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Thermal performance of a selection of insulation materials suitable for historic buildings

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ABSTRACT

Improvement in the thermal performance of the historic building stock has the potential to reduce building operational energy and its associated negative impact on the environment. Currently, there is a lack of knowledge on the performance of traditional solid walls and the impact of internal insulation on their hygrothermal behaviour.

This paper investigates the in-situ thermal performance of seven internal insulation options, on a historic brick wall, using heat flux sensors (U-value measurement), thermal imaging survey and internal wall temperature. The insulations include thermal paint, aerogel, cork lime, hemp lime, calcium silicate board, timber fibre board and PIR board. Their performance is compared to a traditional lime plaster finish. Additionally, their density and specific heat capacity is measured in the laboratory.

The brick wall with lime plaster (c.840 mm) has a higher U-value of 1.32 W/m^{2}K than expected. All the internal insulations were found to reduce the U-value of the wall (between 34 and 61%) with the exception of a thermal paint which had no effect. The thermal imaging survey corroborated the U-value results, and insulations with low wall U-values also had high wall surface temperatures. Internal wall temperatures showed a similar trend; a reduced temperature at the wall/insulation interface for low thermal conductivity insulations. Lastly, the in-situ insulations underperformed when compared to their manufacturer's specified properties (wall U-value higher by 13–25% with the exception of cork lime). This is attributed to real in-situ environments compared to ideal testing laboratory conditions.

1. Introduction

Climate change is widely considered as the most serious environmental challenge of this century. The building sector is responsible for degradation of the environment owing to resource depletion, energy consumption, gas emissions and waste production. However, government policy, technology advances and increased public awareness are contributing towards efforts to reduce this impact. Building operational energy, a large proportion of which is used on heating, is a large contributor towards energy consumption and producing emissions. In Ireland, 44% of the existing building stock was built prior to the introduction of energy specific building requirements [26]. Consequently, retrofitting existing buildings to reduce unnecessary heat loss has the potential to contribute towards minimising their adverse impact on the environment.

This research investigates the in-situ thermal performance of a range of internal insulations applied to historic solid brick walls. It considers laboratory measured and provider values and those measured in-situ. Particular emphasis is placed on the aesthetic and building durability concerns of historic buildings. Thin insulations (<45 mm) are investigated to minimise their adverse visual impact on room proportions and historic features. This research is part of a wider project which also investigates hygric properties and continuously monitors the moisture behaviour of a historic brick wall following the application of a range of internal insulations to ensure the insulation does not undermine the durability of the building fabric.

1.1. Heat loss through walls

The amount of heat loss through walls is frequently speculated and figures ranging between 10 and 45% are commonly quoted. There is no average value and actual heat loss depends on countless variables including wall surface area, age, composition, condition

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and construction technology. However, the application of insulation to walls and the resulting reduction in thermal conductivity should significantly contribute to an overall improvement in the energy performance of a building. The magnitude will depend on several variables such as building type, climatic conditions and performance of insulation materials [1].

Historic buildings (built before 1944) form a large proportion of the existing building stock of most European cities and are a difficult category of building to find appropriate energy retrofitting solutions. These buildings are typically of architectural and historic interest and it is essential that any thermal upgrading does not undermine their special character. In most cases, a balance can be found between protecting the heritage value of the building and appropriate energy saving interventions that lessen their adverse impact on the environment, reduce building energy costs and improve occupant comfort ensuring the long term viability of such buildings.

There is a widespread perception of the poor thermal performance of historic structures compared to more recent buildings although researchers have shown this to be untrue [2,19]. Rhee-Duverne and Baker [23] observed that commonly used software can overestimate energy use in traditional buildings by up to 40%. There is consequently large scope for further research on the thermal performance of historic structures and appropriate retrofitting techniques.

1.2. Compatibility of insulation with historic buildings

The architectural and historic significance of the exterior facades of historic buildings precludes the use of external insulation for most structures. Internal insulation is considered a more viable alternative although it can still be quite invasive; introducing new materials, replacing historic linings, disturbing internal features such as joinery and distorting the original room proportions and consequently is only appropriate for certain buildings.

