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Embodied greenhouse gas emissions from refurbishment of residential building stock to achieve a 50% operational energy reduction

Nils W.O. Brown*, Stefan Olsson, Tove Malmqvist

Division of Environmental Strategies Research (fms), Department of Sustainable Development, Environmental Science and Engineering, KTH – Royal Institute of Technology, Stockholm, Sweden

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A B S T R A C T

Mitigating climate change through operational energy reduction in existing buildings is of highest priority for policy-makers in Europe and elsewhere. At the same time there is increasing understanding of the significance of impacts arising from material production for buildings. The aim of this work has therefore been to evaluate the importance of embodied GWP for refurbishment for operational energy reduction on a stockwide basis. It is further intended to judge the relative significance of embodied GWP for specific refurbishment measures implemented for operational energy reduction. We study the case of operational energy reduction in the Swedish residential building stock by 50% compared to 1995.

The total embodied GWP to achieve the noted operational energy reduction is 0.35 Mt CO_2-e/year. 83% of this total is due to ventilation and window measures alone. Compared with previous studies assessing GWP mitigation from operational energy reduction, the "GWP payback time" is just over 3 years.

Many types of measure that contribute significantly to achieving the above operational energy goal had average embodied GWP between 10 and 20 g CO_2-e/kW h operational energy reduction, notably window and ventilation measures. Indoor temperature reduction (to 20 °C), was also significant for stockwide operational energy reduction but had a very low GWP of 0.4 g CO_2-e/kW h operational energy reduction. If this measure proves unfeasible to implement on a stockwide basis then more expensive measures with higher embodied GWP will be needed to achieve the stated energy reduction goal.

1. Introduction

1.1. Increasing the energy efficiency of existing buildings

Increasing energy efficiency in all sectors is a key focus in the European Union (EU) in order to mitigate the emission of greenhouse gases (GHG) [1]. This has been expressed most recently with the energy efficiency directive [2]. This requires amongst other things that member states establish energy efficiency targets, and a long term strategy for refurbishment of national building stocks. Similarly, the sharpened EU Directive on energy performance of buildings increasingly points at the significance of reaching high energy efficiency standards when performing refurbishments on existing buildings [3]. In line with these supra-national goals, the Swedish government has established a goal to reduce energy demand in buildings by 50% per unit heated area in 2050 compared with 1995 [4–6]. Åkerman et al. (2007) point out that to achieve this goal, a dramatic increase in energy efficiency of existing buildings is necessary [7].

Meanwhile, the Swedish National Board of Housing Building and Planning (hereafter SNBHBP) calculate that operational energy demand reduction by 50% in residential buildings existing in 2005 (considering the goal outlined above) requires a reduction from 92.2 TW h/year in 2005 to 42.6 TW h/year in 2050 [8]. Their study shows that this can be achieved with refurbishment measures with a total annuitised investment cost of 3.5 Bn€/year, or an average of 0.07 €/kW h [8]. In a parallel study, Mata et al. (2013) evaluated the techno-economic potential for operational energy demand reduction in the stock of Swedish residential buildings existing in 2005 [9]. With the range of refurbishment measures considered, her work shows a possible reduction of 55% from 96.5 TW h/year to

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* Corresponding author. Tel.: +46 8 790 7396; fax: +46 8 790 8580.
E-mail addresses: nils.brown@abe.kth.se (N.W.O. Brown), stefan.olsson@abe.kth.se (S. Olsson), tove.malmqvist@abe.kth.se (T. Malmqvist).

