Proceedings Paper:

Pelsmakers, S. orcid.org/0000-0001-6933-2626 and Andreou, E. (2015) Should the Passivhaus standard include the environmental impact of materials in its standard? In: Tagungsband 19 Internationale Passivhaustagung 2015. 2015 International PassivHaus Conference, 17-18 Apr 2015, Leipzig. TIB , Leibniz . ISBN 9783000486036

Should the Passivhaus standard include the environmental impact of materials in its standard?

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1 Introduction

Human activities are significantly contributing to an upsurge of greenhouse gases that lead to climate change (IPCC, 2014). Building construction and operation are responsible for ~40% of energy consumption worldwide and for ~30% of the greenhouse gases emitted into the atmosphere (UNEP, 2009). These high emissions has forced UK authorities to promote mitigation measures to improve the energy efficiency of buildings, hence reduce energy consumption (e.g. the EU's EPBD demands 'nearly-zero energy buildings' by 2020).

At present, operational energy in buildings and especially space-heating, which represents the highest proportion of energy use in UK housing (Shorrock, 2005), are regulated in building codes. However, in order to reduce this operational energy, there is usually an increased demand for high-intensity materials and construction processes which, although they may improve the building energy performance, in turn increase the building's embodied energy (Lane, 2010, Crawford & Stephan, 2013). An unintended consequence of regulations imposing the design of low-energy buildings may be that they require more energy for their construction (Lane, 2010), leading to an increase in associated CO_2 and CO_2e emissions (CO_2e : the greenhouse potential of emissions, considered as if they were all CO_2 – Pelsmakers, 2012). This paper discusses whether the environmental impact of materials used in the design of Passivhaus buildings should form part of the Passivhaus (PH) Standard, alongside its operational energy requirements. The paper presents research results from an investigation of an as-built PH case study located in the UK.

2 Case study background and methodology

Plummerswood PH, a single-family dwelling of 297m^2 situated in the Scottish Borders, was designed by Gaia Architects with a target specific heat demand of 14kWh/m^{2}a and a target specific primary energy demand of 112kWh/m^{2}a. The building is the first UK Brettstapel project to meet the Passivhaus Standard and is constructed of mass timber (Gaia Architects) and has woodfibre insulation with a thermal conductivity of 0.037 W/mK in roof, walls and floor. All windows are timber framed triple-glazed.

The life-cycle energy demand of the building, in GJ, and the global warming potential (GWP), in kgCO_2e, were estimated; this includes the product stage (initial embodied energy: EE, in GJ) and the use stage (life-cycle operational energy: LCOPE in GJ). GWP includes the carbon sequestration potential of materials while EE does not. A building lifespan of 50 years is used for comparison purposes with other research, recognising that this is a worst case scenario and shorter than the 100-year intended design life of the actual building. This paper focuses on the environmental impact of insulation, as its increased quantity used in a PH was found to substantially increase the total embodied energy of the building fabric (Stephan et al., 2013, Crawford & Stephan, 2013). Three insulation materials were examined: glass wool, EPS and woodfibre (39%, 26% and <1% of the European insulation market respectively - IAL Consultants, 2013). The viability of the alternative insulations was not verified for use in timber mass construction and could harm the fabric, undermining building lifespan and occupant health. The environmental impact of materials was estimated by using the material quantity data provided in the PHPP file and the Inventory of Carbon and Energy (Ice, 2011) and Environmental Product Declarations (EPDs). The embodied energy, the life-cycle operational energy and life-cycle energy (i.e. combined embodied energy and operational energy) were obtained by retaining the same U-values, with a variable width of each insulation material to account for the different thermal conductivities. The embodied energy of each fabric element was derived, including walls, roof, floor and windows. Hence, the embodied energy of the building's structure, excluding insulation, remains the same for each PH scenario; 1037GJ.

3 Results and discussion

3.1. Embodied energy versus operational energy

Woodfibre has a significantly higher embodied energy (758GJ) than the other 2 insulations (Fig. 1); EPS is estimated at 20% less (603GJ) while the embodied energy of glass wool is estimated at 82% lower (134GJ) than woodfibre. For an assumed lifespan of 50 years, the building's life-cycle operational energy is estimated at 6004GJ. When woodfibre is specified, the life-cycle operational energy of the house represents 77% of the total life-cycle energy whereas the embodied energy is as high as 23%. If EPS is used, the life-cycle operational energy's proportion is increased to 79% with the proportion of embodied energy decreasing to 21%. For glass wool, the embodied energy proportion is reduced to 16%, with operational energy accounting for 84% of the 50-year life-cycle energy.

