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The monitored performance of four social houses certified to the Code for Sustainable Homes Level 5

Behzad Sodagar[a,*], Diane Starkey[b]

[a] School of Architecture and Design, University of Lincoln, Brayford Pool, Lincoln LN6 7TS, UK
[b] Longhurst Group, Leverett House, Endeavour Park, Boston PE21 7TQ, UK

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ABSTRACT

This paper presents the energy and water use of 4 social houses certified to the Code for Sustainable Homes Level 5 in Gainsborough, UK. The houses were monitored over 2 years, from July 2012 to September 2014. As the houses have the same construction and energy efficiency characteristics, the study offered a unique opportunity to investigate the effects of occupant behaviour on the dwellings performance. Electricity, gas and water consumptions were measured through data logging and meter readings. Surveys and interviews were conducted throughout to gain insights into tenants understanding and interactions with low energy features in their homes. Significant differences were observed in the amount of energy and water used. The annual space heating consumptions differentiated by a factor of 2.2 per square metre of floor area. Hot water heating demands varied by a factor of 3.5 per square metre of floor area or by 2.5 per person per year. Mains water consumptions varied by a factor of 2.2 litres per person per day in 2013.

1. Introduction

There is a growing concern about the contribution of the building industry to environmental impacts and climate warming. In Europe and the USA, energy consumption of buildings accounts for 20–40% of total energy use [1]. Buildings are a significant contributor to greenhouse gas emissions, with space heating alone responsible for over half of all UK dwellings end use emissions [2]. In 2007, the UK government put in place a National Energy Efficiency Action Plan (NEEAP) to reduce emissions from the UK housing stock by 31% based on 1990 levels by 2020. More recently, the government's Climate Change Act [3] sets a legally binding target to reduce greenhouse gas emissions from buildings by at least 80% on 1990 levels by 2050. In 2008, the residential sector accounted for 27% of the total CO_2 emissions in the UK [4].

The potential of the residential sector to reduce CO_2 emissions has been identified in numerous studies and sources [5–10]. Buildings are currently rated for energy performance potential of the fabric and services at design and on completion. Thereafter they can be rated by comparison of actual annual fuel consumption [11]. There are standards that address environmental performance of the design and build; for example Passivhaus, Code for Sustainable Homes, BREEAM, amongst others. The codes and standards have created lively debates on their practicality which has resulted in a raised awareness within the building industry about the actions required to tackle climate change [12].

In order to reduce the whole life impact of buildings, Life Cycle Assessments (LCA) should be carried out to identify collective distribution of different impacts. As shown in, Fig. 1, adopted and modified from [12]. Performance Assessment Methods (PAM) should be used at the design stage (PMc) to predict and reduce energy demands of buildings, to minimise operational impacts (Rc). Post Occupancy Evaluations (POE) should also be carried out when the building is completed to measure its actual performance.

There is extensive evidence [13–17] to suggest that buildings do not usually meet the energy efficiency targets set at the design stage. In other words, there is a Performance Gap between POE results and PAM as depicted in Fig. 1.

Performance Assessment Methods (PAM) utilising prediction modelling tools may be used to predict the future performance of buildings when built. Currently numerous assessment tools exist ranging from advanced dynamic computer simulation programmes, capable of representing complex interactions in buildings, to more simplified and stationary calculation methods and tools. While dynamic programmes require extensive and detailed value input data, simplified tools may be used with less

* Corresponding author.
E-mail address: bsodagar@lincoln.ac.uk (B. Sodagar).

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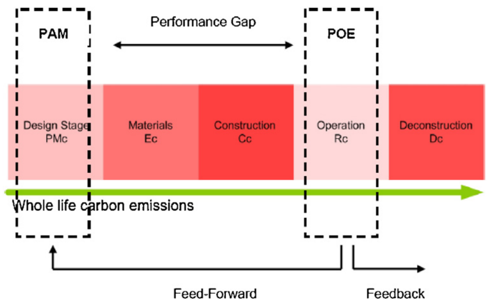

Fig. 1. Whole life carbon emissions of buildings showing the roles of PAM and POE.

data and hence with limited scopes and capabilities. Hensen and Lamberts [18] provide a general view of the background and current state of building performance simulation programmes.

Williamson [17] suggests that more stringent building regulations and higher energy efficiency standards, to make buildings more energy efficient, might result in over-optimistic predictions, creating a wider gap between the expected designed targets and the actual constructed and occupied building. Others [19,20] argue that there are also performance gaps between other performance indicators, such as comfort and indoor air quality, between design predictions and what is actually achieved in buildings when occupied.

