USING DYNAMIC SIMULATION FOR DEMONSTRATING THE IMPACT OF ENERGY CONSUMPTION BY RETROFIT AND BEHAVIOURAL CHANGE

Young Ki Kim[1] and Hasim Altan[1]
[1]Building Environments Analysis Unit (BEAU), School of Architecture, The University of Sheffield, Sheffield, United Kingdom

ABSTRACT

In this paper, dynamic simulation software (in this case, DesignBuilder) has been used to model and to simulate a typical 1960s UK social housing in order to examine the impact of retrofit, occupant behaviour and user lifestyle on energy pattern. In terms of retrofitting study, various energy efficiency measurements have been considered such as improving level of insulations and heating system's efficiency. For the occupant behaviour influence study, three types of heating control patterns have been created such as 'Constant On', 'NCM' and 'Programmed Heating Control'. For the life style influence study, two different user patterns have been defined such as fulltime working and retired couple user groups. Results and findings of the study are further presented within the paper.

INTRODUCTION

UK homes are the oldest stock across the Europe and it is responsible for the nation's Greenhouse Gas (GHGs) emissions of more than a quarter (DEFRA, 2006). The UK government set very ambitious target to meet the Kyoto Protocol requirement which is reducing GHGs emissions by 80% from 1990 level by 2050 (DEFRA, 2008). In line with this target, the government announced that new homes will be built as zero carbon homes after 2016 (CLG, 2006).

There has been a great deal of time and effort dedicated to improving energy efficiency of existing and newly built homes. Improvements to the fabric of the building and the low/zero carbon technology installation should mean that homes use significantly less energy. Housing stock turnover, however, is at about 1% a year (TRCCG, 2008). The sustainable Development Commission estimates that 70% of the UK's 2050 housing stock has already been built (SDC, 2007). This means that improving existing housing stock's energy efficiency will be an important factor to achieve the UK government's ambitious target. Furthermore, relatively little study has been carried out to understand the factors that has the single biggest effect on the energy used in the home which are caused by the occupants.

The paper considered the impact of retrofit, occupant behaviour and user lifestyle on energy use. In terms of retrofitting study, various energy efficiency measurements have been considered. For the occupant behaviour influence on energy consumption, two user patterns have been created. To do these, 1960s typical British steel framed social house was selected and modelled within dynamic simulation software, which is namely DesignBuilder (version 2.2.5). Results and findings of the study are further presented within the paper.

UK HOUSING ENERGY EFFICIENCY

Space heating is responsible for the majority of the domestic energy consumption, followed by lighting and appliances, and water heating. Heating and hot water account for around 84% of energy use in a typical home in the UK (DECC, 2011). Improving the energy efficiency of heating systems, or reducing demand, by even a small amount, can have a far bigger effect on energy use than making changes to, for example, lighting. Therefore, increasing building energy efficiency is the basic principle and method which is adopted by the UK government to reduce energy consumption and carbon dioxide emissions from the domestic sector, and increasing thermal comfort in UK homes.

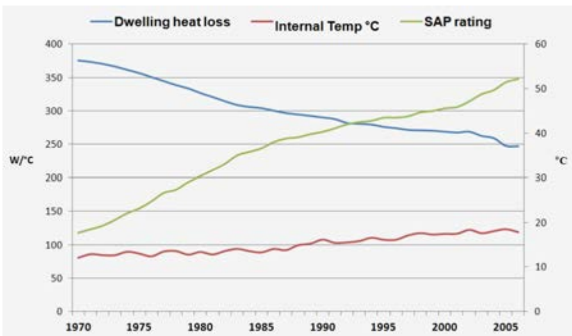


Figure 1 Energy efficiency of UK housing

Since the government funding for energy efficiency schemes introduced, a considerable progress has been made with the improving insulation levels and replacing inefficient boilers. All of these energy efficiency measures made the average heat loss of a typical dwelling decreased from 376W/°C in 1970 to 246.8 W/°C in 2006. The average SAP[1] rating in

[1] The Standard Assessment Procedure (SAP) is used by the government to determine the energy efficiency of a UK dwelling.

1970 was about 18 and by 2008 this had increased to about 53 (see Figure 1) (Utley 2008). After the increased energy efficiency of the home such as the use of central heating system and improved fabrics' heat loss, the average temperatures inside domestic dwellings have increased from 12°C in 1970 to 17.3°C in 2008 (DECC, 2011).

