EXTENDING THE UK'S GREEN DEAL WITH THE CONSIDERATION OF OCCUPANT BEHAVIOUR

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ABSTRACT

This paper introduces a study, which extends the current UK's Green Deal through a consideration of modifying occupant behaviour in buildings to save building energy consumption. A case study was carried out in a typical mid-terraced residential building located in the Southwest of the UK. In the study, dynamic building performance simulation was used to predict the energy saving potential of various behaviour change options so as to help occupants use the building more energy efficiently. Feedback from building occupants reveals that this approach is helpful in reducing energy demand in a real building application, but also points out the need for future work.

INTRODUCTION

In 2013, the UK government launched the Green Deal in order to help reduce the UK's energy use and carbon dioxide emissions arising from the domestic sector. The Green Deal enables households to take on loans to pay for energy efficient upgrade measures (e.g. installing solid wall insulation, solar PV and low energy lighting). The loan is consequently paid back through the energy bill in relation to the savings achieved from the energy efficient upgrade installed.

As part of the existing scheme, certified Green Deal assessors visit the homes of interested homeowners and undertake a survey of the current condition of the building and building systems. The survey data is then entered into a Simplified Building Energy Model (SBEM) to produce a series of energy efficiency upgrade recommendations based on the predicted energy and financial savings.

At present, the Green Deal assessors only provide recommendations related to physical changes to the building or building systems. These recommendations generally require building occupants to accept a financial loan, which is a difficult decision in the current economic climate. Whilst DECC (2013) claims that 56% of households who have had a Green Deal assessment have chosen to install at least one energy efficiency measure, the remaining households have not, meaning no improvement to the energy efficiency of these dwellings has been achieved despite the time invested by the Green Deal assessor.

It has been widely accepted that occupants have a significant impact on the actual energy consumption of buildings (Haas et al. 1998, Al-Mumin et al. 2003, Fabi et al. 2013). In the past several decades, a series of studies about occupants' behaviour in buildings have been carried out, involving explorations of various behaviour types, such as building occupancy (Newsham et al. 1995, Page et al. 2008), window opening/closing behaviour (Wei et al. 2013, Fabi et al. 2012), space heating operation (Wei et al. 2014, Fabi et al. 2013) and blind/curtain usage (Haldi and Robinson 2009, Raja et al. 2001), for better predicting building performance by simulation. In recent years, initial explorations on using building performance simulation to help increase building energy efficiency have been carried out, by predicting the impact of changing occupant behaviour on building energy demand (de Wilde et al. 2013, Kim and Altan 2013, Porritt et al. 2012, Love 2012).

Due to the high importance of occupant behaviour on building energy performance, it is suggested here that through the introduction of an occupant behavioural survey delivered by the Green Deal assessors, all homeowners will at least receive useful advice on how to achieve energy savings in their homes through behaviour modifications at zero financial investment.

This paper reports on work where the researchers conducted an existing Green Deal assessment, coupled with an innovative behavioural survey in a real UK residential building. Beyond the traditional Green Deal scheme, in this study building performance simulation was used particularly for helping the building occupants understand the behavioural modifications they could make to reduce their building's energy demand. The study consisted of three steps: (1) gathering data about the investigated building (e.g. building construction, heating and cooling systems, occupants and their behaviour) and developing a simulation model for the building, used as the base case model; (2) presenting available building upgrading options and behaviour change options to the building occupants and asking them to choose the one(s) that they are interested in; and (3) using building performance simulation to predict the potential impact of each behaviour change option as well as the combination of options, on the basis of the base case model and showing the results to the building occupants.

This paper first sets the context to the work by introducing an ongoing UK research project, eViz (Energy Visualisation for Carbon Reduction), within which the study was carried out. It then introduces the three steps and their initial results sequentially, followed with a discussion of feedback from the building occupants. Conclusions of this study and possible future work are provided at the end of the paper.