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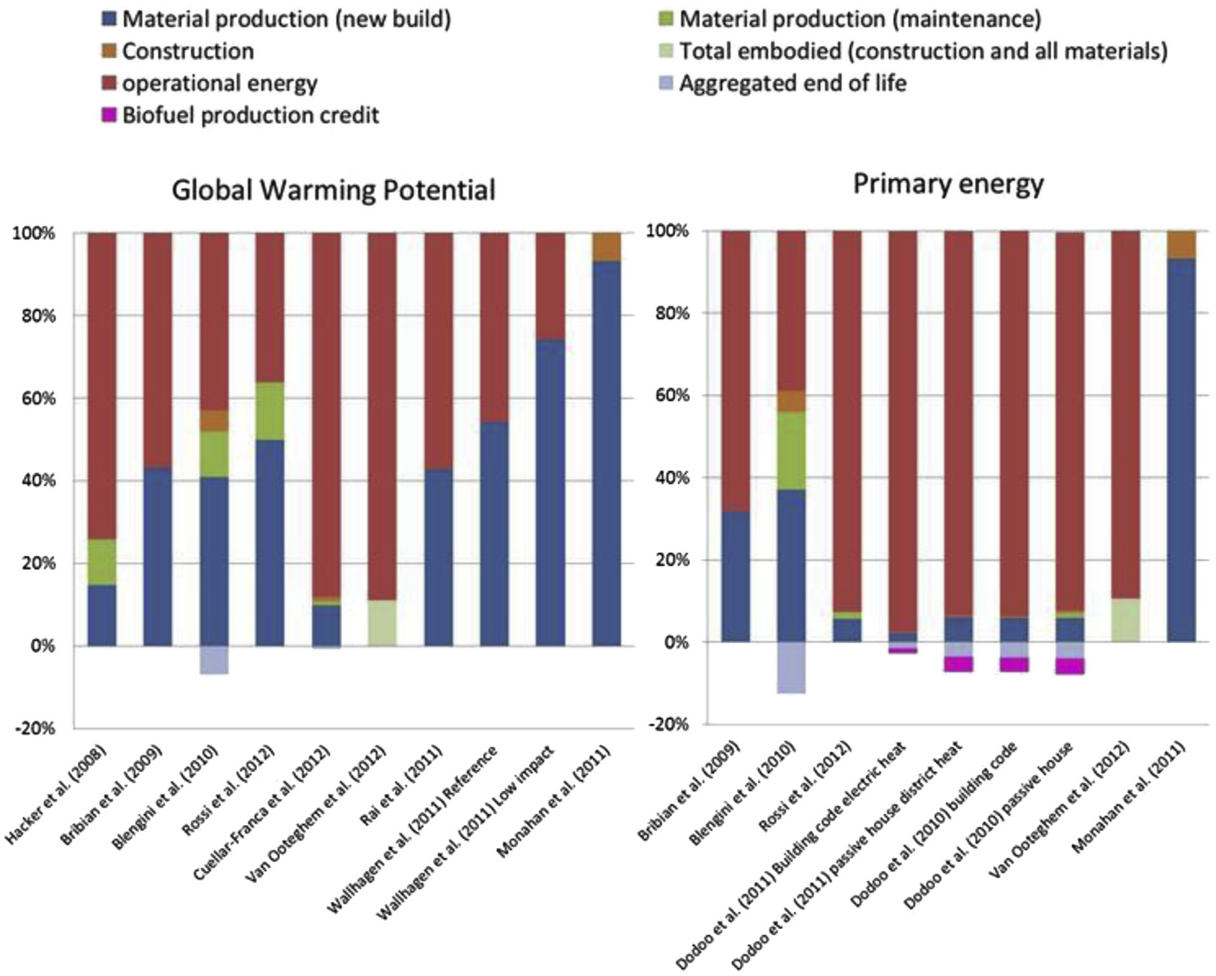

Fig. 1. Comparison of building level environmental assessments (with exception of Monahan et al. (2011) [18] that looks at material production and construction for a building only) with life-cycle thinking from past 5 years on the basis of calculated life-cycle global warming potential and primary energy. Citations in the figure refer to the following: Hacker et al. (2008) [19], Bribian et al. (2009) [16], Blengini and Di Carlo (2010) [17], Rossi et al. (2012) [15], Cuellar-Franca and Azapagic (2012) [20], Dodoo et al. (2011) [21], Dodoo et al. (2010) [22], Van Ooteghem et al. (2012) [23], Monahan et al. (2011) [18], Rai et al. (2011) [24], Wallhagen et al. (2011) [13].

43.1 TW h/year and corresponding reduction of carbon dioxide emissions (not including non-CO_2 GHGs) of 63% due to this reduced demand, from 4.97 to 2.07 $MtCO_2$/year [9].

1.2. *Low-energy buildings in a life-cycle perspective*

Calculations and estimates such as those mentioned above interpret the reduction in environmental impact achieved by stockwide refurbishment as a reduction in operational energy demand and associated impacts. As significant as these reduced impacts are, the overall effects of such measures are more fully understood when approached from a life-cycle or systems perspective. In the case of buildings, the life-cycle or lifetime is considered to consist of the following four stages: product, construction process, use (or operation) and end-of-life [10].

A growing body of literature is underlining the rising importance of the product stage with regards to energy use and environmental impact of buildings' life-cycles [11,12]. This is clearly relevant for new production standards for low energy buildings and in national contexts in which the use of fossil fuels in energy supply mixes has gone down, as is the case in Sweden [13]. A recent input–output based study of environmental impact and energy use of the Swedish building and construction sector shows that construction and management activities for buildings, *excluding operational energy use* accounted for 12% of the total national greenhouse gas emissions (our analysis of Ref. [14]). For comparison, the same study calculated the GHG emissions due to heating buildings to constitute 6% of total national emissions [14].

Considering life-cycle thinking as applied to buildings further, Fig. 1 shows the calculated life-cycle primary energy demand and global warming potential (GWP) from selected cases from building-level environmental assessments published in scientific journals in the last 5 years. The figure clearly demonstrates that there is agreement amongst the works reviewed in that it is product and use stages that taken together dominate overall life-cycle environmental impacts. It also shows that the reviewed works are as much in disagreement as to the contributions of product and use stages. One possible source of the observed differences is the variation in sources for operational energy demand. Rossi et al. (2012) [15] is an example where operational energy comes from sources with very low GHG emissions (nuclear, hydropower and waste heat) meanwhile Bribian et al. (2009) [16] is an example where active heating comes primarily from a natural gas boiler supplemented with a solar hot water system. Both houses are built to relevant current building codes. Blengini and Di Carlo (2010) [17] on the other hand is an example of a house with low energy demand where active heat is supplied from a heat pump assuming fossil-dominated electricity mix. Other possible reasons for the