USER INFLUENCE

Behaviour Influence

Research suggested that changing occupant behaviour will allow more energy to be saved than through architectural and technical strategies alone. Differences in individual behaviour can produce large variations of more than three times the average energy consumption, even when differences in housing, appliances, heating, ventilation, air conditioning and family size are controlled (Janda, 2011). According to the World Business Council for Sustainable Development's research, even if people live in identically constructed house, different users will have very different energy consumption patterns. Deviations of ±50% from the average consumption value are not exceptional (WBCSD, 2007).

Heating controls are important and BRE's Home Group research (unpublished report) shows that users may not actually be using their timers or controls as designed, but instead using other more intuitive ways of controlling the temperatures such as using their thermostats as an on/off switch.

Lifestyles

Lifestyle factors that may increase the length of time spent at home, and therefore increase the likelihood that heating duration and energy consumption will be higher, include home working, unemployment, permanent ill health, disability and retirement. During the winter months in particular, space heating may increase if occupants are at home for longer periods during the day. For example, a single person out at work all day will have different energy needs to a family with young children who spend a large proportion of their time in the home. Other considering influence is that a rise in household incomes and the purchase of more and bigger appliances in homes. In addition, people tend to keep their homes warmer in winter than they used to and there has also been increase in the number of households, as the number of people who live alone has increased (DECC, 2011). Therefore, the success of reducing carbon from the housing sector depends upon not only improving the fabric performance, but also understanding the relationship between how occupants use the property and their particular personal circumstances (Bell et al, 2010).

Ratings range from 1 to 100 and the higher the SAP score, the more energy efficient the property.

METHODOLOGY

The research presented here examined the effect of a range of single and combined retrofitting. The term retrofitting covers a range of adaptation to the building fabric (see Table 1 and 3) and it also looked at the user influence such as modifying heating habits (see Table 4) and changing lifestyle (see Table 5) of heating energy consumption which was based on user influence studies in previous section.

To consider the effect of heating operating habits on heating energy consumption, three different heating operating habits have been created which were namely 'constant heating on' as worst case scenario, 'NCM' as typical UK home's heating habits which is based on a case home and 'programmable heating system' as ideal scenario.

To consider the effect of user lifestyle on total energy consumption, two different user lifestyles have been created which are namely 'working family' and 'elderly couple'.

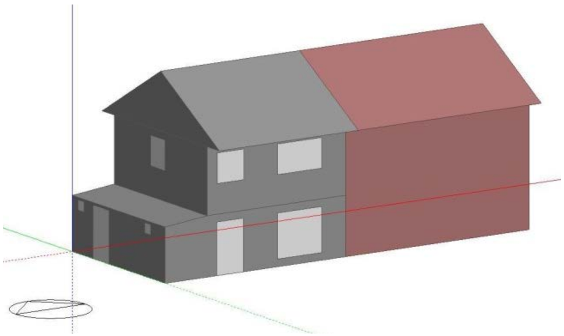
Computer simulation was used to assess the effectiveness of the retrofitting and user behavioural change. DesignBuilder v2.2.5 has been used with the integration of the EnergyPlus v4.0 calculation engine. The dynamic thermal simulations have been performed in the study, enabling hourly prediction of the thermal conditions and energy consumption in a multi-zone building model by an interactive calculation process. The DesignBuilder was developed in the UK and adopted several UK building standards to simulate the energy consumption and CO_2 emissions, and thermal conditions. DesignBuilder is the first comprehensive user interface to the EnergyPlus dynamic thermal simulation engine with fully applying the calculation engine. DesignBuilder is approved by the UK government to generate an Energy Performance Certificate (EPC[2]) and its database is based on the UK's National Calculation Method (NCM) for construction, activity and schedule data.

Case Study Home

In 1944 various non-traditional house construction systems were assessed by the Interdepartmental committee on Housing Construction to identify the most promising for immediate development. The British Iron and Steel Federation (BISF) steel framed house was one of those selected and a programme was planned for the construction of 30,000 three-bedroom two-storey semi-detached houses in England and Wales (BRE, 1986).

