website[2]; the Beacon Homeowner Manual [24]; the Consumer NZ website[3], which reports the results of independent testing of a wide variety of products; the Smarter homes website[4]; and the Building Research Association New Zealand, an independent testing agency providing information for the building sector. We provided links to these sites where appropriate and occasionally to other trusted NZ and international sites.

The page starts with an explanation of how the action alternative treats the problem ('How does it work?'). While this explanation can be somewhat technical, the aim is provide the rationale for the action in an accessible way. Where appropriate, web-links to helpful explanatory videos as well as to more advanced technical information are included.

The next section aims to help the householder evaluate whether the action alternative is suitable for his or her situation ('Is it right for you?'). Critical issues are how well the action will fit with the house and with the characteristics and behaviours of the householders. Continuing with the heat pump example, the section describes the climates in which a heat pump works well and its various advantages and disadvantages in installation and use. This information helps the householders' start to think about how to tailor actions to their context,

The next section describes how to implement the action ('How do I do it?'). In the case of installing a heat pump, the section identifies key issues to consider, such as size and placement. The section may list local installers or provide a link to a directory of installers, as appropriate. The section may also either describe DIY installation or link to one or more good descriptions.

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[2] www.energywise.govt.nz
[3] www.consumer.org.nz
[4] www.smarterhomes.org.nz

The page then describes complementary actions, such as other improvements or changes in behaviour ('What else should I consider?'). In the case of installing a heat pump, one could also consider improving insulation (in any of various ways) and developing habits to use the heat pump most efficiently. These suggestions link to other pages describing these actions. The web page concludes with links to other reliable and accessible sources of information, such as independent product reviews or sites that provide more detailed information. The goal is to make accessing reliable information as easy as possible.

4 Testing

A pilot version of PEP has been constructed and tested in Dunedin, New Zealand. The software proceeds in four stages, as illustrated in Fig. 1. Initially the list of energy efficient actions contains all those identified in Table 1 presented in a random order. As the user progresses through PEP, they first select 6 attributes of the 25 outlined in Table 2. The software uses this information to order the actions according to the limited information provided so far; that certain attributes are more important than others. The user is then guided through a choice survey, where they make trade-offs between pairs of attributes, such that the relative value of each attribute can be determined. This enables the list of actions to be prioritised according to the user's preferences, and presented back to them in this fashion. They are then able to click on each action on the list to access further information.

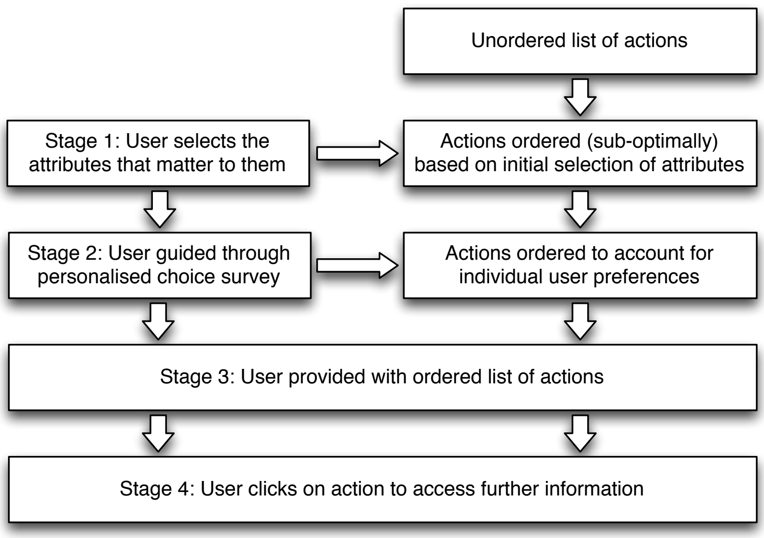

Fig. 1. The four stages of PEP

To test PEP we selected a random sample of 450 single-family, owner-occupied homes in three suburban areas of Dunedin, New Zealand with census demographic characteristics similar to those of New Zealand homeowners generally. An invitation to participate in our pilot survey was sent in the name of the householder listed in city council records. After follow-up telephone calls, 149 (33%) respondents completed the survey, which consisted of working through the trial version of PEP and then completing a more standard tick-the-box survey.

Of primary research interest in this pilot study was the variation across households in the attributes they care most about, i.e., in the heterogeneity in preferences for attributes. Each household was required to choose six attributes (in addition to upfront cost which was selected automatically). We conducted a cluster analysis designed to uncover clusters of households who chose similar sets of attributes. After experimentation, a six-cluster solution seemed the most informative.

A large majority in all clusters chose energy efficiency or 'value for money' as an important attribute. Over 80% of respondents in the three largest clusters, comprising 70% of respondents in total, also considered it important that the action be as energy efficient as advertised. A similar proportion considered it important that the action works reliably. These attributes are all sensibly seen as important, and it is not a surprise to see a large majority that consider them important.

The clusters are mainly distinguished by other attributes. About 30% value other practical aspects, including the lifespan of the improvement, the amount that the investment capitalises into house value, and that it needs only infrequent maintenance. About 22% care mostly about environmental benefits, 17% about dampness and ventilation, 16% about home safety, 9% want to avoid structural alterations and fiddly operation, and 7% prefer DIY installation and achieving independence from the grid. The characteristics of the respondents in each cluster correlate only weakly with the house and householder characteristics collected in the survey; preferences for attributes of action alternatives seem rather idiosyncratic.

Of interest is that 62% of respondents agreed or strongly agreed with the statement "making choices about energy efficiency in the home is complex", whilst only 25% disagreed. Most respondents also agreed with the statement "it's difficult to know what information about energy efficiency to trust", suggesting that there is a need for decision-making support tools such as this. In addition, 60% agreed that they "have the skills to make effective energy efficiency changes"; further suggesting that access to appropriate information is providing a barrier to action. Regarding the design of the online tool, 85% of respondents found the format of PEP easy to follow and 60% found it easy to answer the trade-off questions. Although only 5% found answering the trade-off questions very difficult, there is some room for improvement here.

5 Conclusions and Recommendations

Our pilot project provides useful information about the heterogeneity in consumer preferences for the attributes of energy-efficiency actions. The survey results indicate that most respondents find the format of the platform easy enough to understand and are also able to work through the decisions that elicit their personalised preference weightings. However, additional work that explores the extent to which users find the information provided by PEP to be beneficial, trustworthy, and engaging, and their likelihood to use that information to help make improvements and change behaviour would be useful to inform further development. In addition, the ability to track respondents over time and observe the extent to which their interaction with PEP encourages improvements to the house and coordinated changes in behaviour is recommended. That is, we would like to test user levels of engagement and interaction with PEP over time.

Engagement over time raises a key issue: home energy efficiency improvements, especially those to appliances or the building envelop, often happen incrementally over extended periods of time, usually years. For example, householders may choose to install a more energy efficient heating system one year, add some double-glazing a couple years later, and so on. With each incremental change, householders change how they interact with their altered environment, building new habits. Furthermore, once an incremental change has been made, it may have implications for choices in the future. It would be an advantage if householders could envisage and plan for the sequence of changes that might occur over perhaps the next decade.

This raises a challenge for the design of a tool such as PEP: How do users interact with it over potentially long periods of time? How does it take into account changes that a household has already made? Can it learn not only from the hypothetical decisions in the choice survey, but also from the actual decisions householders make? And can it help householders plan the sequence of improvements they would like to make over an extended period of time? Further work investigating these questions and the impact of such a tool on user interaction and subsequent behaviour change is recommended.

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