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Case study

Monitoring the hygrothermal and ventilation performance of retrofitted clay brick solid wall houses with internal insulation: Two UK case studies

Neil Campbell[a,*], Teresa McGrath[a], Sreejith Nanukuttan[a], Siobhan Brown[b]

[a] School of Natural Built Environment, Queen's University Belfast, United Kingdom
[b] Hearth Housing Association, 66 Donegal Pass, Belfast, Northern Ireland, United Kingdom

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ABSTRACT

This work assesses the hygrothermal and ventilation performance of two 'hard-to-treat' historic, clay brick, solid wall houses that are internally insulated. Retrofit A is a two bedroom bungalow with the addition of internal plasterboard and air cavity and Retrofit B is a 5 bedroom house with sheep wool, phenolic and plasterboard insulation. To evaluate the long term performance of the retrofit measures, the testing is carried out 7 and 8 years respectively after completion. The first part of the work investigates whole building hygrothermal performance, ventilation and internal conditions. It was found that both retrofits are operating below specification in regards to their ventilation performance. An *in-situ* performance based specification for mechanical ventilation *via* CO_2 monitoring is proposed. The second part focuses on the hygrothermal behaviour of the clay brick wall assembly. Both presented high relative humidity within critical layers of the wall make up. In Retrofit A the wall thermal transmittance was found to be much higher than designed due to inappropriate construction detailing while Retrofit B showed excellent thermal performance and minimal effects of thermal bridging.

1. Introduction

The UK government has committed to legally binding targets to lower its total CO_2 equivalent emissions by 80% of 1990 levels by the year 2050 [1]. In 1970 the UK domestic housing stock contributed 24–27% of total UK CO_2 emissions but this has risen to 28–36% [2,3]. Exacerbating this, existing housing stock in the UK is also aged and underperforming with the most recent review of UK standard assessment procedure (SAP) ratings it was found the housing stock averaged 52/100, which corresponds to an energy efficiency rating 'E' [4]. It is estimated that approximately 60% of current UK housing stock will be standing in 2050 [5,6] and that the average SAP rating of buildings will have to be at least a 'B' to achieve CO_2 levels proposed in the UK Climate Change Act. Due to these facts widespread retrofitting is unavoidable and is recognised by both academia and industry [7,8].

To contextualise this, there are 9.2 m 'hard to treat' homes in the UK, being defined as having solid walls, no space for roof insulation, have no gas network connection or are high rise [9]. Of this number, 6.5 million are solid wall [9] and have been widely recognised as being particularly hard to treat with retrofit actions due to both technical issues and cost [9,10] Focusing particularly on solid walls, improvements in the thermal performance can be achieved in two ways: externally retrofit insulation or internally retrofit insulation. External insulation can be used to achieve thermal transmittances similar to or better than modern cavity construction, which is common in UK new build houses [11], is faster to fit than internal insulation and may improve the appearance of a

* Corresponding author.
E-mail address: ncampbell23@qub.ac.uk (N. Campbell).

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deteriorated structure [12]. This being said, in some cases external insulation can be unsuitable. In the case of historic buildings conservation laws can ban its use and its widespread application may diminish the architectural heritage of a locality. Due to this internal wall insulation cannot be avoided but concerns exist over moisture build up in the building fabric, interstitial condensation [13], thermal bridging losses [12] and durability issues [14].

The hygrothermal performance of an internally insulated solid wall house is particularly important due to the more porous nature of historic building materials compared to their modern counterparts [15] with this being highlighted as a particular issue in climates like the UK [16]. Previous case studies have shown conflicting results: there are clearly concerns with moisture build up within the insulation layers [15–17] but others have found the reduced drying effect of internal insulation to be negligible [18] and in one study it was shown no condensation formed during a 4 year monitoring period [19]. In another study, [20] four different internal insulation systems were installed on the internal face a 430–510 mm brick wall with materials then monitored for 9 months after installation. The measured and modelled results showed that the hygrothermal risk was directly related to the moisture content within the existing brick at the time of installation, therefore the time of installation is a critical factor. The interaction between the hygrothermal performance of the wall assembly and the whole building hygrothermal and ventilation performance is important in retrofitted structures, with many studies modelling these phenomena [21], with [22] focusing specifically on solid wall buildings.