EVIZ – ENERGY VISUALISATION FOR CARBON REDUCTION

The eViz project (Pahl and de Wilde 2012) is a large interdisciplinary project carried out by four UK universities. It brings together expertise from a range of domains; apart from building science it includes psychology, architecture, interdisciplinary arts, civil engineering, multi-media systems, computing, and human computer interaction. The project explores the options to transform building users into "smart occupants", who play an important role in curbing building energy use demand.

The research conducted in eViz consists of various workpackages, and includes in-depth monitoring of energy use and occupant behaviour in a range of domestic buildings, as well as simulation of the thermal performance of these buildings. Other work includes the development of digital systems to change occupant behaviour, and user studies to analyse the impact of these digital systems on actual occupant behaviour. This paper presents a first attempt to combine all of these in an initial PDSA (Plan-Do-Study-Act) cycle.

DATA GATHERING AND MODEL DEVELOPMENT

Data gathering

The study was carried out in a mid-terraced house located in the Southwest of the UK, as shown in Figure 1. The house has two floors and its floorplans are shown in Figure 2. For each casement window in the house, there is an outward opening on the top, and the remaining part is fixed. The approximate opening area of the window is about 30% of the total area of the top light. In order to build a base case simulation model that is as close as to the real condition of the building, a data gathering process was carried out. This process collected data from two aspects: (1) information about the building and its systems; (2) information about the occupants and their behaviour. The former data was collected from documents provided by the house owner, and he got these documents from the previous house owner when he was purchasing the house. The latter data was collected by a survey including questions about the building occupants and their behaviour. For example, "how many people are living in this building?" and "how will you use your living room windows during the winter time?".

Figure 1 Case study house

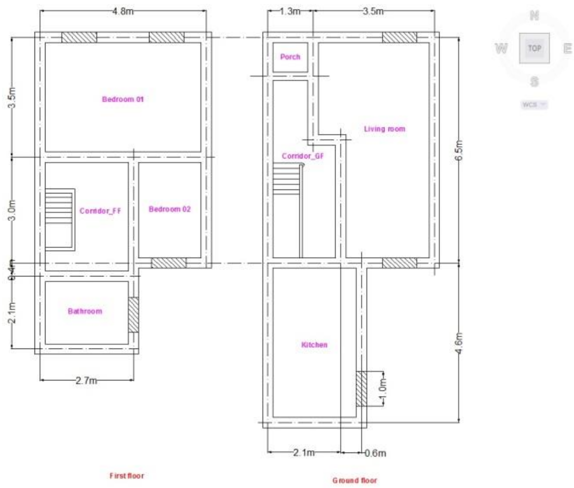

Figure 2 Floor plans

Table 1 lists the useful information for developing the base case simulation model, with respect to the building construction and its systems, and Table 2 lists the information about the occupants of the building and their behaviour influencing to the building heating energy consumption.

Table 1
Information about the case study house (building and systems)

CATEGORY	DEFINITIONS
House layout	As shown in Figure 2
External wall (U-value = 2.071)	Brickwork Outer Leaf (100mm) + Brickwork Inner Leaf (100mm) + Gypsum Plastering (13mm)
Internal wall (U-value = 1.639)	Gypsum Plasterboard (25mm) + unventilated cavity (100mm) + Gypsum Plasterboard (25mm)
Ground floor (U-value = 1.463)	Cast Concrete (100mm) + Floor Screed (70mm) + Timber Flooring (30mm)

Internal floor (U-value = 2.929)	Cast Concrete (100mm)
Ceiling (U-value = 0.388)	Plywood (10mm) + Cast Concrete (100mm) + unventilated cavity (100mm) + Plasterboard (13mm) + Glass wool (75mm)
Roof (U-value = 2.930)	Clay Tile (25mm) + unventilated cavity (20mm) + Roofing Felt (5mm)
External window (U-value = 3.159)	Clear double glazing, filled with air, and only the upper smaller window is operable
External door (U-value = 3.159)	Door with clear double glazing glasses, filled with air
Internal door (U-value = 2.251)	Wooden door
Blind	Venetian blind (light)
Airtightness	Poor airtightness condition[1]
Boiler	Seasonal efficiency of boiler is 60%.