[2] The EPC shows how energy efficient a building is and gives it a rating from A (very efficient) to G (inefficient). It also shows how costly it will be to heat and light, and what its carbon dioxide emissions are likely to be. The EPC will also state what the energy efficiency rating could be if improvements are made, and highlights cost-effective ways to achieve a better rating.

a) Case study home

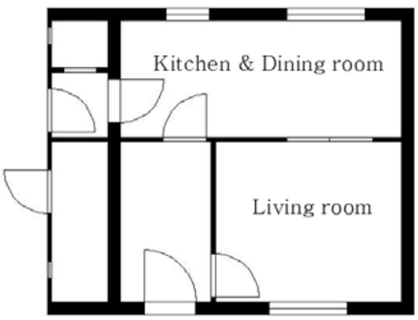


b) Simulation model

Figure 2 Case study home and simulation model of BISF semi-detached house

The simulation model presented in this paper represents a two-storey semi-detached three-bedroom house, located in a Leeds suburban area (see Figure 2).

The house is constructed from BISF walls, with solid concrete ground floor and a clad with asbestos cement profiled sheets roof. The house comprises a living room (at the front and south-facing), dining room with kitchen, bathroom and three bedroom and total area is around 90m² (see Figure 3).



a) Ground floor

b) First floor

Figure 3 Case study home floor plans

The EPC was used to establish the construction and insulation properties for the base case model. According to the EPC, base case model has been assumed that the original single glazing has been replaced with uPVC framed uncoated double glazing and the level of loft insulation is 150mm of glass fibre. The construction and thermal properties are summarised in Table 1.

Table 1
BISF house base case model construction and thermal properties

ELEMENT	DETAILS	U-VALUE (W/M²K)
External walls	Steel (2mm) with 100mm unventilated cavity and steel (2mm) with plasterboard (13mm)	2.5
Roof	Asbestos cement profiled sheets with 150mm insulation	0.25
Ground floor	Uninsulated solid concrete floor	1.1
Internal partitions	Timber faming lined with plasterboard (13mm) each side	1.6
Windows	pre 2002 double glazing with uPVC frame	2.8
Door	Wooden	-
Airtightness	16.1m³/(h.m²)	-
Boiler	Seasonal efficiency of boiler is 58%	-

Internal gains for people and appliances were used through the UK's NCM database and living room and bedrooms were assumed to use low energy light bulbs.

Based on the Chartered Institution of Building Services Engineers (CIBSE) recommended comfort criteria for dwelling including heating and cooling temperature set points have been considered in Table 2 (CIBSE, 2006).

Table 2 Recommended comfort temperatures (°C)

ROOMS	HEATING	NAURAL VENTILATION
Bedroom	17-19 (18)*	22**
Livng room	22-23 (22)	
Kitchen	17-19 (18)	
Rest of rooms	21 (21)	
* heating set point temperaure for simulation model is represented in brackets. ** window ventilation commences when the room operative temperature reaches 22°C.		

Simulation Scenarios

This section described the simulation scenarios. This research has been focused on three sensitivity studies such as, retrofitting, heating profiles and user lifestyles.

- Study A considers the effect of retrofitting on heating energy consumption.
- Study B considers the effect of heating operating habits on heating energy consumption.
- Study C considers the effect of user lifestyle on total energy consumption.

Table 3 shows the details of retrofitting interventions for simulation study A.

Table 3 Modelled retrofitting details

<table>
<tr><th>RETROFITTING</th><th>DESCRIPTION</th></tr>
<tr><td>External insulation</td><td>Adding external insulation to 70mm to achieve U-value of 0.35 W/m^2K.</td></tr>
<tr><td>Replacing boiler</td><td>Replacing old boiler to 90% seasonal efficiency.</td></tr>
<tr><td>External insulation, loft insulation and replacing boiler</td><td>Adding external insulation to 70mm to achieve U-value of 0.35 W/m^2K; Increase loft insulation to 250mm to achieve U-value of 0.16 W/m^2K; Replacing old boiler to 90% seasonal efficiency.</td></tr>
<tr><td>Adapted 2006 Building Regulation Part L[3]</td><td>Adapting 2006 Building Regulation standard into case study house which makes the case study home more airtight and improved fabrics' thermal property as described in further below table.
<table>
<tr><th>Constructions</th><th>U-value (W/m^2K)</th></tr>
<tr><td>External wall</td><td>0.35</td></tr>
<tr><td>Ground floor</td><td>0.25</td></tr>
<tr><td>Roof</td><td>0.16</td></tr>
<tr><td>Window/Door</td><td>1.978</td></tr>
<tr><td>Airtightness</td><td>$10m^3/(h.m^2)$</td></tr>
</table></td></tr>
</table>

[3] Building Regulation Part L sets out the legal requirements for the conservation of fuel and power in all buildings. To do this, it sets minimum requirements for thermal property of building fabrics, level of insulations and airtightness.

