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Combining energy efficiency measure approaches and occupancy patterns in building modelling in the UK residential context

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ABSTRACT

The UK faces a significant retrofit challenge, especially with its housing stock of old, hard-to-treat solid walled dwellings. In this work, we investigate the delivery of heated thermal comfort with a lower energy demand through four types of energy efficiency interventions: passive system, conversion device, method of service control, and level of service demanded. These are compared for three distinct household occupancy patterns, corresponding to a working family, a working couple and a daytime-present couple. Energy efficiency measures are considered singly and in combination, to study whether multiple lower cost measures can achieve comparable savings to higher cost individual measures. Scenarios are simulated using engineering building modelling software TRNSYS with data taken from literature. Upgraded insulation of wall and roof resulted in highest savings in all occupancy scenarios, but comparable savings were calculated for reduced internal temperature and partial spatial heating in scenarios in which the house is not at maximum capacity. Zonal heating control is expected to achieve greatest savings for the working couple who had a flexible occupancy pattern. The results from this modelling work show the extent to which energy consumption depends on the appropriate matching between energy efficiency measures and occupant type.

1. Introduction

Domestic energy accounted for 29% of UK total energy use in 2013 [1] with space heating contributing 60% of this [2]. The UK has committed to reduce 80% of its greenhouse gases emissions by 2050 compared to 1990 levels (UK [3]). Even greater emission cuts are required in the building sector due to limited emission reduction potential in other areas, such as transport and industry [4]. Pressures to improve the energy efficiency of homes also come from trying to address high levels of fuel poverty and concerns over energy security. It is estimated that a majority of the buildings that will be in place in 2050 have already been built [5–7]. The culmination of these factors highlights the presence of a significant retrofit challenge. However, there is even evidence that figures for energy use in similar buildings vary greatly [8–10] and therefore a given energy use does not only depend on the standard of the fabric the house.

The aim of this paper is to demonstrate the variation of energy savings achieved by implementing different Energy Efficiency Measures (EEMs) for varied household occupancy patterns. In order to achieve this, a range of seven EEMs are chosen based on different approaches to delivering the energy service of heated thermal comfort. The savings achieved by the EEMs are compared for three different occupancy patterns which are derived based on common household scenarios in the UK, backed up by literature.

In order to calculate energy demand values before and after EEM interventions, a model of a typical UK 'hard-to-treat' house is developed using TRNSYS, a commercially available and well used building energy model. The modelling of the EEMs is based on literature data from academia and industry in order to attain the most likely values for model parameters before and after an intervention is adopted.

This paper begins with a literature review of related academic work in Section 2. The methodology is presented in Section 3 which includes an outline of the modelling process (Section 3.1), description of the EEMs which are selected according to how they deliver the energy service of heated thermal comfort (Section 3.2), and

Abbreviations: EEM, energy efficiency measure; TRV, thermostatic radiator valve; HDD, heating degree day.

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details of the occupancy patterns under consideration (Section 3.3). The results of the modelling work are revealed in Section 4, including a comparison of the results with similar studies, both empirical and modelled. Section 5 is the discussion, covering how the results relate to future and past policy priorities and additional considerations required when making recommendations for retrofit work. The paper concludes in Section 6 by recapping on what the paper has achieved and includes further steps which can be taken to gain additional insight into how EEMs can best be selected for different houses and occupants.

2. Literature review

2.1. Representing occupancy in building modelling

In recognition of the effect that occupancy behaviour has on real world energy use, the inclusion of more realistic occupancy profiles has been a focus of building modelling literature in recent years. As an approach to including realistic occupancy patterns, statistical pattern generators have been developed which take data from time use surveys (TUS) and create a tool for simulating random daily occupancy for model input [11–15]. Alternatively, occupancy archetypes have been defined to include in building modelling [16–19]. These allow for the variation between different types of occupants to be identified. Other studies have measured occupancy usage and behaviour directly and inputted these into building models to compare the modelled and measured data [20–22].

