Building and Environment 85 (2015) 182–189

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

An environmental impact comparison of external wall insulation types

Danielle Densley Tingley*, Abigail Hathway, Buick Davison

Civil and Structural Engineering Department, The University of Sheffield, Sir Frederick Mappin Building, Mappin Street, Sheffield, S1 3JD, UK

ARTICLE INFO

Article history:
Received 27 August 2014
Received in revised form
18 November 2014
Accepted 22 November 2014
Available online 28 November 2014

Keywords:
Retrofit
External wall insulation
Environmental impact
LCA

ABSTRACT

A large proportion of existing buildings require thermal efficiency improvements to the building fabric. One method which can be utilised is external wall insulation. It is important for designers to have a good understanding of the materials that they specify and this includes the initial environmental impacts that occur from extraction, processing and manufacture of insulation. This paper quantifies and compares the environmental impact of three insulation materials: expanded polystyrene, phenolic foam and mineral wool insulation. It was found that expanded polystyrene had the lowest environmental impact in fourteen of the sixteen impact categories examined. When applied to a typical dwelling, all three insulation materials demonstrated a net positive benefit over a thirty year life span due to the reduced heating requirements of the building. A study of embodied carbon also included PIR and woodfibre boards. This demonstrated that woodfibre board had the lowest embodied carbon, mainly due to carbon sequestration. Modest savings (e.g. 115 kgCO_2eq if EPS is used instead of phenolic foam) can be made from insulation choice for a single house but these savings become much more significant if scaled across the large number of UK homes that would benefit from external wall insulation.

1. Introduction

There is a crucial need to improve the energy efficiency of homes in the UK in order to reduce carbon emissions and eliminate fuel poverty [1]. One way in which to improve efficiency is to minimise heat loss through the building fabric. For some homes this involves installing cavity wall and loft insulation, however, for other 'hard to treat' homes, measures can be more expensive and complex. 'Hard to treat' homes include solid wall properties and some non-traditional housing types such as British Iron and Steel homes [2]. There are two main ways to improve the building fabric of these 'hard to treat' homes, either internal or external wall insulation. External wall insulation is particularly suited to those properties which would benefit from aesthetic improvement in addition to thermal comfort improvement. Other benefits of external wall insulation include reduced risk of cold bridging, no impact on internal floor area and less disruption to occupants (they can remain living in the building during the retrofit). Internal wall insulation is ideal for use in buildings where the external appearance should be preserved. This paper focuses on insulation used for external wall insulation systems, although these materials could also be used for internal application.

External wall insulation systems are built up from different layers (Fig. 1) of which an insulation material is the main component. The environmental impact of insulation is often considered to be negligible due to the in-use savings that can be accrued after its installation. However, if a life cycle approach is taken then the environmental impacts across the whole life cycle can be estimated. This paper makes a quantitative comparison of the environmental impacts of several external wall insulation materials: expanded polystyrene (EPS), phenolic foam and mineral wool boards. In addition, a wider embodied carbon comparison is made, which also includes PIR (polyisocyanurate) boards and woodfibre boards.

EPS, phenolic foam and PIR boards are all derived from fossil fuel derivatives. In contrast mineral wool is made from volcanic diabase rock and woodfibre board principally uses waste soft wood offcuts from sawmills [3]. All the materials are formed into rigid boards that can be used for external wall insulation, but could also be used in different retrofit applications, such internal wall insulation.

If the scale of retrofit required across the World is considered, it is clear there is a huge demand for insulation materials. In England

* Corresponding author. Present address: Department of Engineering, The University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, UK. Tel.: +44 01223 332672.

E-mail address: dod21@cam.ac.uk (D. Densley Tingley).

http://dx.doi.org/10.1016/j.buildenv.2014.11.021

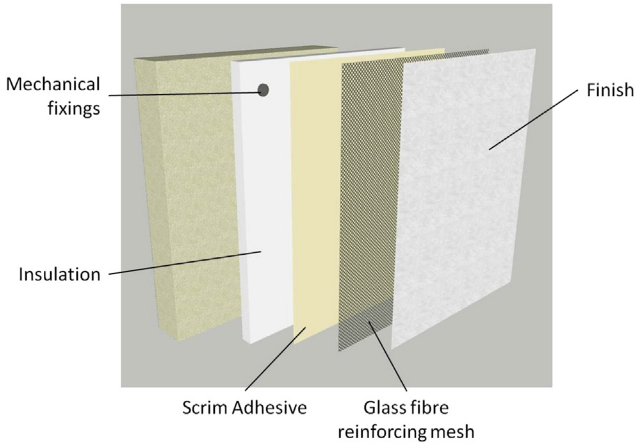

Fig. 1. External wall insulation system build up.

alone 24% of homes are either non-traditional construction or have 225 mm (9″) thick solid wall [4], making them possible candidates for external wall insulation. The quantity of insulation that will be required to retrofit these five million homes will be significant. It is therefore important to understand the potential whole life environmental impacts of retrofit insulation choice, which this paper explores.

