Energy Efficiency Educator – early stages of an interactive tool to help reduce heating energy demand in residential buildings

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Abstract
Reducing residential energy consumption is a key target for energy demand reduction and for achieving the UK Government's 2050 target for CO_2 emission reduction. Reducing energy consumption in residences requires the engagement of occupants, e.g. using more efficient appliances, low carbon technologies, retrofitting one-off energy saving measures (such as insulation and draught proofing) and adopting daily energy saving behaviours. This paper introduces an Energy Efficiency Educator (EEE) developed as part of the Energy Visualization for Carbon Reduction (eViz) research project in the UK (eviz.org.uk). The EEE aims to combine dynamic building simulation with a user-friendly interface to allow exploration of tailored options that leads to better decisions in non-experts.

The EEE offers a menu of energy-efficiency parameters to be input and changed by the occupants so that they can model the effect of changing building operations, e.g. turning down the thermostatic setpoint or reducing the boiler running time. The energy saving potential of adopting these energy-efficient behaviours is estimated using dynamic building performance simulation in EnergyPlus, based on typical UK housing types. This responds to a desire in building users to be given tailored advice, as opposed to exemplar case studies (Abrahamse et al., 2005, Guy and Shove, 2000, Gifford, 2014).

This tool was based on collaboration between researchers from both psychology and building science. It uses dynamic building performance simulation to demonstrate the impact of interventions on building energy demand so as to help building occupants make decisions on changing behaviour by showing them the likely consequences of their actions, but tailored to their own building and environment.

This paper presents some initial qualitative feedback from a pilot study (N = 14) exploring the tool with real building occupants, so as to assess the usefulness of such a tool and how potential tool users respond to it. These findings will enhance and inform further development of this tool.

Introduction
Reducing societal energy consumption has become a global issue. Buildings, as a big energy consumer of society, have therefore received great attention. In 2013, the UK government launched the Green Deal (GOV, 2015) as an intervention aiming at reducing the energy consumption of domestic buildings. It provides the householders with a mechanism for funding retrofits to their houses, avoiding the barrier of paying an up-front fee for energy efficiency upgrade measures but instead taking a loan to pay for measures, such as installing solid wall insulation, solar PV and low energy lighting. The loan is then paid back through the energy bill in relation to the savings achieved from the energy efficiency upgrade installed. At present, however, the Green Deal only covers physical changes to the building or building systems and does not provide recommendations on changing occupants' daily use of the building to save energy, such as turning down the thermostatic settings and reducing the window opening time. The Department of Energy & Climate Change (DECC, 2013) has announced that only half of the householders who have had a Green Deal assessment have chosen to install at least one energy efficiency measure, meaning that the remaining dwellings have got no improvement on energy efficiency from the Green Deal. Due to

the high importance of occupant behaviour on building energy consumption (Wei et al., 2014a, Haas et al., 1998) and occupants various use of the buildings in reality (Fabi et al., 2012, Wei et al., 2013, Wei et al., 2014a), it is believed that promoting the energy efficiency of how occupants use the buildings can have a significant contribution to saving UK residential energy consumption (Wei et al., 2014b, Ben and Steemers, 2014).

eViz (Energy Visualization for Carbon Reduction), is an interdisciplinary research project collaboration between four UK universities, namely, Plymouth, Birmingham, Bath and Newcastle Universities (Pahl et al., 2013). eViz aims to research how energy visualisation affects energy consumption behaviour, including both retrofitting energy efficiency measures (Goodhew et al., 2014) and changing building operations (de Wilde et al., 2013). As part of the eViz project, dynamic building performance simulation is being explored as a tool that predicts the energy saving effect of various behavioural change options on the building heating demand with a view to helping householders make changes to optimise the energy efficiency of their buildings (de Wilde et al., 2013). In this tool, promoting the energy efficiency of occupants' use of their buildings is greatly concerned.

In order to convert the dynamic building performance simulation so that it is suitable for public use, it has been integrated into an interactive Energy Efficiency Educator (EEE). This offers a menu of energy-efficiency parameters to be input and changed by the occupant so that they can model the effect of changing, e.g. the thermostatic setpoint or the boiler operation. The energy saving potential of adopting these energy-efficient behaviours is estimated using a dynamic building performance simulation engine, EnergyPlus, based on typical UK housing types.

