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The influence of different electricity-to-emissions conversion factors on the choice of insulation materials

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ABSTRACT

The current practice of building energy upgrade typically uses thick layers of insulation in order to comply with the energy codes. Similarly, the Norwegian national energy codes for residential buildings are moving towards very low *U*-values for the building envelope. New and more advanced materials, such as vacuum insulation panels (VIPs) and aerogel, have been presented as alternative solutions to commonly used insulation materials. Both aerogel and VIPs offer very high thermal resistance, which is a favourable characteristic in energy upgrading as the same insulation level can be achieved with thinner insulation layers.

This paper presents the results of energy use and lifecycle emissions calculations for three different insulation materials (mineral wool, aerogel, and vacuum insulation panels) used to achieve three different insulation levels (0.18 W/m^2 K, 0.15 W/m^2 K, and 0.10 W/m^2 K) in the energy retrofitting of an apartment building with heat pump in Oslo, Norway. As advanced insulation materials (such as VIP and aerogel) have reported higher embodied emissions per unit of mass than those of mineral wool, a comparison of performances had to be based on equivalent wall *U*-values rather than same insulation thicknesses. Three different electricity-to-emissions conversion factors (European average value, a model developed at the Research Centre on Zero Emission Buildings – ZEB, and the Norwegian inland production of electricity) are used to evaluate the influence of the lifecycle embodied emissions of each insulation alternative. If the goal is greenhouse gas abatement, the appraisal of buildings based solely on their energy use does not provide a comprehensive picture of the performance of different retrofitting solutions.

Results show that the use of the conversion factor for Norwegian inland production of electricity has a strong influence on the choice of which of the three insulation alternatives gives the lowest lifecycle emissions.

1. Introduction

Both the building industry and building stock are energy-intensive sectors and causes of significant greenhouse gas emissions. Production, installation, transportation and disposal of building materials, and the energy use for achieving indoor comfort, are the main forces driving the current energy consumption rate. According to many sources [1–3] the building sector in the EU area accounts for about 40% of total primary energy use and for about 25% of CO_2 emissions [4]. This refers to the energy used during their operation phase. To follow the path of the Kyoto Protocol, several European countries have adopted various measures and regulations that address energy-saving strategies in the residential sector. However, implementation of the newest building standards is not sufficient to reach the targets if a consistent campaign of renovation of residential buildings is not set up. A study from Nemry et al. [5] shows that the energy use and CO_2 emissions of the newest residential constructions of the EU-25 countries only account for a negligible share of the total. Clearly, the need for retrofitting of the existing stock is an urgent issue, particularly because space heating is responsible for a high percentage of the total energy use in buildings.

Energy efficient renovation of the EU residential stock is critical for reducing the global energy use for space heating and, consequently, for abating greenhouse gas emissions. In order to achieve effective reduction of total energy use in the EU area the residential

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stock should aim towards the highest classes of energy efficiency, such A and A+. The current energy retrofitting practice focuses primarily on reducing energy use. However, the objective of the European 20-20-20 climate and energy targets goes beyond energy use in buildings and includes a 20% reduction in EU greenhouse gas emissions. The EU 2020 climate and energy package is part of the wider roadmap to a European low-carbon economy by 2050, when the residential and tertiary sector are assumed to have their greenhouse gas emissions reduced by 88–91% [6].

The use of greenhouse gas emissions as a metric for evaluating and comparing the interventions on the building stock is not yet common practice, however. Building energy demand still remains the most commonly used metric. Some studies [7,8] show that as the energy demand of a building decreases, the share of embodied energy and greenhouse gas emissions increases. The picture is quite complicated when emissions are considered, as the greenhouse gas emissions calculated will depend on the specific country's electricity production and will vary from country to country, as shown in [9]. In such a perspective, two buildings, with equal performances, would have different final emissions when located in different countries. Similarly, the use of different materials for achieving the same insulation value would produce different results, due to the different embodied emissions associated to their production. The currently agreed European electricity-to-emissions conversion factor will not represent realistic values if the European energy grid will be based on a higher use of renewable energy sources in the near future [10,11]. A study by [12] proposed a forecast of the electricity-to-emissions conversion factor based on the current and future energy exchanges and sources within the European countries. The energy-use scenarios they studied indicated that future conversion factors may have lower emissions per produced kWh of electricity than those calculated for the current factor (0.361 $kgCO_{2\text{-eq}}$/kWh). The difference is estimated to be between 50% and 95%.

