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Effects of fabric retrofit insulation in a UK high-rise social housing building on temperature take-back

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ABSTRACT

This paper presents a two year long empirical study on the effects of fabric retrofit insulation on a high rise social housing building (a 23-storey block with 157 flats) in Newcastle upon Tyne (UK). The study has followed a quasi-experimental approach coupled with qualitative methods and examines whether temperature take-back is taking place; whether it operates independently of socio economic characteristics due to saturation effects; and the relationship between temperature take-back, physical factors and occupant's behavioural change. The presented empirical evidence suggests that, first, temperature take-back as extra warmth (or energy consumption savings) is not occurring. Second, the saturation effect has taken place. This supports the assumption that temperature take-back decreases owing to saturation effects when pre-intervention internal temperatures saturate (approaching 21 °C) in lieu of the hypothesis that low-income householders take the benefits of an energy efficiency intervention as extra warmth rather than energy savings. Third, an upper level or maximum take-back temperature was achieved for the dwellings ranging from 20.85 °C to 24.81 °C. Fourth, behavioural factors such as turning on the heating appear to be less relevant than physical factors such as energy-efficiency improvements to explain the increased of standardised mean internal air temperature. The study also suggests that local building characteristics (e.g. heating pipes routing) play an influential role and that to evaluate appropriateness of retrofitted energy-efficiency insulation measures pre-intervention variables such as internal temperatures, heating system and building fabric performance should be taken into account.

1. Introduction

This empirical study stemmed from a query raised by a social housing provider (Your Homes Newcastle – YHN) to better understand the effects of building fabric retrofit on a deprived area. Social housing is defined as housing that is affordable, provided on a needs-driven basis where housing provision is not met by the market and includes households renting from Registered Providers, for example, a Local Authority or an Arm's Length Management Organisations (ALMOs) such as YHN. The housing provider outlined their expectations such as a decrease in the heating bills, decrease full poverty, improve the property value and contribute with the regeneration of this area.

It is known that energy demand in social housing is affected by factors which are complex and often poorly understood [1]. Teli et al. [2], specifically, highlights the need to use empirical data as typical conditions representative of social homes could be far from those expressed in building energy models. Furthermore, empirical information on temperatures in domestic dwellings is valuable in appraising energy conservation interventions as, for example, the benefits of an energy efficiency intervention can be taken as energy consumption savings or extra warmth (i.e. required energy service) [3,4] depending on household income level [5].

Building upon previous research propositions and findings, this investigation primary research proposition is that the reduction of energy consumption saving defined through temperature take-back exists and can be observed. In general, temperature take-back is defined as the change in mean internal temperatures following the building fabric retrofit and the reduction in energy consumption saving associated with that change. This means lower than expected gains of energy-efficiency improvements due to increased demand for energy services such as warmth [5]. Previous quantitative studies have shown that following retrofit predicted energy consumption savings are converted into increased internal temperatures [4,6]. For example, a meta-review of 12 studies of household heating consumption concluded that the temperature take-back ranged from 0.14 °C to 1.6 °C. This take-back is not insignificant as a "1 °C increase in internal temperature may increase the

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energy consumption for space heating by 10% or more" [4, p. 26]. Furthermore, Sorrell [4] estimates that up to 100% of energy savings is lost through temperature take-back with a mean around 20%.

Several studies have proposed that temperature take-back is higher in dwellings occupied by low-income householders [3,4]. One suggested reason is that financial constraints on low-income dwellings would lead to very low pre-intervention temperatures as these dwellings are often not warm enough for occupancy [3]. This means that low-income groups are more likely to have unmet demand for energy services (e.g. warmth -expressed as internal temperature), and, as a result of the unfulfilled demand, a higher temperature take-back. Other investigators have further suggested that it is likely that pre-retrofit internal temperature and low income are correlated [6] but few studies include measures of both. This study examines the association between temperature take-back and low-income dwellings.

Temperature take-back may also operate independently of socio economic characteristics. Sorrell [4] suggested that temperature take-back decreases owing to saturation effects when pre-intervention internal temperatures saturate (approaching 21 °C). This has been conceptualised as the saturation effect: the reduction in the level of service required (e.g. internal temperature) as the gap between that required service and thermal comfort level is reduced. The saturation effect implies that in a household where indoor temperatures approach the maximum level for thermal comfort adding more energy efficiency measures (e.g. wall insulation, double glazing) to the building's fabric and heating system will yield a negligible decrease in energy saving consumption in absolute terms. In this study, Sorrell's saturation assumption is tested.