Table 4 shows the heating operating hours in simulation study B. As mentioned above, the NCM represents a typical UK home and a base case home in this study. All simulation models' were identical to the same as base case home except the heating operation habits of 'constant heating on' case and 'programmed heating system' case.

Table 4 Heating operating control

HEATING METHOD	OPERATING CONTROL
Constant heating on	Always on through the year
NCM	Base Case Home
Programmable heating system	05:30 ~ 07:30 and 19:00 ~ 22:00

Table 5 shows the occupied hours for living room, bedrooms and the kitchen for case study home in simulation study C. This simulation study C was only considered the influence on energy consumption by the different length of occupied hours.

Table 5 Occupied hours for living rooms, bedrooms and kitchen

LIFESTYLE	LIVING ROOM	BEDROOM	KITCHEN
Working family	18:00 ~ 22:00	22:00 ~ 07:00	06:30 ~ 08:00 and 18:00 ~ 20:00
Elderly couple	09:00 ~ 22:00	22:00 ~ 07:00	07:00 ~ 08:00, 12:00 ~ 13:00 and 18:00 ~ 20:00

RESULTS

Dynamic simulations were carried out for the base case model based on Table 1 construction data in order to check model validation then for the research interests based on Tables 3, 4 and 5. The simulations predicted heating energy consumption and the results presented in subsequent sections showing the effect of the various simulation scenarios.

Model Validation

According to the case study home's EPC, the case study home is rated as E and an average UK home's EPC rate is also rated as E. The average UK home's heating energy consumption is about 20,500 kWh/yr (Ofgem, 2011). From the base case model's simulation, the consumed heating energy is of 21,246 kWh/yr and the difference between an average UK home's heating consumption and the base model's heating consumption is around 4%, and this difference is acceptable to carry out further simulations.

Study A Result

Dynamic simulations were carried out for the base case model and then for the range of retrofitting listed in Table 3. As can be seen in Figure 4 and model validation study, the base case home's heating energy consumption is almost same as the typical UK home's heating energy consumption. According to the retrofitting scenarios, in general, as increasing the energy efficiency of the base model, total heating energy demand is decreased. The most significant reduction is predicted when the base case home is refurbished to the 2006 Building Regulation standards which required less than a fifth from the base case home. The single most efficient retrofitting is external insulation and its heating demand is almost 45% less than the base case home.

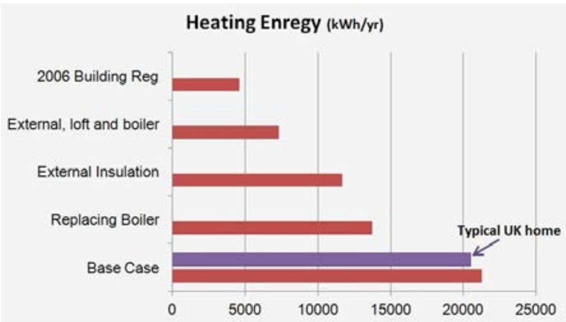


Figure 4 Study A results

Study B Result

Figure 5 shows how heating operation patterns affect the heating energy consumption in the case study home. As a result, 'constant on' schedule shows the worst performance which is almost 35% more heating energy demand than the base case study home namely as NCM. Comparing NCM and programmed heating scenario, it shows that programmed heating performed almost with 45% less heating demand. Again, comparing 'constant on' and programmed heating, it showed that programmed heating required 40% of heating energy more from the 'constant on' scenario.