2. Objective

The objective of this work is therefore to analyse some possible energy retrofitting packages from the perspective of greenhouse gas emissions and to evaluate their effectiveness.

Results from the greenhouse gas emissions analysis of several alternative retrofitting packages applied to an apartment building located in Oslo, the Myhrerenga Borettslag, are presented. A reference solution of energy retrofitting of this building is compared to alternative options with different thicknesses of insulation materials. For each energy-retrofitting alternative the annual energy demand and the lifecycle greenhouse gas emissions were calculated.

The greenhouse gas emissions from the energy use for building operation of each of the retrofitting alternatives are calculated for three different electricity-to-emissions conversion factors. These are the European average (0.361 $kgCO_{2\text{-eq}}$/kWh), the Norwegian inland production 0.019 $kgCO_{2\text{-eq}}$/kWh), and the conversion factor developed at the Research Centre on Zero Emission Buildings – ZEB (0.152 $kgCO_{2\text{-eq}}$/kWh). The use of different conversion factors highlights how the balance between the emissions due to the materials production (lifecycle embodied emissions) and the emissions due to the building energy use varies. A low-emissions energy grid is expected to favour the alternatives with low lifecycle embodied emissions, while a high-emissions energy grid is expected to favour the alternatives with low energy use for building operation.

The reference solution, which represents the realized renovation of the building [13], is compared to options with three different insulation materials (mineral wool, aerogel, and VIP) and three different insulation values of the external walls. The insulation level of the façades in the reference solution is 0.12 W/m^2 K, and the insulation material used is mineral wool.

To better understand to what extent it is environmentally wise to use thick insulation layers in energy upgrades of residential buildings the thickness of each of the three insulation materials was set to meet the *U*-value levels required in the national building code [14] for the energy retrofitting of residential buildings. These levels are 0.18 W/m^2 K for class-1 low-energy houses, 0.15 W/m^2 K for passive houses, and 0.10 W/m^2 K for exceeding the passive house insulation level, respectively. The environmental consequences of using the super-insulating options versus the less-insulated ones are shown by analysing the $CO_{2\text{-eq}}$ emissions for each option.

3. Method

3.1. The reference building

An apartment building in Oslo, Norway, the Myhrerenga Borettslag (a housing cooperative), is used as a reference building in the energy and greenhouse gas analysis. Conforming to the building trend of post-war decades, the Myhrerenga Housing Cooperative represents one of several examples of residential buildings that have shaped the urban landscape of most Norwegian towns and currently account for approximately 23% of the entire Norwegian dwelling stock [15]. Each of the seven buildings is approximately 65 m long and 10 m wide and has 24 apartments divided in eight units per floor plus a basement. The apartments, which face both East and West, vary from 54 m^2 to 68 m^2 in size and are served by four stairwells positioned on the East side of the building. There are partially enclosed balconies on the West façade (Fig. 1).

The whole complex of buildings was recently renovated. This was needed due to the very poor thermal performance of the buildings and the very high energy-use for heating. The balcony slabs were fully exposed and abutting the concrete floors, which resulted in problems of thermal bridging occurring at all the structural connections. The existing energy supply system consisted of an inefficient central electric oil boiler which delivered heat to the building through a hydronic system with radiators in each apartment. The full description of the renovation package proposed for the Myhrerenga Housing Cooperative can be found in [13]. This energy renovation, which upgraded all of the seven buildings to passive house standards, represents the starting point for this research. It is termed the *reference building*, and the proposed energy retrofitting alternatives are based on this.

3.2. Energy retrofitting alternatives

The three different façade retrofitting alternatives are evaluated for three thicknesses of insulation each: 250 mm, 140 mm, and 100 mm for mineral wool; 100 mm, 60 mm, and 45 mm for aerogel; and 60 mm, 35 mm, and 25 mm for VIP. These thicknesses give *U*-values of 0.10 W/m^2 K, 0.15 W/m^2 K, and 0.18 W/m^2 K, respectively. The mineral wool thickness in the reference building is 200 mm, and the external façade *U*-value is 0.12 W/m^2 K. Details of the different retrofitting alternatives are shown in Tables 1 and 2.

3.3. Energy model

The energy model details the interior arrangement of the apartments of one building only. Considering that the apartments located at the ends of each building will have somewhat special conditions, these have been fully described as separate thermal zones in the model. Of the 18 middle apartments, only the central 6 units are considered as separate thermal zones. The remaining 12 units are aggregated into two adiabatic zones. The indoor