In the UK, the Standard Assessment Procedure (SAP) [21] was first published by DOE (now the Department of Energy and Climate Change, DECC) and BRE in 1993. Currently SAP is used as proof of compliance with Part L1A of the Building Regulations [22] in the UK, to evaluate the consumption of fuel and power to determine the performance of dwellings. It is also used in a range of UK governmental measures and policies requiring the calculation of the energy performance of dwellings such as the Code for Sustainable Homes (CSH), Warm Front, the Carbon Calculator, Stamp Duty Exemption for Zero Carbon Homes, Green Deal, Renewable Heat Incentive (RHI), and Energy Performance Certificates (EPC).

SAP is a simplified version of BREDEM, Building Research Establishment Domestic Energy Mode [23] and is based on energy balance, taking into account a range of factors that affect the energy performance of dwellings. These include: building materials used, thermal insulation, air leakage characteristics, heating system efficiency, solar gains through openings, type of fuel used, energy consumption by lighting, pumps and fans, as well as energy produced by microgeneration technologies. SAP does not however include a range of other factors such as electricity demands of electric appliances which contribute to the so called unregulated energy consumptions of homes. These omissions are in line with the Part L Building Regulations, requiring an estimation of the energy that will be consumed in the building for space heating, cooling, water heating, and lighting, as well as energy required to power their controls. Inherent in simplified methods, SAP also uses standard patterns as parts of its inputs. For example it assumes standard occupancy and space heating patterns representative of national norms. The main purpose of SAP may therefore be viewed as a national rating system to give a standardised measure from which the energy performance of dwellings can be compared against each other in a meaningful and systematic way. Such an approach may however lead to rather imprecise approximations of real consumptions for individual homes [24].

In light of wide spread gaps between predicted and actual performances, the construction industry and research community are increasingly realising the benefits of Post Occupancy Evaluation (POE) in narrowing the gap between design intents and actual performance of build. POE can be effectively used to improve the whole life performance of buildings and reduce their carbon emissions. As schematically depicted in Fig. 1, POE can be used to feed-forward information to the Design Stage (PMc), to improve the design as well as the prediction of its performance through the enhancement of Performance Assessment Methods (PAM). It can also be used to feedback information and data to users and facility managers, to better understand and work with the building and its component, which in turn should reduce operational impact (Rc) and enhance user comfort and satisfaction.

2. Aims and objectives

The aim and scope of this paper is to investigate the actual performance of 4 recently built dwellings designed to Code for Sustainable Home (CSH) Level 5, through environmental monitoring with a view to identifying influencing factors which might affect the performance of houses. Although comparisons have been made between actual and predicted performance, the intension is not to solely demonstrate the accuracy of SAP, which has been used for the purposes of Building Regulation compliance and design stage CSH assessments to predict energy consumption, but how energy demands in 4 houses built to the same specifications may be varied due to occupancy behaviour.

3. Research methodology

The research uses a mixed approach using both quantitative and qualitative analyses and investigations. The former required quantitative measurements and forensic investigation using environmental monitoring and diagnostics testing, while the latter employed a range of socio-technical methods using structured interviews, surveys, walk through and questionnaires. Performance evaluation approaches, combining quantitative and qualitative techniques in POE have received considerable attention in recent years [14,25,26].

Longitudinal approaches covering various seasons have been recommended for POE in order to achieve meaningful and detailed analysis [27]. The results reported in this paper span over two years, started in July 2012 and completed in September 2014, analysing the performance of the houses through different seasons.

3.1. *Quantitative measurements: environmental monitoring*

The monitoring systems were installed in June 2012. The monitoring systems use a Wi5 data hub GPRS wireless data logging installed in House 3 to process data collected from all four houses. All data was collected at 5 min intervals. All the instrumentation provided and installed for monitoring purposes complied with the requirements contained in CE298 'Monitoring energy and carbon performance in new homes' [28]. An on-site weather station measured external air temperature and relative humidity. The data collected in each house includes:

- Room air temperature and relative humidity in the main bedroom and living room.
- Concentrations of CO_2 in the living room.
- Air temperature and relative humidity at supply and extract positions of MVHR.
- Electricity generated by PV.
- Utilities metering for electricity (kWh), gas (m^3), and mains water (m^3).

Building performance tests, including air permeability, infra-red thermography, and in situ *U*-value measurements were conducted to analyse the performance of the building fabric. Continuous