2.2. Retrofit decision models

The use of building energy modelling software to compare approaches to building retrofit is of current interest both within literature and policy programmes. In various policy programmes such as Energy Performance Certificates and the UK's Green Deal, the Standard Assessment Procedure (SAP) is used to predict savings from different energy efficiency measures and recommendations for retrofit are given. Within literature, models have been used to compare different approaches to improving the thermal resistance of the building envelope [17,23] and different heating strategies [18]. Rysanek and Choudhary [71] compared energy demand savings modelled for a range of single and combined improvements to energy supply systems and demand side measures in non-domestic buildings, with the inclusion of a stochastic model of occupancy behaviour, (including set-point temperatures, equipment use and lighting) and economic pay-back time. Recommendations for retrofit options could therefore be made based on real-world aspects of building use and decision making. De Meester et al. [17] investigated heating energy savings from increased insulation and three factors of human behaviour and occupation mode (family size and mode of occupation, thermostat setting and management of heating area). They found that equivalent savings could be attained by increasing insulation levels or by changing behavioural factors, but that the impact of behaviour on energy usage became smaller and less pronounced as the amount of insulation increased.

3. Methods and materials

3.1. Modelling process

In order to simulate energy demand savings for EEMs within this project, we are modelling a typical UK house using TRNSYS, a dynamic simulation software, which performs energy balance calculations using transient thermodynamic equations. By defining the building geometry, thermal envelope characteristics and occupancy details, the state of our building can be evaluated over 15 min time steps. Table 1 lists and justifies modelling variables. The geometry of the house is shown in Fig. 1.

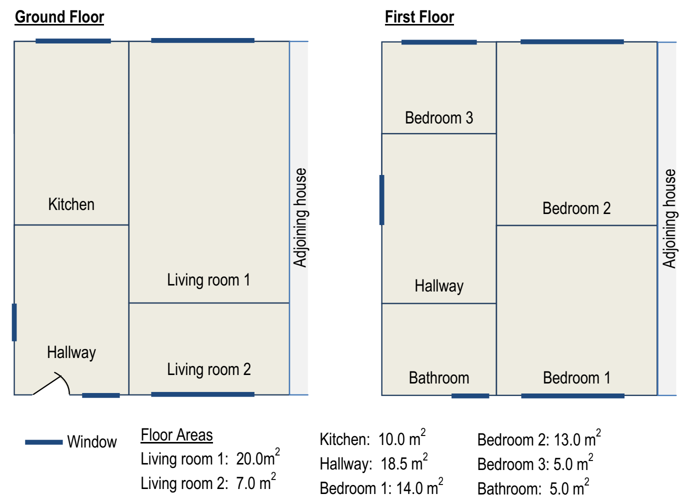

Fig. 1. Plan of modelled house.

3.2. Energy efficiency measures

3.2.1. Energy services approach to retrofit

EEMs are installed with the aim of delivering the service of a warm occupied space with lower energy input. The delivery of energy services has been discussed in literature as the step between energy supply and satisfaction of welfare [24]. The supply side of the energy system (comprising the conversion of primary energy to final delivered energy) has received the greatest attention in energy policy and therefore this paper focusses on the energy demand side of the chain. A framework has been developed using this theory of energy service delivery so as to identify four different approached of EEMs. The first two are derived from Cullen and Allwood [25] who describe the delivery of energy services from final energy as comprising an active conversion device and a passive system. The conversion device is the technical component which can convert an energy carrier into a useful form of energy (such as chemical energy within gas being converted into heat energy in a boiler). The passive system is 'the final technical component in the energy chain' within which the useful form of energy delivers an energy service (such as the room, with or without insulated walls, in which heat energy delivers thermal comfort). Technical efficiency improvements in the conversion device or the passive system can enable the same service to be delivered with lower energy input. The third option is a lower level of service demand, both in terms of internal temperature and amount of space heated. The level of energy service required to fulfil human welfare depends on lifestyle and is linked to cultural norms and habits [24,26] and therefore adapting to a lower level of service could be achieved both by adaptive methods or changes in societal expectations. Finally, inefficiencies in the way in which the energy service is delivered can be removed by better control and this is covered by the fourth approach, service control.

Data used in the modelling work has as far as possible been based on the most realistic values through a review of literature from academia and industry. The process for finding this data and the values identified are given in the following section. The values for initial and improved levels of each EEM are presented in Table 2.

3.2.2. Conversion device: Boiler

Central heating is now the most common means of domestic heating in the UK, present in around 90% of households [27]. Typically, a boiler burns natural gas (mainly methane) to produce