Table 2
Information about the case study house (occupants)

CATEGORY	DEFINITIONS
Number of occupants	two occupants (one house owner, one tenant)
Occupancy	For the house owner: **Weekdays:** 00:00 to 08:00 (sleeping in the bedroom 1) + 08:00 to 09:00 (breakfast in the kitchen) + 9:00 to 14:00 (working outside) + 14:00 to 15:00 (lunch in the kitchen) + 15:00 to 17:00 (relaxing in the bedroom 1) + 17:00 to 21:00 (working outside) + 21:00 to 24:00 (relaxing in the bedroom 1). **Weekends:** 00:00 to 09:00 (sleeping in bedroom 1) + 09:00 to 10:00 (breakfast in the kitchen) + 10:00 to 14:00 (relaxing or working in the living room) + 14:00 to 15:00 (lunch in the kitchen) + 15:00 to 24:00 (sleeping and relaxing in bedroom 1). For the tenant: **Weekdays:** 00:00 to 08:30 (sleeping in bedroom 2) + 08:30 to 09:00 (breakfast in the kitchen) + 09:00 to 24:00 (studying and doing part-time work outside). **Weekends:** 00:00 to 12:00 (sleeping in bedroom 2) + 12:00 to 16:00 (Relaxing or working in the living room) + 16:00 to 24:00 (doing part-time work outside).
Window operation	In winter, the window in the Kitchen will only be opened between 14:00 and 14:30 when the house owner is cooking the lunch. The window in bedroom 1 will be left open for one hour after the house owner gets up in the morning. The window in bedroom 2 belongs to the tenant, who will keep the window open all the time. The window in the bathroom will be opened for one hour in the morning and one hour in the afternoon, for ventilation purposes. All other windows will not be opened in winter.
Door operation	External doors are closed always. Internal doors for the two bedrooms will be always closed. All other internal doors will mostly be kept open.
Blind operation	All blinds will be closed before sleeping and will be reopened in the morning after getting up.
Heating operation	The timer on the boiler is not used so the boiler is on all the time. The room temperature settings are: Bedroom 1: 20 °C; Bedroom 2: 20 °C; Corridor: 18 °C; Kitchen: 18 °C; Bathroom: 22°C; Living room: 20 °C.

[1] In DesignBuilder, the air tightness level is defined as five levels: excellent, good, medium, poor and very poor. Each air tightness level is defined as a combination of air leakage from Openings (windows, doors, vents), Walls, Floors/ceilings and Roofs.

Model development

Based on the information listed in Tables 1 and 2, a simulation model for the case study house was developed, as shown in Figure 3, used as the base case model for the later simulation work.

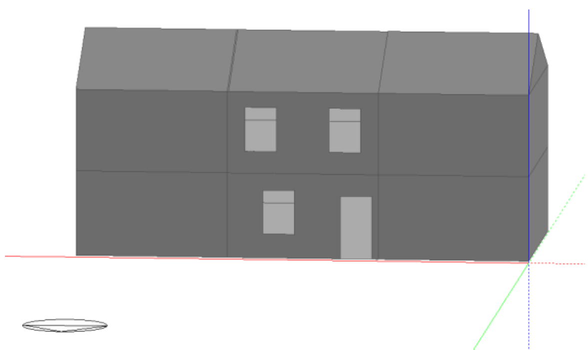

Figure 3 Base case simulation model

DesignBuilder V3.2 was chosen as the simulation tool in this study, by which dynamic thermal simulations were performed to predict the building energy performance during the winter time hourly. DesignBuilder is the first comprehensive user interface of EnergyPlus (DesignBuilder 2014), and DesignBuilder V3.2 adopts EnergyPlus 7.2 as the engine for dynamic thermal simulations.