2. Literature review

The application of life cycle assessment (LCA) to insulation materials is becoming increasingly common. Schmidt et al. [5] conducted one of the first studies of this type in 2004, comparing the life cycle impacts of stone wool, paper wool and flax. Different building envelope build ups have also been assessed; Azari [6] compares six building envelope options, with mineral wool and fibreglass batts being the insulation materials of choice. Whilst Shrestha et al. [7] suggest a protocol for assessing the environmental impacts of insulation over their life cycle and indicate that further work will include a comparison of insulation materials using this protocol.

Product specific LCAs are also conducted, Intini and Kuhtz [8] quantify the initial environmental impacts of polyester fibre insulation and Zampori et al. [9] assessed the impacts and benefits of hemp based insulation. Two studies investigate the environmental impacts of plant based, kenaf-fibre insulation products [10,11]. Ardente et al. [10] conduct a cradle to grave LCA on a kenaf-fibre insulation board, the environmental impacts are then compared to stone wool, flax, paper wool, PUR, glass wool and mineral wool, where the highest impacts are shown to be for PUR in the majority of categories. Whereas Batouli et al. [11] conduct a comparison study assessing the impacts of a kenaf fibre reinforced polyurethane insulation for different percentage contents of kenaf. This demonstrated that small additions, 5%, of kenaf decrease the environmental impact of the product, but further increases result in increased density and thermal conductivity, requiring more material to provide the same *R*-value and thus increasing the environmental impact.

The use of recycled products in insulation materials has also been investigated using LCA studies. Ingrao et al. [12] used an LCA study to assess the potential of using recycled PET bottles to form PET fibre based insulation panels. Whilst, Ricciardi et al. [13] investigate insulation panels which utilise recycled polyethylene fibres and waste paper. The thermal and acoustic properties are tested in addition to a cradle to gate LCA study. The extensive use of glues in the panel as well as the high density are suggested as reasons for relatively high embodied energy and carbon when compared to insulation products such as cellulose and mineral wool.

The environmental impacts of new insulation materials have also been studied, as part of a multi-criteria assessment. Dowson et al. [14] assess the environmental impacts of transparent aerogel, demonstrating that these would payback during the use phase. La Rosa et al. [15] conduct an LCA comparison of four external wall construction methods, three of which use cork insulation panels within the system, the fourth a PVC foam. The study showed that the lightweight cork composite panel that was being proposed had higher impacts than the cement coated alternative during the manufacturing stage, which had the lowest impact in seven of the nine assessment criteria. The use of epoxy resin in the lightweight panel increased the overall impacts.

It is evident that there is a growing body of work that assesses the environmental impacts of insulation using an LCA approach. However, to date, no study has conducted a comparison of the insulation choices that are used within external wall insulation systems for the retrofit of homes. This study seeks to fill this gap, and provide an LCA comparison which could be used to help inform external wall insulation choice, as well as demonstrating the magnitude of the CO_2 savings possible based on the scale of the retrofit challenge in the UK.

3. Method

This paper utilises LCA to compare the environmental impact of insulation boards. The cradle to gate impacts are quantified and compared. A cradle to gate study includes impacts from the extraction, processing and manufacturing of the product, to the point where it is ready for use. The study takes a process approach, similar to that of Batouli et al. [11], utilising material flows to account for the environmental impacts of a product for a functional unit.

The functional unit (‘quantified performance of a product system for use as a reference unit’ [16]) for this study is 1 m^2 of insulation with an *R*-value of 3 m^2 K/W. Insulation of this thermal conductivity, applied to even a very poorly performing existing building fabric, would meet the UK building regulations for existing dwellings, *R*-value = 2.8 m^2 K/W [17]. Selecting a constant *R*-value means that in-use savings will be the same for the options compared, and the initial impacts can be directly compared on a per m^2 basis.

The life cycle impact assessment (LCIA) method used is the International reference Life Cycle Data system (ILCD), this gives recommended characterisation factors, from specified derived models, for fifteen impact categories (climate change, ozone depletion, human toxicity-cancer effects, human toxicity-non-cancer effects, particulate matter, ionizing radiation human health, photochemical ozone formation, acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, land use, water resource depletion and mineral, fossil and renewable resource deplection) and an additional interim recommendation for a sixteenth category, ionising radiation ecosystems [18]. A characterisation factor is applied to the range of inventory data within a category to convert these into a single common unit, e.g. CO_2eq. Table 1 gives the units and explanation for each of the sixteen impact categories used in the cradle to gate study.

A full environmental impact comparison is made for EPS, mineral wool and phenolic foam based on the functional unit. A range of data sources are used, ecoinvent [24] for EPS and mineral wool, Densley Tingley et al. [23] for phenolic foam, the Inventory of Energy and Carbon (ICE) [25] for PIR and EPD-PTX-2010121-D [3] for woodfibre boards. A comparison concerned only