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Energy retrofit and occupant behaviour in protected housing: A case study of the Brunswick Centre in London

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ABSTRACT

This study examines the impact of behavioural and physical variables on the energy saving from retrofitting protected housing. Protected housing in England is referred to as 'listed' housing managed by English Heritage. The result of the study demonstrates that balanced approaches can be developed to retrofit listed housing by taking into account occupant behaviour factors, to meet the requirement of both energy efficiency and heritage conservation. A case study of the Brunswick Centre in London shows that the highest household energy use can be 2.2 times higher than average consumption. According to the modelling results from Integrated Environmental Solutions (IES) software, the impact of positive behavioural change ranges up to 62–86% of the total potential savings in the tested dwellings, where the lower behaviour change effect is associated with a higher retrofit level. However, rebound behaviour could offset estimated energy saving from physical improvement. Based on the findings, a framework of intervention measures is developed, which demonstrates that the proportion for behavioural change and building technology varies with respect to household energy use level. In summary, this study shows that in listed housing behavioural change has the potential to bring substantial energy saving far exceeding that from physical improvements, and thus tackling behavioural change plays a pivotal role in developing integrative strategies for listed housing retrofit.

1. Introduction

> "Listed buildings are those included on the statutory List of Buildings of Special Architectural or Historic Interest. Controls apply and Listed Building Consent is required for any works of alteration or extension – both external and internal – which would affect a building's character." [1]

Improving the energy efficiency in the domestic housing stock is a key priority to the success of achieving national carbon emissions reductions such as the UK Government's target to tackle climate change [2,3]. The UK aims to reduce its greenhouse gas emissions by 80% by 2050. The residential sector accounts for 27% of total CO_2 emissions, which is therefore one of the most important sectors to address [4]. It is estimated that about 75% of the existing housing stock in the UK will still be in use by 2050 [5]. Consequently, retrofitting existing housing to become more energy efficient is critical to reduce energy consumption. Listed housing represents the finest building stock among existing housing, where retrofit intervention should balance historic value and energy efficiency [1,6,7].

In the context of improving energy efficiency in listed housing, this paper examines ways to enhance the potential energy savings from retrofits. However, the energy savings that are realised in practice often fall short of expectation. One explanation is that improvements in energy efficiency encourage greater expectations of the energy-related services such as thermal comfort. Behavioural responses such as these have come to be known as the rebound effect [8]. While this effect may be sufficiently large to lead to zero (or even less than zero) energy savings, an outcome that has been termed 'backfire', positive behavioural changes may increase energy savings following retrofit, known as 'green behaviour'.

Occupant behaviour plays a major role in determining building energy use according to the existing literature [9–19]. It is usually the main reason causing the significant gaps between actual and predicted energy performance of buildings [10,20,21]. Studies have shown that occupant behaviour may vary to such an extent that the resultant building energy use differs by a factor of two or more [22,23].

Studies carried out for energy retrofit of heritage buildings have mainly concentrated on technical improvements [1,6,24–31]. The

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extent to which these improvements can actually achieve energy savings, taking into account possible behavioural change, has rarely been explored to any great extent in an integrated manner. The lack of assessment of such behavioural impact calls for further investigation with respect to a balanced approach for heritage conservation and energy efficiency.

This paper aims to reveal to what extent occupant behaviour has an impact on the energy saving from listed housing retrofit, seeking to improve energy efficiency potential by taking behaviour change into account. Given the constraints on physical interventions into the fabric of listed buildings, the hypothesis is that in the retrofit of listed housing, if occupant behaviour changes are fully realised, then substantial energy savings can be achieved from the improvement that addresses both historic conservation and energy efficiency.

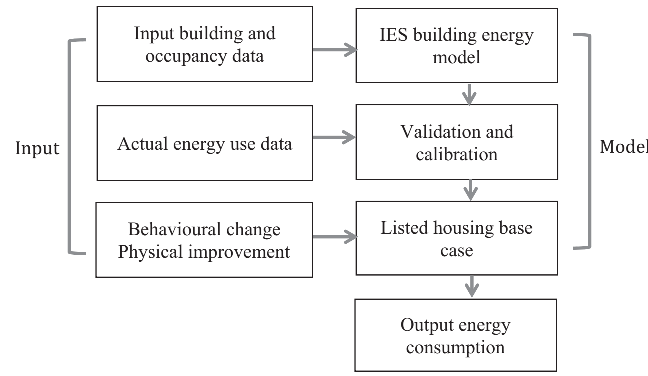

Fig. 1. Retrofit Model Framework (RMF).