SELECTION OF INTERESTED BUILDING UPGRADING AND BEHAVIOUR CHANGE OPTIONS

As the energy bill is included in the rent of the tenant, she is not concerned much about the house energy consumption, hence is not very interested to take part in this study. Therefore, the study focused on the house owner, who is reponsible for paying the energy consumed by the building. To let the house owner choose his interested building upgrading options and behaviour change options, two option lists are provided, one for upgrading the house (Table 3) and another one for improving building operation (Table 4). Table 3 follows the traditional route of the Green Deal and Table 4 is the added content in this study, which considers occupants' operation of the building.

Table 3
Available options for upgrading the house

ITEMS	BUILDING UPGRADING OPTIONS
Upgrading façade insulation	(1) Adding external wall insulation; (2) Adding ground floor insulation; (3) Adding further ceiling insulation; (4) Adding roof insulation.
Improving building air tightness	(1) Adding membranes; (2) Adding weather-stripe/draft excluders for windows/doors.
Upgrading external windows	(1) Adding window layers; (2) Changing filling materials.
Upgrading external doors	(1) Adding door layers; (2) Improving door insulation.
Upgrading the heating system	(1) Installing energy-efficient heating systems; (2) Installing smart control strategies for the heating system.
Upgrading curtains/blinds	(1) Fitting heavier blinds/curtains.

Table 4
Available options for improving building operation

ITEMS	BEHAVIOUR CHANGE OPTIONS
Window operation behaviour	(1) Reducing window opening time; (2) Closing all windows when leaving homes; (3) Closing all windows before sleeping at night; (4) Closing all windows in unused rooms.
Door operation behaviour	(1) Reducing back door opening time; (2) Closing the back door when the adjacent room is not used; (3) Closing the internal door of the unconditioned porch.
Blind/curtain operation behaviour	(1) Shutting off all blinds/curtains during the night-time; (2) Opening the south-facing blinds/curtains when it is sunny outside.
Thermostat operation behaviour	(1) Lowering the thermostat settings; (2) Turning down the thermostat settings when leaving homes; (3) Turning down the thermostat settings before sleeping at night.
TRV operation	(1) Setting different temperatures for different rooms; (2) Lowering the TRV settings; (3) Turning down the TRV settings when leaving homes; (4) Turning down the TRV settings before sleeping at night.
Boiler operation	(1) Turn off the boiler when leaving homes.

The house owner decided not to select any option from Table 3 as he currently has no plan to invest in an upgrade of his house. However, he showed a high interest in knowing how he can improve the building operation to save energy. In the study, he finally chose three options from Table 4, and wanted to see the impact of doing these actions on the house energy consumption:

1. Turning down the TRV setting for bedroom 1, the bathroom, and the living room to 18°C before sleeping at night (Reason: the house owner wanted to know the potential influence of undertaking additional TRV adjustments before sleeping on the house heating energy demand);

2. Turning off the boiler between 09:00 and 14:00 and between 17:00 and 21:00 for weekdays, when both the house owner and the tenant are not at home, using the timer function on the boiler (Reason: the house owner wanted to know the energy saving potential of using the timer function on the boiler, for period when the house is unoccupied);

3. Asking the tenant to close her window when she is not at home (Reason: the house owner was worried about the additional energy consumption caused by the extremely active window opening behaviour of the tenant and he wanted to know if the tenant always closes her bedroom window before leaving the house, how much energy can be saved).

IMPACT PREDICTION

The impact prediction was carried out by comparing the house heating energy consumption before the behaviour change and after that, representing as the energy saving potential of each behaviour change option. The simulation period is defined as from 1st October to 31st March and the weather data used in the simulation was collected in 2002, from the main campus of Plymouth University, which is about 1 mile away from the case study house.

Impact from individual behaviour change option

Figure 4 shows the predictions for performing a single energy saving action in the case study, with the estimated financial savings by changing that behaviour, which were estimated based on the unit rate of gas consumption from British Gas (4.360 p/kWh, including VAT – Value Added Tax), the energy provider of the case study house.

