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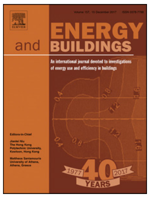

Validating solid wall insulation retrofits with in-use data

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ABSTRACT

Improving the energy efficiency of the UK housing stock is important both to meet carbon emission reduction targets and to reduce fuel poverty. For this reason, domestic properties are frequently retrofitted with energy saving measures. This study looks at how the energy consumption, thermal properties and internal temperature of 14 dwellings change as a result of a solid wall insulation (SWI) retrofit. A decrease in heat transfer coefficient of $11^{+6}_{-7}\%$ was calculated for 2 dwellings, which is slightly lower than the previously modelled value of 18%. However, many houses displayed evidence that the full benefit of SWI was not being realised as, for example, energy savings were offset with increases in internal temperature. Future retrofit schemes should therefore consider supplementing the changes in fabric with increased guidance for the occupant.

1. Introduction

In 2015, the domestic sector accounted for 29% of UK total energy consumption [1] and of this percentage, space heating can account for around 60% [2]. The large amount of energy expended on domestic heating means that reduction strategies are vital if the UK government is to reach is target of cutting greenhouse gas emissions by 80% by the year 2050 [3]. Two of the simplest ways to reduce emissions from domestic heating are to ensure that houses are heated efficiently and to ensure they retain that heat well. Legislation is currently in place to work towards this, with the 1995 edition of the 1991 UK Building Regulations being the first that required step changes in energy efficiency requirements of new homes [4]. However, the English Housing Survey reports that over 80% of homes were built prior to this legislation coming into force and these homes are therefore expected to have generally poorer thermal performance [5]. This means that large scale retrofitting is crucial for increasing the efficiency of houses [6], and it has also been demonstrated that wider socio-economic health and community wide benefits can be achieved via retrofit policy [7–9].

Recent retrofit efforts including the Carbon Emissions Reduction Target (CERT), Renewable Heat Incentive (RHI), Community Energy Saving Programme (CESP) and the Energy Companion Obligation (ECO) have been relatively effective, as reflected in the fact that dwellings with A-C Energy Performance Certificate (EPC) ratings have risen from just 5% in 2005 to 28% in 2015 [5]. This also implies, however, that there is still a substantial way to go and it has been suggested that in order to meet the 5th UK Carbon Budget, the domestic sector is expected to cut emissions by a further 22% between 2015 and 2020 [10].

There are several options available when retrofitting a dwelling that can focus on the fabric or the services in the home. Of the 2 million measures installed via ECO, 38% were cavity wall insulation (CWI), 26% loft insulation and 21% boiler upgrades [11]. Government statistics on annualised gas data from a large number of homes show that these measures result in a saving of 8.4%, 2.1% and 8.3% respectively on average household fuel bills [12]. As a result, these three measures are often deemed to have the most carbon savings.

The benefits of solid wall insulation (SWI) are less well studied, with this lack of information due, at least in part, to the relatively low installation rate of SWI. This is a significant oversight since 34% of the UK housing stock is estimated to have solid walls, 98% of which remain uninsulated [13]. A summary of literature on the potential savings from SWI has been published by the BRE [13], and individual case studies often reveal that SWI can result in higher savings than CWI - upwards of 60% [14] or even 80% when part of a deep renovation [15]. However, assessment methods used to validate the effectiveness of retrofits on small numbers of dwellings, as in the case of SWI, inherently have low statistical power and high uncertainty. Conversely, savings for conventional measures are derived from samples of tens of thousands of homes [12].

SWI may be applied as internal wall insulation (IWI) or external wall insulation (EWI), with installation approach typically dependent on local factors such as building geometry and local

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Table 1
Summary of dwelling retrofits.

Dwelling ID	House type	Wall type	Insulation measure	Primary heating type
E-9	Semi-detached	In-Situ Concrete	EWI	Gas
E-15	Semi-detached	Concrete	EWI	Gas
E-23	Semi-detached	Solid Brick	EWI	Electricity
E-25	Mid-terrace	No-fines concrete	EWI	Gas
E-30	Mid-terrace	Solid Brick	IWI to front, EWI to rear	Gas
E-31	Mid-terrace	Solid Brick	EWI to rear only	Electricity
E-32	Semi-detached	Concrete panel	EWI	Gas
E-33	End-terrace flat	No-fines concrete	EWI	Gas
E-34	Mid-terrace flat	No-fines concrete	EWI	Gas
E-35	End-terrace flat	No-fines concrete	EWI	Gas
E-36	End-terrace flat	No-fines concrete	EWI	Gas
E-37	Mid-terrace flat	No-fines concrete	EWI	Gas
E-38	Mid-terrace flat	No-fines concrete	EWI	Gas
E-39	Semi-detached	Solid Brick	EWI	Gas

