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Do deep low carbon domestic retrofits actually work?

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ABSTRACT

This paper uses a socio-technical building performance evaluation (BPE) approach to assess the *pre*- and *post*- actual performance of two discrete deep low energy retrofits in the UK – a Victorian solid-wall house and modern 1990s cavity-wall house. A 'low-energy first, then low-carbon' approach was adopted in both cases, to achieve an 80% reduction in annual CO_2 emissions. Pre-retrofit, both houses had lower measured annual gas consumption as compared to predictions made by energy models, although the electricity consumption in the modern house was higher than modelled, due to occupancy pattern and occupant behaviour. Post-retrofit, it was found that the Victorian house achieved nearly 75% CO_2 reduction, while the modern house achieved only 57% CO_2 reduction over the baseline emissions. Key reasons were higher than expected air permeability rates, installation issues with micro-renewable systems, lack of proper commissioning, usability of controls, occupant preferences and behaviour. Despite the gap between expected and actual carbon emissions, occupant comfort and satisfaction was significantly improved across both retrofits. This evidence-based understanding of the process and outcomes of deep low carbon retrofits is vital not only for learning and innovation, but also for scaling-up deep retrofit programmes for meeting national and international carbon targets.

1. Introduction

The 2011 UK Carbon Plan [1] states that "By 2050, all buildings will need to have an emissions footprint close to zero". Specifically, as of this writing, the UK is legally committed to an 80% greenhouse gas emissions reduction target for 2050 and to five year carbon budgets in the interim set by the committee on climate change [1]. To meet this target, deep renovation[1] of existing buildings will be required as 28 million homes in the UK, of which 70% will exist in 2050, are responsible for about one-third of UK carbon emissions [3]. However as of the summer of 2015, in an effort to remove spending of taxpayer money from home energy efficiency, a number of policies with direct impact on energy in the housing sector have been terminated by the UK Government; the Green Deal Finance Company (ending further Green Deal[2] finance), the Green Deal Home Improvement Fund (solid wall insulation support), and Zero Carbon Homes to name a few. In addition, the RHI and FiT are considered to be at risk, i.e., further reduction in incentives for small scale renewables [5]. Though these policies were not specifically created to deliver deep renovation of housing alone, they do/did make up the majority of the mainstream support of active energy efficiency and renewable renovation in the housing sector.

1.1. Retrofit for the Future programme and beyond

Along with the UK's old housing stock, 13 million dwellings built before 1960 and 4.7 million built before 1919, all European countries are faced with the challenge of improving the energy efficiency of their large stock of inefficient existing housing [6]. One approach to address this issue and to support a retrofit market in the UK was the Retrofit for the Future (RfF) programme sponsored by the UK Government's Technology Strategy Board (TSB; now Innovate UK) from 2009 to 2013. The programme was a 'living lab' competition of many different experiments proposed to

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[1] Deep renovation, as often used in Europe, typically includes a focus on the building shell of existing buildings in order to achieve very high-energy performance, the improvement of technical systems such as HVAC and lighting, and the incorporation of renewable energy technologies. A deeply renovated building consumes around 75% less primary energy compared to the status of the existing building before the renovation [2]. *Note*: for the purposes of this paper retrofit is synonymous with deep renovation in the sense that the whole-house approach is taken; the reduction targets are however not the same.

[2] The Green Deal was designed to overcome the key barrier to energy efficiency uptake of high up-front costs by providing financing to install a package of measures with a facility to pay back this finance through the resultant savings in fuel bills [4].

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Nomenclature

$m^3/(h\,m^2)$@50pa Air permeability rate
ppm Parts per million
$W/(m^2K)$ Thermal transmittance

test and demonstrate innovative approaches to deep-retrofitting of the UK's social housing stock, using a whole-house approach for achieving an 80% CO_2 emission reduction target, inspired by the UK Government's target in the Climate Change Act. The programme involved rigorous and systematic evaluation of each project, comprising short-term physical tests of building fabric; long-term physical monitoring of energy use and environmental conditions; standardized post-occupancy evaluation (POE) of primary resident experiences; post-construction reviews (PCRs) of construction quality and holistic review of projects [7]. Almost two hundred retrofit projects across the UK were awarded funding of up to £20 000 to develop a design and implementation strategy towards meeting the target (Phase 1) and about 86 projects were awarded up to £150 000 to demonstrate the effectiveness of their strategy in reality (Phase 2) [8]. To quantify the outcome, a single CO_2 emissions target was set across the programme independent of location, building type and condition. This was done by using an estimated average emissions (1990s) baseline figure for the UK housing stock, i.e. 97 $kgCO_2/m^2$/yr (from an $80m^2$ semi-detached house). From this figure whole house CO_2 and primary energy targets were calculated and expressed as absolute limits per unit floor area and year [8].