From available literature only limited information is available on the hygrothermal performance of case study 'hard to treat' houses [22] and [23] also notes the gap between hygrothermal design practise and what is seen *in-situ* in.

To gain a holistic view of the hygrothermal performance of two 'hard-to-treat' internally insulated solid wall houses, this work is split into two sections. Firstly the whole building hygrothermal and ventilation performance is assessed and secondly the hygrothermal performance of the internally insulated wall is investigated. The review on Retrofit A and B is taking place 7 and 8 years respectively after completion, meaning a long term review of the home is being considered therefore problems not immediately identifiable at completion are considered, such as moisture build up and condensation issues.

2. The case studies: two retrofitted solid wall houses

The first case study house (Retrofit A) is a two bedroom solid wall red brick bungalow built in 1885, and is located 10 miles outside Belfast, Northern Ireland. The house is maintained by a Social Housing Association hereafter referred to as 'landlord' and is rented out to tenants hereafter referred to as 'occupier'. The structural layout and insulation levels of the house remained largely unchanged until 2005 when measures to improve the energy efficiency of the house were introduced. These upgrades included the addition of internal insulation, upgrading of loft insulation and the addition of a mechanical ventilation and heat recovery (MVHR) system. The layout of the bungalow can be seen in Fig. 1 and an overview of the design specification before and after retrofit in Table 1. It is important to note that the house is a Grade II Listed Building (a UK protected historical building) therefore limiting the external work that can be implemented, including the replacement of the single glazed sash windows. This type of building poses a particular problem to designers and the landlord. A balanced approach is needed to improve the performance of the house with consideration for architectural conservation, CO_2 emissions and occupant running costs.

The second property investigated (Retrofit B), maintained by the same landlord, is a four bedroom solid wall red brick house built in 1878 and located in central Belfast, Northern Ireland. The building was in a state of disrepair before renovation work was completed in 2007. Walls were internally insulated, double glazing installed, space heating provided by an air source heat pump and ventilation *via* a MVHR system. Layout and design specifications can be seen in Fig. 1 and Table 1 respectively.

These two buildings represent the first houses that the landlord retrofitted with energy saving solutions, and were selected for investigation to gain an understanding of the long term effect of the alterations on the hygrothermal performance of the building. Testing was carried out in the same month in spring at both properties. Average temperatures in the region for this month were 6.5 °C (1.1 °C below the 1981–2010 average) with 77.3 mm of rainfall (long term average 75.0 mm) with the sunshine levels being 113% of

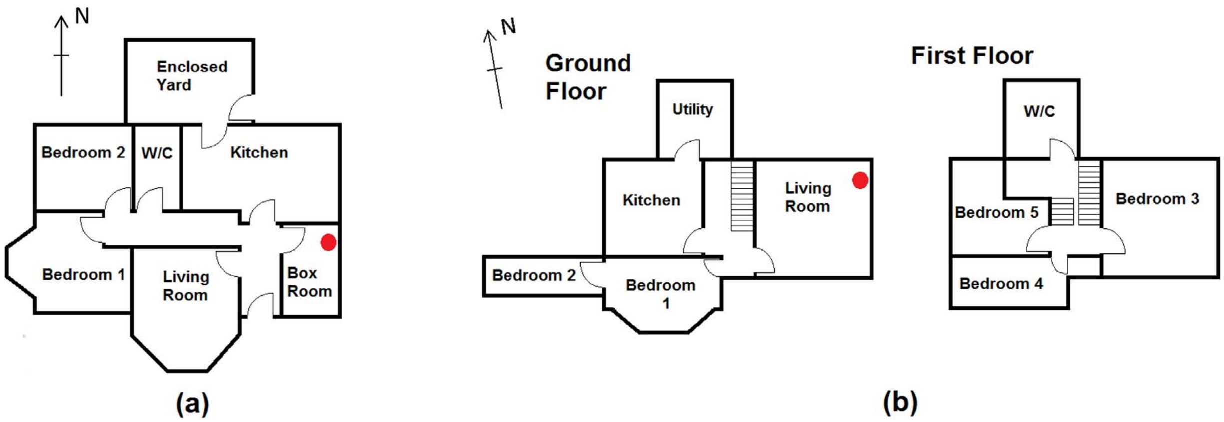

Fig. 1. (a) Floor plan of Retrofit A (b) Floor plan of Retrofit B. Red dot denote wall monitoring locations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)