The current prototype of the EEE is being developed in response to a desire in building users to access tailored energy efficiency advice (Abrahamse et al., 2005, Gifford, 2014), personal to their own building and situation. The perceived problem is that building users understand that energy efficiency is particular to buildings, dependent on multiple factors ranging from the orientation and the age of the building to their own behavioural choices about temperature setpoints and running duration of the heating system (Guy and Shove, 2000). When energy efficiency advice is given in a case study format about an example building, the danger is that the user has little confidence in the energy efficiency advice and so the advice can be discounted by the user, i.e. this case study is very different from the factors in 'my building'. This generates a dichotomy, in that to use a tool which gives a higher level of relevant and tailored energy efficiency information, the user will need to input detailed building data (the level of data that would be expected to be input into a building simulation model). Would a building simulation approach work for the general public?

At the current stage of the EEE, before further enhancements are made, the potential users' acceptance of a decision making tool based on dynamic building performance simulation is worth exploring, so that the findings can inform the next step of the tool development, adopting a user-centred development process. To assess users' response, a qualitative, focus group approach was taken using 14 real building users, and this paper reports on the initial feedback from these users.

Methodology

BUILDING PERFORMANCE SIMULATION

Building performance simulation involves the replication of building performance, such as energy efficiency, using a computer-based, mathematical model. It is based on applying fundamental physical principles and engineering models, and therefore is also known as 'first principle modelling'. Whereas some engineering calculations can be performed by hand, solving equations with say 10 variables, simulation typically involves much larger numbers, which are often in the range of 10,000 or more. Simulation can involve different performance aspects, such as thermal, lighting, air flow and acoustics, and a good introduction to this discipline has been given by Hensen and Lamberts (2011).

EnergyPlus (DOE, 2015a), which is developed by the U.S. Department of Energy, has been adopted in this study, as the dynamic building performance simulation engine of the EEE. Compared to other simulation tools, such as ESP-r, IES VE and Ecotect, EnergyPlus has the following advantages for this study:

1. It uses up-to-date building performance prediction methods (Crawley et al., 2001) that have been critically validated for various building applications (Mateus et al., 2014, Tabares-Velasco et al., 2012, Zhou et al., 2008);
2. It can be easily linked with 3rd party tools, such as MATLAB, for further development (DOE, 2015b); and,
3. It is a free tool, so there will be no additional cost in the EEE for the simulation engine.

ENERGY EFFICIENCY EDUCATOR (PROTOTYPE)

The EEE is developed based on the dynamic building performance simulation function in EnergyPlus and the Graphical User Interface (GUI) function in MATLAB. Figure 1 shows the main window of the EEE. The EEE consists of three main steps to give householders advice on behavioural changes (e.g. turning down the thermostatic setting or reducing the daily use of the heating system). In Step 1, users (usually building occupants) are asked to provide some basic information about their building and building systems. In Step 2, they are required to input information about how they currently use the heating systems in their buildings and where do they want to change this behaviour to. In Step 3, the EEE will estimate the effectiveness of all behavioural changes defined by the householders in Step 2. This is done by predicting the building energy consumption using EnergyPlus for both the current behavioural circumstance and the ones they would like to change to, and then calculating the difference between them. The predicted financial saving for each behavioural change intention will be shown in Pound Sterling based on the information imported by the users in Step 1 and Step 2 and the simulation results obtained in Step 3.

Figure 2 depicts the sub-window where users input information about their building and building systems according to their real living conditions, based on the options listed in Table 1. If the user does not know some essential information such as the main orientation of the house and the energy efficiency rate of the boiler, further help can be obtained online by clicking the buttons below the question. This tailored

