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A longitudinal building fabric and energy performance analysis of two homes built to different energy principles

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ABSTRACT

This paper reports on the building performance monitoring and annual energy demand of two homes built side-by-side over an occupancy period of three years. The study compares the results from on-site monitoring against the assumed parameters and calculations from compliance modelling at design stage. It focuses on the differences and impact of occupancy behaviour, weather conditions, quality of construction and operation which contribute to an increase in energy consumption creating a gap in performance between design and actual. The results from the study show disparities in the fabric performance reflecting on the overall consumption of energy. This longitudinal analysis highlights how building performance needs to be evaluated over longer periods in order to fully understand how homes and their occupants operate and consume energy. The impact of the real performance of homes in Scotland over longer periods needs to become standardised, and a mechanism for feedback into regulatory mechanisms and construction practices applied, if carbon emission targets are to be met.

1. Introduction

The analysis of energy consumption and carbon emissions from buildings has been well documented, particularly domestic properties subject to reduced performance levels [1–6]. According to Itard and Meijer [7], in the EU 30% of energy use comes from the residential sector where 57% is consumed by space heating, 25% for water heating, 7% cooking and 11% electrical appliances. In Scotland, excluding the transport sector, 40% of total energy consumption (electricity and heat) is consumed domestically [8]. The above figures show that the energy performance of existing and new stock residential buildings is of concern and creating new policies and addressing the technical and social issues around them should be of importance.

To address these issues, the Energy Performance of Buildings Directive (EPBD) 2002/91/EC and its recast 2010/31/EC [9] requires each Member State to evaluate and certify their buildings. These guidelines introduced the use of Nearly Zero Energy Buildings (NZEB) in 2010, suggesting low energy demand linked with on-site renewable energy use [10]. The UK's approach introduced the Code for Sustainable Homes (CfSH) in England & Wales now enforced in Part L Building Regulations [11,12] and in Scotland the Section 7 Sustainability [13] in the Scottish Building Standards (SBS) Technical Handbooks as recommended by Sullivan [14] and Zero Carbon Homes [15,16]. For energy calculations the National Calculation Methodology (NCM) created the Standard Assessment Procedure (SAP) generating Energy Performance Certificates (EPC) [17–19]. EPC results have become the commercial and analytical method of understanding building performance as discussed by Sutherland et al. [20], SBS [21] and Castellano et al. [22].

There are other EU standards aligned to the NZEB criteria. An example is the *Passivhaus* standard, seen as being a rigorous method of minimising heat loss through a highly insulated envelope, its design and construction criteria is explained fully by Feist et al. [23] & Müller and Berker [24]. It relies on a hybrid heating system evaluated with its own calculation method called the *Passivhaus* Planning Package (PHPP)[25,26].

The aim of this study is to assess the performance of two homes during three years of occupation and to learn if new and innovative building methods of construction are performing as expected. Results from monitoring are presented and analysed, later compared against regional benchmarks. This comprehensive measurement of building fabric and energy consumption provides an insight into the impact of identified issues in low energy homes,

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such as incompatibilities between the as-designed calculations and the as-built occupant behaviour.

This study is significant because it equally assesses two homes that have performed over a period of occupation. Most studies report on one property and its performance [26] or have uncommon elements to compare against and are apart from each other [27,28]. Their proximity, placement, orientation, wind exposure and solar incidence, make these homes worthy of comparison. Occupation and dwelling demographic is also distinct throughout this study; resident numbers and hours of use have remained marginally unchanged, allowing for a straightforward comparison between years, unpresented in the social housing sector.

2. Literature review

Despite the rigorous calculation process adopted in the UK and by the *Passivhaus* standard, making sure homes have been built as-designed and calculated has not been a streamlined process. Many studies in the UK and other EU countries have noticed a gap in performance demonstrating discrepancies between the calculated energy use and the actual energy consumed [26,29,30].

Performance gap has been largely attributed to the design stage, particularly the proficiency and quality of the energy calculation [31,32]. de Wilde [31] highlights faults that overestimate energy requirements such as accuracy and proficiency of the thermal compliance model. Other issues have been studied such as accuracy of the manufacturer's energy efficiency data for technology and materials [34,35], complexity of original design [36,37], badly assembled and interpreted thermal details during the construction process [38], poor supervision and site communication between main contractors and sub-contractors [39] and also installed inefficiencies and complicated controls [40,41].