A further concern with internal insulation is its physical compatibility with traditional construction. Changing the balance between heat, air and moisture movement in a wall can affect the building's integrity (Rhee-Duverne and Baker, 2013 [23]). The application of internal insulation on the interior of a traditional wall can result in the accumulation of moisture within the wall and potential interstitial condensation, frost damage, timber decay and mould growth. Moisture accumulation in the wall occurs on account of the two primary reasons; reduced permeability of an insulation impedes the drying potential in the direction of the interior and the insulation lowers the temperature of the wall resulting in reduced drying capacity of the wall and increased likelihood of moisture condensing within the wall.

1.3. Measuring of heat loss through a wall and discrepancies between in-situ and calculated/modelled U-values

The building industry commonly uses thermal transmittance (U-values- W/m^2K) to measure heat transfer by conduction, convection and radiation through walls. The in-situ methodologies of measuring thermal transmittance of a wall are heat flux sensors and thermographic surveys [3] and both methodologies are employed in this research. Here, U-value measurements using heat flux sensors are supported qualitatively by thermal imaging. Infrared thermography is not typically used quantitatively due to several parameters affecting measurement including emissivity, reflectivity, environmental conditions and colour.

The typical, widely accepted, standard U-value for a 220 mm solid brick wall with 13 mm internal plaster is 2.09 W/m^2K [13] although authors investigating in-situ U-values of solid brick walls measure lower values with an average of 1.3–1.4 W/m^2K [5,21,25]. Overestimation of wall U-values can result in misguided assessments of energy saving options, over specification of insulation requirements, lower than expected improvements in thermal performance and incorrect estimation of energy savings.

In-situ measurement is important, as there is significant discrepancy between as-built and calculated/modelled wall U-values. As noted above, the in-situ, U-value of solid brick walls is often lower than estimated. Additionally [24] observed that software overestimated the U-values of traditional walls compared to in-situ figures in 77% of cases. The lack of correct thermal conductivity data for traditional building materials is contributing to these erroneous results [8,24]. Rhee-Duverne and Baker [23] note that the use of software to calculate U-values can be in reasonable agreement with in-situ results provided accurate data inputs are used. In addition, the actual U-value of a wall is dependent on several parameters that are difficult to accurately measure including moisture content, physical properties of the brick such as density and composition, mortar proportion, thickness and presence of air cavities.

However, conversely, for newer constructions, [7] measured U-values typically 20% higher than predicted by Ref. [9]; resulting in an underestimation of true energy loss. Similarly [3] found the measured U-values higher than the calculated ones. He attributes this to over declared performance of building materials for marketing, differences between ideal laboratory and real in-situ environments and workmanship. These discrepancies highlight the importance of in-situ measurement of thermal performance to obtain an accurate assessment of the true thermal performance of a wall. This information can then be input back into models to improve their accuracy [8].

1.4. Types of insulation

Thermal insulation is a material that retards the rate of heat flow by conduction, convection and radiation [1]. Insulation reduces heat loss through a wall by reducing the thermal transmittance (U-value) with further thermal benefits including warmer surface temperature and reduced air permeability through the wall. In recent years, there has been increased interest in vapour permeable insulations in place of conventional vapour tight systems. Sustainable insulation materials with lower embodied energy and reduced environmental emissions are also increasing in popularity and a large number of innovative insulations are constantly entering the market. A range of insulations are investigated in this research and compared to a traditional lime plaster. These include thermal paint; aerogel, cork lime; hemp lime; calcium silicate board, timber fibre board and PIR board.

A traditional lime plaster was used as a control by which to compare the performance of the other insulation materials. Lime plaster is not considered an insulation material although it has good thermal properties [27]. A layer of lime plaster known as torching or parging was traditionally placed on the underside of roof slates to provide a secondary barrier against wind driven rain and also contributed towards improving the insulation of the roof. Researchers have measured the thermal conductivity and specific heat capacity of 0.73 W/mK and 970 J/KgK [12] and 0.836 W/mK and 867 J/KgK [32] for 1:3 hydrated lime:aggregate mixes.

The thermal paint in this research incorporates hollow microspheres of ceramic material. The reported premise is that these particles reflect the radiant energy from heated objects and thereby reduce energy transfer through the walls. However, there is great disparity of opinion on the performance of thermal paints. Several researchers have reported that paint coatings can reduce heat transfer Refs. [4,28,29] but others have concluded that they are