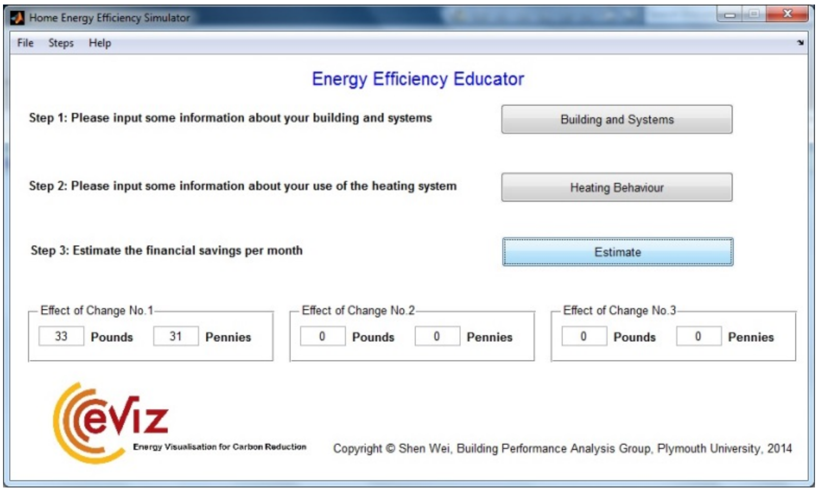

Figure 1. Main window of the EEE.

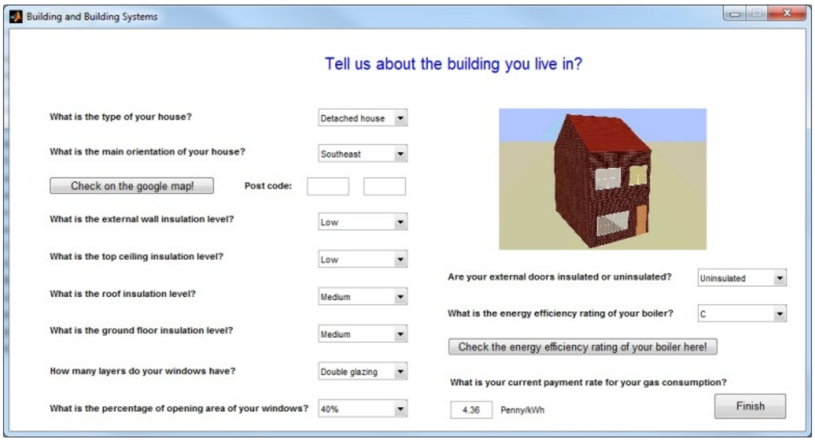

Figure 2. Sub-window defining the building and building systems (Step 1).

information helps to increase the accuracy of the later predicted building performance by EnergyPlus. The information classifications in Table 1 aim to capture possible scenarios in real UK dwellings and further improvement is still needed. However, this study aimed to test occupants' responses to a decision support tool on changing behaviour, based on tailored evidence from dynamic building performance simulation. At this stage, it was the response of the user that was the focus of attention. Accurate classifications and assumptions for these options will need to be improved in future developments of the tool.

Figure 3 depicts the sub-window where users define their heating use behaviour, for both the current state of behaviours and the one(s) they would like to change to (e.g. defined as Behaviour 01, 02 and 03). This section starts with a question about the user's normal occupancy schedule, which will be used to control the heating behaviour defined later. The second group of questions asks for information about the user's preferred indoor air temperature, at the occupied time, unoccupied time and sleeping time respectively. The last group of questions is about the use of the heating boiler for both unoccupied and sleeping times. The first column in these two groups is used to define the user's current heating behaviour and they have been provided with up to three options to change their behaviour in columns 01, 02 and 03. This information will then be used to drive the dynamic building performance simulation shown in Figure 1, for an evaluation of the impact of various heating operations on the building energy consumption.

USER RESPONSE FOCUS GROUP METHOD

To assess the users' response to the EEE, three focus groups consisting of four/five participants each were held. The sample consisted of four male and ten female participants, all were over the age of 21 and all paid their own energy bills in their homes. The procedure began by asking the participants to choose one particular building that they had lived in (not necessarily their current home) and use the parameters in the EEE for that building. It was explained that the EEE was in development with an interface that could enable a householder to access building simulation information; in other words they could change the conditions of their home and the tool would display the corresponding effect on their energy use. For example, participants were told that "you can change the heating temperature that you usually set to see the effect of reducing or increasing it, or you can set the heating on for longer or shorter periods".

Participants were then given instructions in how to operate the EEE. Researchers demonstrated the screens shown in

Table 1. Required information from users (usually building occupants) with respect to the building and building systems.