2. Background information of listed housing case study

The Brunswick Centre in London has been chosen as the case study for listed housing. This residential complex is a notable post-war housing scheme praised for its high-density low-rise design and mixed-use development. The building was designed by Patrick Hodgkinson in 1967, listed 'Grade II' by English Heritage in 2000, and renovated by Levitt Bernstein in 2005–6. Its aim was to create an exemplary urban environment where everyone was brought together without social segregation. As a concrete 'mega-structure' social housing scheme, the Brunswick contains 407 flats with a shopping centre on the ground floor and car parking below. All the flats are served by a gas-fired district-heating system.

The Brunswick building contains four types of dwellings, including bedsits, one-bedroom flats, two-bedroom flats, and maisonettes. Two-bedroom flats are found to be the most common type (see Section 3, baseline model), accounting for approximately half of the total dwellings. In each of these wide-frontage single-aspect flats, the living room extends to a winter garden and connects to the kitchen space as a whole. In this way, daylight can reach deeply into the dwellings, especially with the raked section of roof glazing that helps with increasing light angles. In addition, both living room and bedrooms intercommunicate but are insulated from access corridors by service rooms. Due to the setback at each floor level, there is an external strip of exposed floor along the back of each flat.

3. Research methodology

The specific purpose of this section is to provide a basis for carrying out more detailed study on assessing the impact of occupant behaviour on the overall energy saving in listed housing. This section presents the development of the Retrofit Model Framework (RMF) (Fig. 1), which provides a structure for modelling energy use from domestic retrofit at individual dwelling level, while assessing the potential impact of occupant behaviour on the energy saving. It is a bottom-up physical model, based on building physics equations and algorithms, taking different sets of scenarios into account that influence the retrofit energy saving. For the physical modelling we use the validated energy simulation tool, IESVE [32]. This approach provides a sufficient degree of flexibility and capability in modelling occupant behaviour and testing scenarios related to changes in both physical and behavioural parameters.

3.1. Input parameters

A baseline dwelling model (Fig. 2) has been adopted for the purpose of standardisation, to allow various parameters to be meaningfully compared. It is characterised by being a west facing mid floor two-bedroom flat at the Brunswick Centre. The source for the climatic condition and site data was the IES ASHRAE [32] weather database for London. The input parameters of building construction profiles for the base case are shown in Table 1. The flat height is measured as 2.7 m, with a width of 9.6 m and a depth of 9.0 m (including winter garden). Standardised input behavioural parameters have been extracted from existing models and the literature (Table 2). The rest of input parameters that are unavailable from the surveys carried out have been obtained from IES default data [32] or published data (ASHRAE and CIBSE Guide) (Table 3).

3.2. Calibration of baseline model

The survey at Brunswick shows the annual bill for heating is £866.81 per flat in 2012/13 [33]. This represents the average heating cost of the base case flat. In order to estimate the heating energy consumption, we use gas unit rate at 4.37 p/kWh (this figure is taken from British Gas online tariff rates, under the category of postcode WC1N 1QF and Direct Debit payment). By dividing the annual consumption by the floor area of the base case (70.68 m^2), the gas usage is estimated as 280 kWh/m^2 y that is used as the figure for calibration of the model.

Table 1
Construction profiles for the base case.

Construction	Description	Thickness (mm)	*U*-value[a] (W/m^2 K)
External wall (external front and back)	Themalite blocks with cavity	250	1.7
Party wall (between flats)	Bricks with cavity	215	1.6
Floor/ceiling	In situ concrete	200	1.2
Front door	Wood	40	3.0
Winter garden rooflight	Double-glazing with metal frame, argon filled (low-E, 0.2, hard coat)	15	2.9
Winter garden vertical glazing	Single-glazing with metal frame	6	5.7
External wall below window	Concrete block with cavity	230	1.7
Kitchen and bathroom window	Single glazing with metal frame	16	5.7
Balcony door	Single glazing with metal frame	6	5.7

[a] Figures taken from the Standard Assessment Procedure (SAP), 2009.