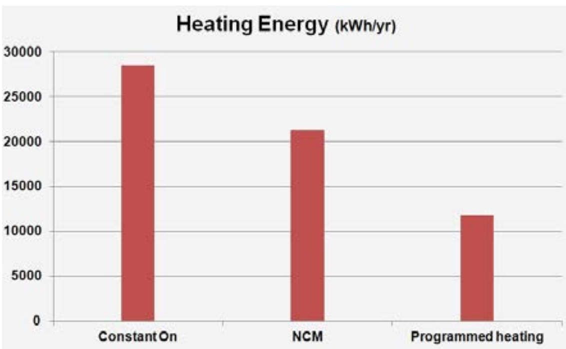


Figure 5 Study B result

Study C Result

Figure 6 shows that the lifestyle influences on heating energy consumption in the case study home. It also considered various retrofitting options with lifestyle effect on heating energy consumption. In general, longer time spent at home seems consuming almost 7% more than working family. Retrofitting to the 2006 Building Regulation standards, the heating energy consumption difference between the 'working family' and 'elderly couple' scenarios are decreased and the difference is only 3%.

Figure 6 Study C result

Table 6 shows that electricity consumption in each cases and the difference between them is almost 6%. Therefore, total energy consumption difference between working family and elderly couple is from 9% to 14%. It confirmed that time spent at home can have an effect on energy consumption and the longer the stay at home the more the energy consumption.

Table 6 Electricity consumption (kWh/yr)

WORKING FAMILY	ELDERLY COUPLE
4730	5016

DISCUSSION

The UK has the oldest housing stock in Europe and almost 70% of this stock would be stood in 2050s. Therefore, improving existing homes energy efficiency is crucial strategy in order to achieve the UK government's ambitious target. As a result, the study shows that the typical 1960s BISF house could save almost 80% of its heating energy demand by improving its fabric thermal property. In terms of intervention or retrofit options, single most efficient way to reducing heating energy demand is adding more insulation into external walls due to external walls are the most expose surface area to external and the most heat losses/gains is expected through external walls.

This research shows that more than 75% of UK households answer 'they know how to control their heating system'. Nevertheless, most of them do not know how to use their heating system properly and operating energy efficiently. This often leads to the wasted energy and conditions that are satisfactory but not ideal. As a result of simulation study B, it can be seen that if we could control our heating system with a programmable setting, the heating energy consumption would be reduced by more than 60% from an on/off control setting which is namely as 'Constant On' within this research. This reduction is almost same as installing the external insulation for the case study home investigated. Therefore, even the home is built to the most energy efficient standards, the energy consumption would vary and this highly depends on the knowledge and understanding of its heating system and operation.

Time spent at home is an important issue as the more time people spend at home the more likely they are to have their heating on, use lights, and so on. The increase in the availability of technology in the home has contributed to increase in the number of home workers, which has risen from 2.3 million in 1997 to 3.1 million in 2005 (Ruiz and Walling, 2005). Carins et al (2004) suggest that if this trend continues there could be around 30% of the UK workforce home working for at least some of the time by 2014. As a result of simulation study C, it shows that the heating energy consumption difference between working family and elderly couple would be from 3% up to 8% through retrofitting options which are considered within this research. In general, increasing energy efficiency of homes, the difference is getting smaller and it could be explained that energy efficient home can hold warmth for longer hours than energy inefficient homes, and during the daytime, solar gains would contribute to the remaining rooms' warmth. Therefore, energy efficient home would not have much difference in heating energy consumption in relation to various lifestyle and user patterns. However, electricity consumption would be very different in lifestyles and user patterns, and the lifestyle could be a significant effect on electricity consumption. For example, number of appliances and its energy consumption is gradually increased from 5% of total energy consumption in 1970 to 12% in 2008, and its trend would increase due to increasing in the purchase of appliances because of inexpensive prices and having multiple of the same products such as TVs, laptops and tablet PCs. When households spend time at home longer, they use more appliances and lighting, and as a result, this has influence on electricity consumption.

Lifestyle factors, such as time spent at home, use of appliances and lighting and the level of heating also have a significant impact. Potential trends, which may affect energy consumption, also need to be taken into consideration, such as the ageing population and changes in home working and home parenting. More research is needed into the effects of these different variables on energy consumption. This research points out that changing occupant behaviour such as using heating system with programmable setting, will allow more energy to be saved than the retrofitting and the technical strategies alone.