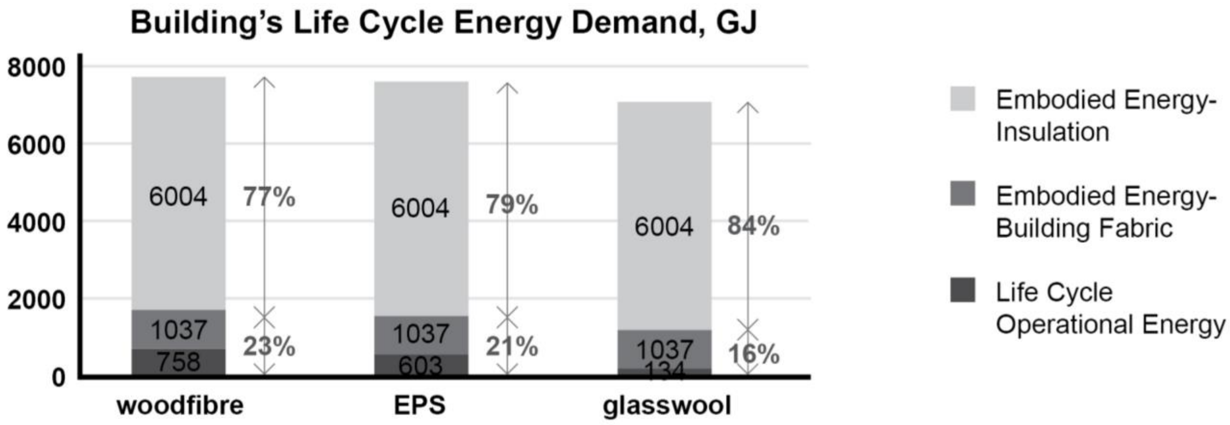

Fig. 1 Building's Life Cycle Energy Demand

Woodfibre, while being a tree-derived material, is a heavily processed material (Gutex, 2011) and its embodied energy was found to be considerably higher than the other studied insulations. Compared to cork, for instance, which has comparable thermal characteristics but is less processed, the embodied energy would be around 119GJ, representing the lowest embodied energy impact of all studied insulations in this paper.

3.2. Global warming potential (GWP)

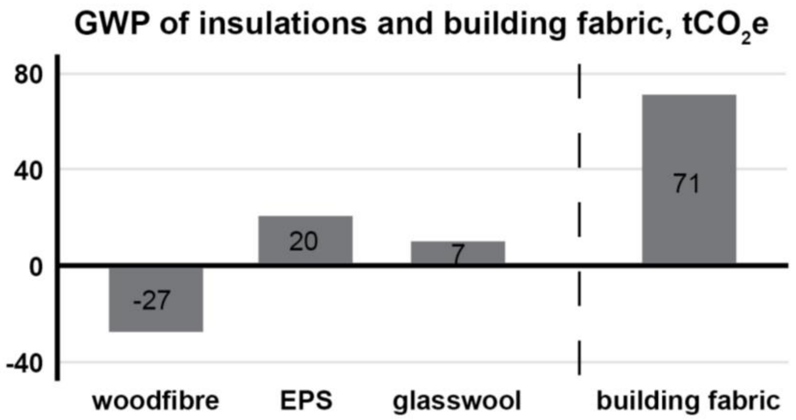

Fig. 2 GWP of 3 insulations and building fabric

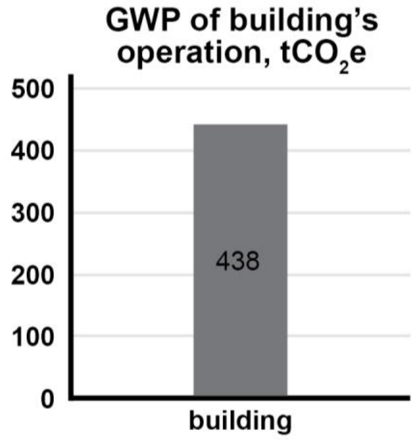

Fig. 3 GWP of building's operation

The building's total CO_2e operational emissions (GWP) over its assumed 50-year lifetime are estimated at about 438tCO_2e (Fig. 3). Note that this assumes the building will perform to the modelled PH standard while utilising the same energy sources with the same CO_2e intensity over this lifespan. The GWP of the building fabric (excluding the insulation) is estimated at 71tCO_2e (Fig. 2), however the carbon sequestration potential of the Brettstapel structure could not be estimated due to the lack of consistent information. This means that the actual building fabric's GWP would be significantly less than that stated here, and probably negative: for instance, Gaia Architects (2015) estimate the GWP of the entire structure (including insulation) to be around -243tCO_2e. Regarding the insulations, while the embodied energy of woodfibre may be the highest compared to other insulations, its GWP is negative and estimated at -27tCO_2e. Due to its carbon sequestration capacity it is considered to be a contributor to the reduction of global warming (Climate and Pollution Agency, 2011). Glass wool had a total GWP of 7tCO_2e while EPS an estimated highest total GWP impact of 20tCO_2e (Fig. 2).