Information	Values
1. Type of the house	detached, semi-detached, mid-terraced, bungalow, apartment/flat
2. Main orientation of the house	east, southeast, south, southwest, west, northwest, north, northeast
3. External wall insulation level	low, medium, high
4. Top ceiling insulation level	low, medium, high
5. Roof insulation level	low, medium, high
6. Ground floor insulation level	low, medium, high
7. Number of window layers	single glazing, double glazing, triple glazing
8. Percentage of window opening area	20 %, 40 %, 60 %, 80 %, 100 %
9. External door insulation	no, yes
10. Energy efficiency rating of the boiler	A, B, C, D, E, F, G
11. Current payment rate of gas	any number in the unit of Penny/kWh

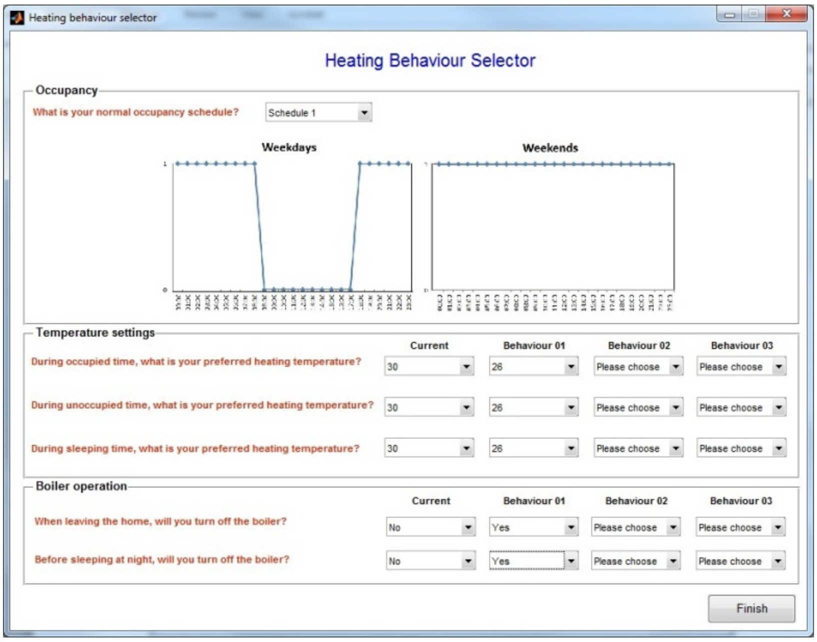

Figure 3. Sub-window defining heating behavior (Step 3).

Figures 1, 2 and 3. During this instruction period, participants input relevant data about their own building and defined their interested behaviours to change, for instance reducing the thermostatic temperature setting when at home. After the instruction period, a twenty-minute period was allowed so that the participants could 'play' with the EEE, changing the building parameters (Table 1 & Figure 2) and their behavioural conditions (Figure 3). This period preceded a thirty minute focus discussion on a series of semi structured questions centred on the following topics:

1. The users' acceptance of the EEE;
2. The users' preference between a more tailored prediction with complex data input and a simplified prediction that is easier to start; and,
3. Users' suggestions on the improvements of either the Graphic User Interface of the EEE or the functionality of it.

Results and discussions

THE USERS' ACCEPTANCE OF THE EEE

In the study, a majority (71 %) of the participants would be likely to use the EEE tool in their daily life for energy saving. Among the other 29 %, some expressed that they would use it after it was further developed. These developments generally meant a call for more details:

> P5: "I would use it if it included more details like whether windows are open and if radiators are on";

> P9: "I would only use is if it showed my own, accurate energy use for the last two weeks";

> P13: "Can the tool take into account high ceilings? The year in which house was built should be considered".

The call for more details suggests an interesting association between the level of building details which participants input into the tool and the acceptance of the EEE predictions on energy saving and monetary savings. As the level of details increased, the acceptance of the validity of the tool increased, and vice versa. Participants were aware that energy use is influenced by multiple factors and if these factors were not part of the 'model' then this undermined their acceptance of predicted energy savings as Guy and Shove (2000) detailed.

THE USERS' RESPONSES REGARDING COMPLEX DATA INPUT

In the prototype, there were certain data points which participants found difficult to input. For example, providing a judgement on whether their floor insulation was of a 'low, medium or high level' was a challenge to some participants and they preferred to think in terms of the known construction type, as shown by the comment from P1,

> P1: "Is a concrete floor low in insulation?"