CONCLUSION

In the UK, more than a quarter of energy consumption is caused by the housing sector due to space and water heating, cooking, appliances and lighting. The UK government has focused on new homes and set very ambitious targets where the new homes will be zero carbon after 2016 and 80% GHGs emissions reduction by 2050 for national levels. Thus, existing homes will continue to be majority percentage of the UK housing stock by 2050 and efforts need to focus on improving existing homes in order to achieve the target.

This paper considered the impact of retrofit, occupant behaviour and user lifestyle on energy use. The research suggests that improving fabric insulation helped significant heating energy reduction and the single most efficient way to reduce the heating energy demand by retrofitting term is adding an external insulation. The most significant and easiest way to reduce heating energy demand is using a heating system with a programmable setting. The lifestyle influence on heating energy consumption shows that the longer stay at home would cause more energy consumption as expected. However, this effect will gradually reduce as improving efficiency of home but not in electricity consumption.

Plenty of studies have considered the effect of improving fabrics' thermal property on heating energy consumption and some provided strong evidences why we need to improve our homes' energy efficiency. However, even in dwellings that have achieved specific standards, the energy consumption may be dramatically different depending on the occupants' energy use behaviour, their lifestyle and any extensions or alterations they make to the house. More research is needed into the effects of occupant behaviour and lifestyles on energy use; this will allow for more targeted interventions to be applied.

ACKNOWLEDGEMENT

The BIG Energy Upgrade programme (also known as the Energy Innovation for Deprived Communities, EIDC) is partly funded by the European Regional Development Fund (ERDF) as part of Europe's support for the region's economic development through the Yorkshire and Humber 2007-2013 programme.

REFERENCES

Bell, M., Wingfield, J., Miles-Shenton, D. and Seavers, J. 2010. Low Carbon Housing, Lessons from Elm Tree Mews. York, Joseph Rowntree Foundation.

BRE, 1986, The British Iron & Steel Federation steel framed house

Cairns, S., Sloman, L., Newson, C., Anable, J., Kirkbride, A. and Goodwin, P. 2004. Teleworking Smarter Choices - Changing the Way we Travel'. Available at: http://webarchive.nationalarchives.gov.uk and www.dft.gov.uk/pgr/sustainable/smarterchoices/ctwwt/chapter10teleworking.

CIBSE. 2006. Environmental Design: CIBSE Guide A (7th edition).

CLG. 2006. Building a Greener Future: Policy Statement, Available at: http://www.communities.gov.uk/documents/planningandbuilding/pdf/building-greener.pdf

DECC. 2011. Great Britain's Housing Energy Fact File 2011, the Department of Energy and Climate Change, Available at: http://www.decc.gov.uk/assets/decc/11/stats/climate-change/3224-great-britains-housing-energy-fact-file-2011.pdf

DEFRA. 2006. 'Climate Change – The UK Programme 2006', London: Department for Environment, Food and Rural Affairs, HMSO

DEFRA, 2008, Climate Change Bill Final Impact Assessment, UK Government

Janda, K.B. 2011. Buildings don't Use Energy: People do. Architectural Science Review, 54: 15-22.

Ofgem, 2011, Typical Domestic Energy Consumption Figures, Available at: http://www.ofgem.gov.uk/Media/FactSheets/Documents1/domestic%20energy%20consump%20fig%20FS.pdf

Ruiz, Y. and Walling, A. 2005. Home-based Working using Communication Technologies. Labour Market Trends, London, Office for National Statistics, pp. 417-426.

SDC. 2007. Stock Take: Delivering Improvements in Existing Housing. Sustainable Development Commission, available at: http://www.sd-www.sd-commission.org.uk/publications/downloads/Stock_Take_UK_Housing.pdf

TRCCG (Three Regions Climate Change Group). 2008. Your Home in a Changing Climate, Retrofitting Existing Homes for Climate Change Impacts, Available at: http://www.london.gov.uk/trccg/docs/pub1.pdf

Utley, J. and Shorrock, L.D. 2008. Domestic Energy Fact File 2008, Department of Energy and Climate Change, BRE, Energy Saving Trust, UK.

WBCSD. 2007. Energy Efficiency in Buildings: Business Realities and Opportunities. Summary Report. Geneva, World Business Council for Sustainable Development.