3.3. Calculation of embodied energy: comparison of PH with Building Regulations and the effect of different materials and methods used

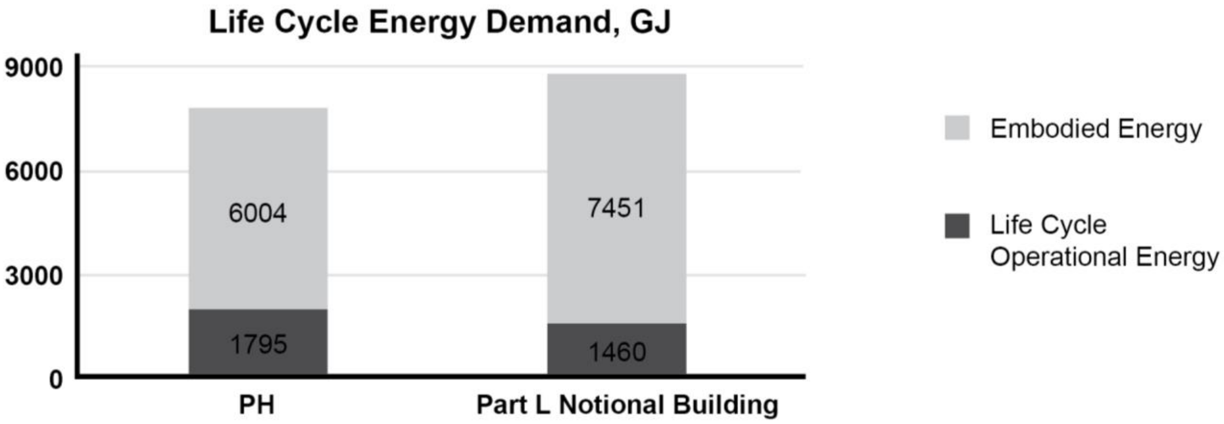

Fig. 4 PH versus Building Regulations house

While there is a variation in embodied energy of the different investigated insulations over a 50-year lifespan, it would be misguided to make embodied energy the sole criterion for choice, especially when a more realistic lifespan of 100 years is considered. The choice of insulation materials should not be an overriding consideration as it is one of the principle passive measures to efficiently reduce the operational emissions of a building (XCO2, 2014). Fig. 4 highlights that when the same case study building is reworked to meet Building Regulations standards, there was a 19% decrease in the building's embodied energy due to the reduced quantity of materials needed to meet the Building Regulations standard. However, Fig. 4 also emphasises the reduced total Life Cycle Energy demand of a PH (despite the additional material requirements), compared to the Life Cycle Energy of a Building Regulations building, highlighting the significance of the PH insulation in the reduction of the dwelling's operational energy demand. Crawford & Stephan (2013), on the other hand, argue that the environmental impact of the insulation in a PH does need to be taken into account due to the increased quantities required. For example, Crawford & Stephan (2013), Stephan et al. (2013) and Thormark (2002) found that the total embodied energy of a PH building over 50 years and with the same boundaries as considered in this paper, can exceed 30% of the total life-cycle energy, which considerably exceeds the estimated embodied energy of the building reported in this paper. A reason for this disparity might be that as the building studied is of timber construction, hence a total lower embodied energy is expected: for instance, an identical non-timber, conventional construction could have a 30% higher embodied energy (McGraw Hill Construction, 2011). Note that this study had to exclude some materials (e.g. building services), maintenance/material replacement and transportation energy due to lack of environmental impact data. This data would lead to an increase in the building's embodied energy.

As illustrated by this paper, the embodied energy of insulation and its GWP should certainly not be omitted: it was highlighted that different materials have diverging environmental impacts: woodfibre's embodied energy represents around 10% of the building's life-cycle energy demand, while more than 8% for EPS and around 2% for glass wool. However, in the case of woodfibre, there is the added carbon sequestration capacity. Hence, caution is needed when undertaking embodied energy and life-cycle assessment studies as different methods, such as embodied energy or GWP, can lead to significant differences on the estimation of the environmental impact, as some methods do not take into account the carbon sequestration of a material. For similar reasons and in support of a transition to a low-carbon economy (Buchanan & Honey, 1993), there would be additional environmental benefit from a shift from conventional brick/block constructions to timber structures, contributing to a reduction of the buildings' embodied energy and associated CO_2e emissions. However, as Monahan and Powell (2011), Himpe et al. (2013) and as this study also argues, decision-making based solely on the embodied energy or GWP of a material would be 'simplistic': the overall performance of a material and not its individual values should be considered. For example, certain materials could provide thermal mass which may be desirable in certain building types (Hacker et al., 2008) and may have superior acoustic, fire, health and hygroscopic characteristics, which should also be considered alongside their thermal performance and environmental impact.

4 Conclusion

At present, the specification of materials is left to the PH design team's discretion, however, as the environmental impact of materials is a variable that is not included in PH certification, it could certainly be argued that similar certification requirements for the use of energy-intensive materials may be appropriate to promote the use of materials with a low environmental impact, contributing to a more sustainable built environment.

Whether for building structure or insulation specification, a careful study has to be undertaken from the early design stages to enable the balancing of a building's life-cycle operational energy with its environmental impact, avoiding reduction of one at the expense of the other. Some form of future moderation of a building's environmental impact may seem inevitable; doing so would provide additional support in the reduction of the building's life-cycle energy demand.

This paper highlighted that different methods to assess the environmental impact of a material or construction could lead to contradictory results; hence, the importance of careful consideration of which assessment tools to use or develop to ensure robust assessment. Given that the PH standard goes well beyond minimum practice regarding operational energy standards and building certification, it could be argued that it is well placed to lead the way with regards to the materials and components used in a PH and development of an appropriate standard.

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