In fact, P1 chose a selection of 'highly insulated' for a concrete floor. Therefore, the EEE should be written to enable the users to choose the factually accurate information, although this will increase the data input by the tool users. In this case, providing an option where the user can choose the type of floor, with most probable U values programmed to this choice.

Interestingly, participants requested more complex data input, as opposed to less. This, in their view enabled a more tailored simulation model.

> P15: "There is no option to choose from when the house has few or one wall insulated rather than all"

> P7: "There should be more options for ceiling insulation"

Data they felt important to include was for example, more occupancy schedules to select from so it can better represent their personal patterns of occupancy;

> P14: 'How can people working part time choose the correct schedule?'

They also asked for options for different temperature settings for different rooms within the house; a possibility of defining window opening operations, allowance for defining the number of residents in the house, the time of year (a setting per season?), the number of rooms in the home and the number of hours that the boiler was switched on. Even more details were asked for such as how often the windows were opened, the size of the windows, the size of the ceilings in the house and whether the radiators were on when windows were open. Furthermore, the variability of the UK weather and the unit price of energy were details mentioned that, if included, could increase confidence in the predictions.

From the above response, it seems to be once participants started to use the EEE, they preferred a more tailored simulation model than a simplified model, albeit they need to input more data to use the EEE.

USERS' SUGGESTIONS ON THE IMPROVEMENTS OF EITHER THE GRAPHIC USER INTERFACE OF THE EEE OR THE FUNCTIONALITY OF IT

To summarise from earlier in the paper, suggestions for improvement involved:

1. Include more variety of occupancy schedules or provide the users with a way of detailing their typical pattern of occupancy;
2. Clarify and rename behaviour 1, 2 and 3 options so that users better understand that these represent the 'model' or prediction, based on users' hypothesised changes to their daily behaviour;
3. Gathering more information such as window opening behaviour, individual room control, to get a more tailored simulation model;
4. Questions to be framed so that the user provides information about the construction type rather than asking the user to judge the level of insulations; and,
5. Consider including more costs, payback periods for actions, and reference to energy bills.

Conclusions and limitations

In order to achieve residential energy savings, a UK research project, eViz, is exploring the use of dynamic building performance simulation to help building occupants make decisions on how they change the use of their buildings. The EEE tool provides information on the effectiveness of for example, changing heating and occupancy behaviours on the building energy consumption. For public use, a popular dynamic building performance simulation engine, EnergyPlus, has been integrated into an interactive tool, which has a working title of Energy Efficiency Educator (EEE). This study has tested the prototype of the tool on real building users to inform the further development of such a tool for real applications.

The small pilot study reported here provides positive feedback on users' acceptance of the EEE, but building users, in order to accept the predictions of the EEE, require a high level of detail specific to the their own buildings to inform the EEE computations. Key comments from users centred around how to respond to the questions the EEE requires for energy calculations. This highlighted a) lack of detailed knowledge on behalf of the building users as well as b) possibilities of improving and specifying the questions further. Moreover, building users seemingly wanted to provide more detail and information about their home and lifestyles. This highlights an interesting trade-off when considering the use of this tool more widely. Asking building users for more information would without doubt improve the energy predictions and make them more tailored. This raises an interesting dichotomy between the level of building 'detail' needed for users to accept the EEE predictions vs. the effort needed from the users when using the tool. Would people really be prepared to spend that much time on setting it up, and would the increase in detail be associated with a commensurate increased in decision quality? These questions have been partly answered in this study but would need to be tested in further research with a larger number of samples.

A focus group provides a small sample of responses and the tool would need to be tested again for a much larger sample of participants once it is developed further. The focus group method also required participants to use this tool for a 20 minute session, whereas in general use, the EEE would have to be attractive enough for people to choose to use it freely and in this sense we did not test the general interest level in using such a tool.

In conclusion, the EEE tool was conceived from research findings suggesting that building users require advice on promoting the energy efficiency of their buildings, but this needs to be tailored to the specific situation of their home. Building performance simulation software is already professionally available to 'model' a range of building parameters and predict the effect of changes to a building in terms of its energy efficiency consequence. Using an adapted interface, this software can be used to allow general householders to 'model' their own buildings and predict the effect of changes to their model. There is considerable potential for developing this tool further given that participants expressed considerable interest in using such a tailored approach.

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