- CO_2 Target: 17 kg/m^2/yr or 20 kg/m^2/yr for projects using Passive House Planning Package (PHPP)
- Primary Energy Target: 115 kWh/m^2/yr

Another successful response is the Superhomes network established by the Sustainable Energy Academy. Superhomes must achieve at least 60% modelled carbon savings and the effort has been particularly successful in demonstrating materials and methods to prospective Superhome owners [9]. Beyond the UK renovation efforts are wide ranging: renZero, an industry supported (insulation, window and heat pump/ventilation producers) effort in Sweden aims to provide cost-effective deep renovation for houses built before 1980; Denmark recognises that for deep renovation to take place at the scale and pace that it must to meet targets, energy renovation needs to be done wherever any typical renovation is done; and in the French regions of Alsace and Picardie there are plans to adapt a version of the property-assessed clean energy (PACE) financing model (renovation loans attached to the property where debt is collected through property taxes; originally explored in California) to achieve deep renovation of detached housing [2]

With the current policy gap in domestic energy efficiency in the UK, options like the Netherland's *Energiesprong* and *de Stroomversnelling* (a.k.a. *Rapids)* are seen as possible solutions. *Energiesprong*, for example, is a programme that works by replacing household energy bills with an *Energy Plan* that is paid to the housing provider. Similar to the Green Deal, upfront costs have to be below the savings made on energy, and with a 30-year guarantee on the performance of the measures installed. The model depends on mass retrofit whereas, if/when there is more demand, industry improves efficiency and cuts costs delivering the solution: a whole-house approach involving pre-manufactured external walls produced off-site and delivered in sections, and solar PV. The UK's Energy Saving Trust is involved in exploring integration of the programme into the UK housing market [10]. There is also discussion of exporting the *Rapids* approach to the UK and France. The initial difficulty involves adjustments to both the technology and the business model, as housing types and the structure of the housing market are very different in each country [11].

1.2. The retrofit performance gap and building performance evaluation

A large number of international modelling studies, such as in Argentina [12], Belgium [13], Germany and The Netherlands [14], Kuwait [15], and USA [16] have demonstrated that energy and environmental performance of existing buildings can be improved through appropriate retrofit methods; however, actual energy savings due to the implementation of retrofit measures in real buildings can be different from those estimated [17]. The following study, along with the RfF programme, defines this difference as the performance gap, i.e. the significant difference between the calculated forecasts for energy use compared with the actual energy use [7].

Though less research exists, plenty of examples demonstrate this performance gap. Results published for the overall RfF programme revealed that among 24 dwellings, a majority measured actual energy use to be 50% more than predicted. Only four cases were marginally off (by 5%). An important lesson learned from these projects is that projects that forecasted lower energy use were likely to achieve lower results relative to other projects even if the outcome was not as low as forecasted [7]. Following the Warm Front Scheme in the UK from 2001 to 2003, 1372 dwellings were retrofitted with cavity wall and loft insulation and new central heating systems. Savings were calculated to reduce fuel consumption by 49% but monitoring revealed savings of only 10–17% and thermal imaging on a sample of dwellings revealed large gaps in insulation [18]. Galvin [19] presents a wide range of results for three retrofitted residential buildings in Germany. These case studies were found to consume 0.02%, 36%, and 73% more heating energy than calculated during design. These studies present valuable insight into a large evidence base for the retrofit performance gap but do not outline the BPE level of detail for individual case studies.

In contrast at case study level, research appears to be more focussed on pre- vs. post-retrofit results excluding modelled results. As examples, a dwelling in Saudi Arabia was retrofitted with four energy conservation measures: external wall insulation, draught proofing around doors and fresh air intake panels (neutralising the building pressure), and ventilation system balancing. The study however focussed on pre-retrofit and post-retrofit energy consumption data with no mention of designed energy reduction calculations or expectations. The dwelling resulted in an 8% increase in total electrical energy consumption comparing six years of pre-retrofit data to six years of post-retrofit data, but realised a 21% mean reduction when comparing the summer peak months of both periods. The smaller overall increase is likely a result of the difference between the two families that lived in the dwelling over the course of the study and their 'significant difference' in user profiles, family size and appliance use [20]. An unoccupied research dwelling in the USA was evaluated following a fabric and duct air tightening retrofit. Evaluation included tracer gas decay technique and whole building pressurization testing using a blower door. The tests showed an envelope leakage reduction of 18% and duct leakage reduction of 80% resulting in an overall energy consumption reduction of 10% after 'several months' of monitoring [21]. Another research house in Nottingham, England was retrofitted with improved external wall, floor and glazing, and upgraded heating system efficiency, a whole-building mechanical ventilation with heat recovery (MVHR) along with increased air tightness. The analysis of the dwelling included building performance simulation to determine the combined effects of the retrofit