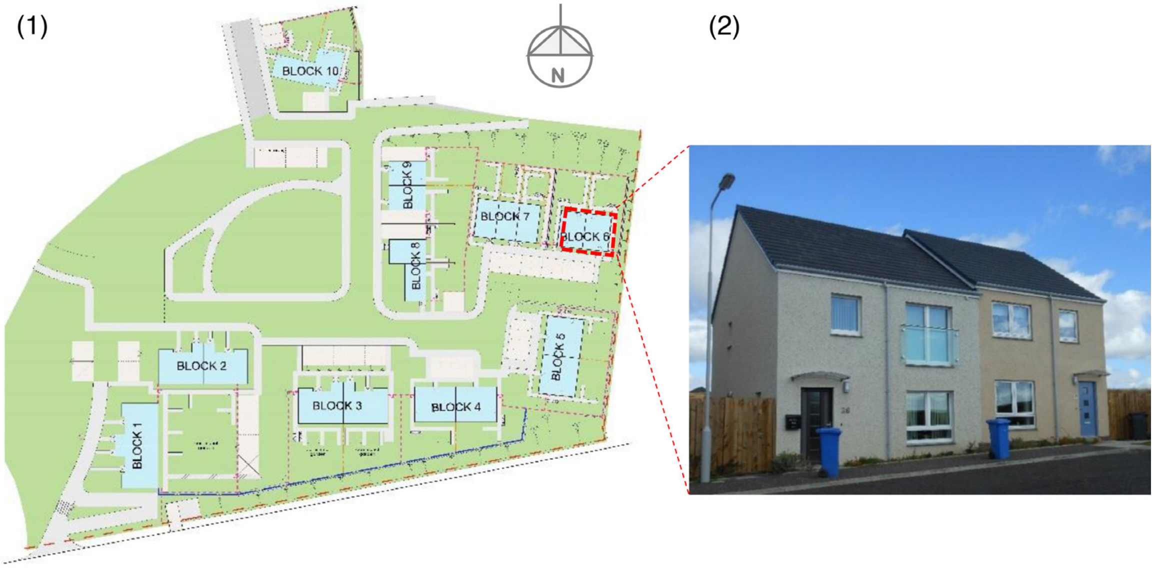
Occupant behaviour also contributes to disguised energy use often unaccounted for. Recent studies identifying behaviour patterns have contributed to the performance of low carbon homes [42]. Thermal comfort and the energy rebound effect are also relevant [43–46]. These occupant related issues are difficult to predict [31,47] and Post Occupancy Evaluations (POE) help to measure the effect of occupant behaviour. Techniques for assessing buildings and occupants revealing avoidable waste, bad maintenance, wrong occupant training, and bad management have provided evidential data of buildings performance [47–52].

Further tests at post-construction stage and after occupancy to assess the building fabric quality and services efficiency are required to realistically assess buildings against as-designed calculations, preferably after whole twelve month periods [29,53]. Building fabric performance and energy consumption while homes are occupied are effective evaluations [54]. Techniques such as; air leakage testing, in-situ U-value of selected components, infrared thermography and internal/external hygrothermal monitoring [1,33,47] can demonstrate performance. Other techniques such as co-heating and tracer gas decay used in other studies [26,29], deemed to be important but impractical in occupied dwellings.

Also essential to recognising building performance is analysing actual energy demand from regulated and un-regulated electricity use and space and water heating needs. Legislation on efficient building fabric and services has considerably decreased energy use for heating, however electricity demand has risen as a result of increased use of appliances in households [55] questioning the real operational performance of buildings once occupied. The current compliance model used in the UK (SAP) [18] calculates heating needs as well as regulated electrical demand, omitting un-regulated electrical demand from household appliances. This creates issues surrounding the direct comparison of delivered electrical energy against the assumed at design stage [18]. For comparison purposes benchmarks and similar archetype and household occupancy types are a useful method to account for total electricity use in households. Yohanis et al. [56] have developed a correlation between average annual electricity consumption and floor area of representative dwelling types. White et al., [57], White, [58] and Zimmermann et al. [59] obtained household energy consumption values based on survey-reported expenditure and owner-occupier domestic appliance use, useful as consumption benchmarks. Studies by DECC, [46] and The Scottish Government, [8] use benchmarks of sub-national household energy consumption statistics, including the National Energy Efficiency Data Framework (NEED) that considers lower domestic meter ranges and the removal of estimated meter readings [61]. A comparison of these benchmarks can be seen in Appendix B in this paper.

3. Dwelling characteristics

The two homes analysed in this paper are part of the Housing Innovation Showcase (HIS), an award winning housing develop-



Figs. 1–2. (1) HIS site plan with boundary line around analysed block. (2) Front elevation of the Passive House (left) and the Control House (right).