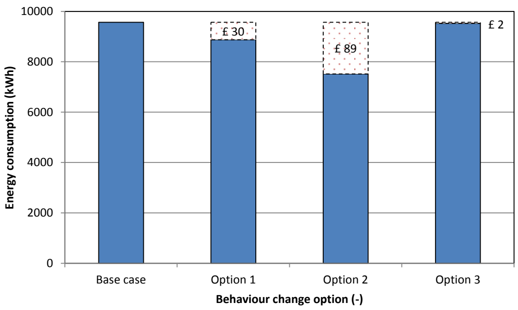

Figure 4 Impact from individual behaviour change option

From Figure 4, it could be found that turning the boiler off when the house is unoccupied has the largest potential of saving energy within the three behaviour change options that have been selected by the house owner: it can save £89.00 for the whole winter season. Additionally, lowering TRV settings before sleeping at night can also contribute to reducing the house heating energy demand in winter. Due to the limited opening area of the window in the bedroom 2, the tenant's extremely active window opening behaviour seems to have little influence on the energy used to heat the house in winter.

Impact from combining behaviour change options

Besides the above predictions, the house owner also wanted to see the energy saving potentials of performing more than one behaviour change option at the same time. The prediction results are shown in Figure 5.

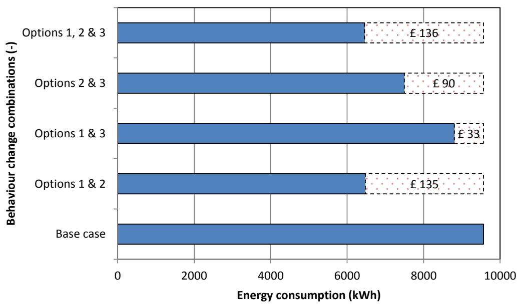

Figure 5 Impact from combining behaviour change options

Comparisons between the predictions shown in Figure 4 and Figure 5 reveal that performing more than one behaviour change option at a time can contribute to saving more energy, compared to performing only one behaviour change option. The maximum energy saving could be obtained when all three behaviour change options are performed, and this can save 3111kWh heating energy, which equals to £136.00 at the current charge rate.

OCCUPANT FEEDBACK

Occupants' feedback will be helpful on judging the usefulness of using dynamic building performance simulation to help real building occupants make decisions. Therefore, at the end of this case study, the house owner's opinions about the study were collected by interviews. Generally, the house owner was happy about the prediction results provided by the building simulation tool, and he thought the whole process is helpful for him on making behaviour change decisions in the future. Based on the prediction results for Option 1 and 2, he had decided to do some adjustments for the TRV settings before sleeping at night and also learn how to use the timer function on the boiler to automatically turn off the boiler when the house is unoccupied. Additionally, for the prediction result of Option 3, he was no longer worried about the tenant's extremely active window opening behaviour in her bedroom.

However, he also provided some advice on how this methodology needs to be further developed:

1. Some deeper introduction about building performance simulation is still needed to make the occupants more confident on the prediction results; and,

2. Simplify the simulation tool for daily use (maybe embed the simulation results into an APP or an Android tool).

CONCLUSIONS

This paper introduces a real case study expanding the current UK's Green Deal through a further consideration of improving occupants' operation of buildings. In the study, dynamic building performance simulation was used to help building occupants make decisions on performing energy saving behaviour changes. The whole process consisted of three steps. In the first step, relevant information about the building, building systems and its occupants was collected for developing the base case simulation model. Then in the second step, the occupants were asked to select their interested upgrade and behaviour change options from a comprehensive list. In the last step, dynamic building performance simulation was carried out to predict the energy saving potential of each behaviour change option selected by the occupants, as well as the combination of those options, to help them make decisions on modifying future use of the building.

Feedback from the occupants reveals that this process is helpful for the house owner who is fully responsible for the energy consumed by the building. For the tenant, whose energy bill has been included in the rent, the whole process is not very interesting. Optimising occupant behaviour in residential buildings is important for achieving the UK government's 2050 target for CO_2 emission reduction (CCC 2008), due to the high contribution of these buildings on the total nation's energy consumption. However, this methodology still needs to be improved in future studies to provide a simplier tool for building occupants to use.

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