Finally, research studies have theorised that a part of the temperature take-back is accounted by the physical factors (e.g. building fabric retrofitted insulation and heating systems) and the remainder by the occupant's behavioural change [7,8]. Sorrell [4], for instance, stated that in household heating studies, building's physical characteristics accounted for nearly half of temperature take-backs and occupants' behavioural change for the reminder. This study probes the link between internal temperature and occupant behaviour.

Thus, on a UK high-rise social housing building, the empirical investigation presented in this paper interrogates: whether temperature take-back is taking place; whether temperature take-back is more prevalent on low-income households or operates independently due to saturation effects; and the relationship between temperature take-back, physical factors and occupant's behavioural change. The article is structured as follows: the methodology is first contextualised and introduced; the results are then presented; and they are explored further in the discussion section.

2. Methodology

2.1. Approaches for estimating changes in energy demand following retrofit interventions

In the UK, bottom-up physics-based modelling, also known as "engineering modelling", has been the foremost approach used for estimating potential savings from retrofit interventions. In the main, engineering studies explore the effect of retrofit insulation determining impact on energy consumption using heat transfer physical laws in steady state conditions to estimate changes on energy inputs. However, it has now been established that standard physics-based models overestimate the energy savings by possibly one half or more in low-income households as stated by Sorrell et al. [6].

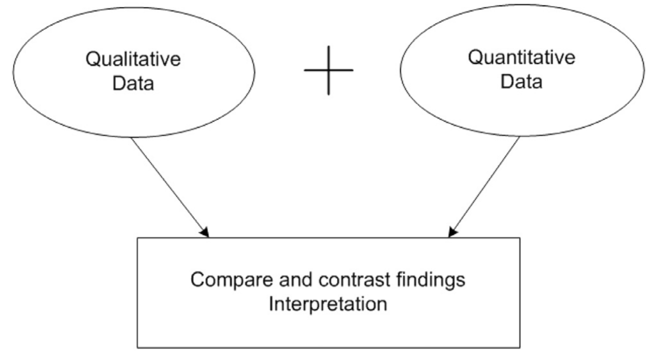

Fig. 1. Convergent design [14].

Predictive and adaptive thermal comfort models have also been used for understanding changes in energy service demand following retrofit. However, predictive models are not entirely suitable for the prediction of comfort in a domestic context as shown in the evidence presented by Hong et al. [9] and sufficient empirical data have not been collected for adaptive models to be applicable to residential buildings [10].

Due to the limitations in engineering and thermal comfort models to estimate energy-efficiency intervention effects on energy demand, recent studies have followed the so called physical paradigm approach. Unlike the engineering approach, it is not based on theoretical models for estimating potential savings but on physical monitoring before and after building retrofit and does not predetermine occupant practices. In a fabric retrofit context, energy-efficiency intervention effects on energy demand can be measured in two categories: measuring the change in energy service or energy input [6]. Moreover, in this context, internal temperature is the preferred energy service demand variable to be observed [11] and taken as a pathway towards measuring temperature take-back in retrofit insulation studies [7]. This is because the energy service being demanded is a certain internal temperature during certain time periods through the day. As a result, an approach to calculating change in energy demand, termed quasi-experimental by Sorrell et al. [6], has emerged. The approach monitors physical variables (such as internal temperature and/or energy consumption), before and after, and goes on to compare the change to a counterfactual scenario. The counterfactual aims to estimate what demand would have been in the absence of the improvement [12] and whose value should be ideally obtained without the use of modelling to avoid, for example, reduction factor sources of uncertainty [4,11]. Recent investigations [7,11,13] on the reduction of energy savings through temperature take-back have used a quasi-experimental approach to quantify the temperature take-back.

2.2. An applied quasi-experimental and qualitative approach

In this study a quasi-experimental approach has been coupled with qualitative methods and follow the so-called convergent research design rationale so that a more complete understanding of the phenomena emerges [14] (e.g. everyday practices on space heating consumption and temperature take back [15]). Within this type of research design, quantitative and qualitative data are collected during the same time frames but stay separate as the findings of one phase are not subject to the results of the other (see Figs. 1 and 2).

For the work in this paper, the *applied quasi-experimental approach* was designed for measuring change in internal air temperature (energy service) and space heating consumption (energy input) before and after retrofit as represented in Fig. 3. The internal air temperature prior to retrofitting acts as a counterfactual