aesthetic. In general, SWI takes the form of EWI, as IWI requires more disruption to the household and reduces internal surface area. Previous estimates for the effect of EWI suggest an 18% reduction in heat loss from the property [16]. However, owing to a lack of empirical data at the time, this figure was derived from building energy models which, in general, have been shown to overestimate the affect of improvements [7,17]. The gap between the predicted and measured performance is due to a combination of factors, including the model's inability to fully incorporate all physical affects, its failure to reflect real-world insulation procedures and its reliance on standardised assumptions around occupant behaviour [18]. In-use factors are often used in an attempt to account for the occupant behaviour, but the uncertainty surrounding these adjustments is still high [13].

Gathering more data on SWI improvements is therefore of great importance to provide more certainty around costs and benefits of this measure, and will potentially allow more effective policy to be written. Similarly, it is important to develop robust assessment methods in order to understand how savings achieved from particular SWI projects compare to savings from more common methods such as cavity wall insulation. This study aims to achieve these two goals by presenting the results from long-term measurement of energy consumption and temperature in 14 solid wall dwellings in which SWI retrofits were undertaken. The project findings will provide insight into the 6.3 million solid wall dwellings in the UK that may in the future have a retrofit [5]. Given the substantial remaining potential and the fact that there will be minimum quotas for SWI in the Help to Heat policy [19], understanding the real improvements achieved by SWI installation is of particular importance in the UK and in other countries experiencing similar domestic energy policy challenges with large proportions of solid wall dwellings in their housing stock.

2. Observations

Retrofit installers, Registered Social Landlords (RSLs) and Local Authorities (LAs) across the North of England who were taking part in government funded domestic retrofit programmes were invited to take part in this research. Securing samples proved challenging, but convenience sampling and snow ball sampling resulted in over 1000 properties being invited to take part in the project from which 45 properties accepted. Of these 45 homes, 14 had retrofits suitable for inclusion in the study and took place within the research project time-scale. Within the sample of 14 properties, 10 had solid concrete walls (e.g. pre fab or no-fines) built between 1950 and 1970 and 4 had solid brick walls built pre 1910 (see Table 1). These property ages are representative of a substantial proportion of solid walls dwellings in the UK housing stock, as 17% of homes in the UK were built before 1910, and 28% were built between 1945 and 1974 [20]. However, there is an over-representation of concrete walls in this sample compared to the UK housing stock, as approximately 86% of solid walls in the UK are masonry and only 14% are concrete [21].

In-use data was captured in each dwelling at half hourly intervals with Orsis sensors and included, where possible, gas (m^3), electricity (kWh), internal temperature (°C) for both upstairs and downstairs, and external temperature (°C). During the course of these measurements, SWI was installed in all of the properties. The installations were taking place independently to the research project and although the occupants were informed of the project, the installers were not. It is therefore anticipated the workmanship of the SWI was representative of a standard installation processes.

The observations and retrofits took place between 2013 and 2016 though the actual monitoring duration at each home differed according to when they had their monitoring installed and if there were delays in the retrofit occurring. How the measured data was distributed pre and post retrofit is shown in Fig. 1.

3. Data pre-processing

Before the data could be analysed, it was first inspected to identify any possible errors. Given that the dataset included approximately eight million data-points, this pre-processing was largely automated and included the following producers;

First, it was noted that the raw data included many periods of "drop-out", in which no data was recorded or sent to the loggers. Data which suffered from these drop-outs was padded with timestamps containing NA values during the drop-out, so that each day contained the same number of data points for each sensor.

The data were further inspected for any error codes sent by the loggers themselves. For the sensors used, the error code corresponded to a reading of -2. As the minimum genuine value that the gas and electricity sensors could record was 0, any value of -2 in the electricity and gas data was certainly an error and was therefore replaced with an NA value. For the temperature sensors, however, it was possible that genuine values of -2 may have been recorded. Genuine values of -2 where therefore distinguished from error codes by searching for rapid temperature changes to -2 and back. Data points fitting this description were identified using methods of outlier detection in time series [22,23], and flagged as potential errors.

Finally, it was observed that several periods of the electricity and gas data contained "flatlines" - periods of time over which the same non-zero value is recorded. The cause of these flatlines is not clear, but the resolution of the electricity and gas sensors (1 kWh and 0.001 m^3, respectively) is high enough that such constant readings over a prolonged period are unlikely to be genuine. Shorter periods of flat readings are potentially genuine, however,