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Aerogel vs. argon insulation in windows: A greenhouse gas emissions analysis

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ABSTRACT

The scope of this study is a comprehensive analysis of the greenhouse gas emissions from the partial substitution of triple-glazing units with argon gas (U-value of 0.79 W/m^2 K) with double-glazing units with either monolithic aerogel (U-value of 0.65 W/m^2 K) or granular aerogel (U-value of 0.31 W/m^{2}d K).

A residential building located near Oslo and fully upgraded with passive house solutions is used as a case study for this analysis. A cradle-to-site analysis is performed on the facade components. Two replacement schedules and three window-to-wall ratios are used to evaluate the differences in total emissions. Sensitivity analyses based on increasing the fraction of the aerogel glazing, varying the greenhouse gas emissions of the aerogel production, and changing the service life of the aerogel glazing are also performed.

Results show that both the options with windows with aerogel are effective in reducing the greenhouse gas emissions, regardless of the total window-to-wall ratio and the replacement schedule used. By increasing the share of the aerogel glazing, the savings in emissions increase from 5% to 9%. The sensitivity analysis shows that the greenhouse gas emissions from the production of aerogel should be at least 8 times higher than those currently reported to totally counterbalance the achieved energy savings.

1. Introduction

Both the building industry and the building stock are energy-intensive sectors and cause 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 several sources [1–3] the building sector in the EU accounts for about 40% of total primary energy use and for about 25% of greenhouse gas 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 building sector.

To overcome the low thermal resistance of the transparent surfaces, multi-glazing types of windows have been developed of which a wide variety is available on the market today. Triple-low-energy-glass windows with low-energy coatings and argon gas filling, for instance, represent an effective energy-saving solution. However, these technologies have the drawback that they drastically reduce the amount of solar radiation that passes through the glass due to use of several coated layers. This condition can be favourable at medium latitudes (such as in central Europe) where there is ample solar radiation in cold winters. However, it can be disadvantageous at high latitudes (such as in Scandinavian countries) where the solar radiation in winter is low in terms of both hourly availability and quantity.

Glazing with aerogel filling has been proposed as a technology capable of providing natural light with the benefit of an insulation value higher than that of classic triple and quadruple glazing solutions. Products available today in the market [5] can provide a stunning 0.3 W/m^2 K (for the centre glazing U-value) but at the sacrifice of losing visible and solar transmittance. Glazed products with granular aerogel are made of two 4-mm thick glass panes and a cavity filled with a layer of granular aerogel of variable thicknesses [5]. On the other hand, recent studies have demonstrated

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that, by taking advantage of the optical properties of aerogel, it is possible to produce double-glazed windows that not only have a very low U-value but also have a visible transmittance higher than that of the correspondingly standard alternative [6,7]. Simulations of the energy consumption of a single family house insulated according to the passive house standard showed that the option with glazing units with monolithic aerogel gives a 19% energy savings compared to the use of triple-glazed units with low-e coatings and argon gas filling [6]. Glazed prototypes with monolithic aerogel consist in two 4-mm thick glass panes and a vacuumed gap filled with a 13.5-mm thick layer of monolithic aerogel [6]. Several studies [6–11] show that windows insulated with aerogel, either granular or monolithic, represent a promising solution to achieve high insulation levels and reduce the total greenhouse gas emissions. On the other hand, aerogel has higher CO_2 emissions per kg for production than those required for argon [12,13]. It is interesting, then, to investigate to which extent the energy savings given by using aerogel as an insulating material for windows are counterbalanced by the disadvantages given by the higher greenhouse gas emissions of the aerogel production.

2. Objective

The objective of the work is to compare and assess the greenhouse gas emissions of three different glazing technologies applied in the energy retrofitting of a housing complex located near Oslo, Norway. Results from the calculations of the annual energy use and greenhouse gas emissions of several alternative combinations of windows technologies, window-to-wall ratios, and replacement schedules are presented. Additionally, sensitivity analyses on increasing the share of the windows insulated with aerogel, the variation of the emissions of the aerogel production, and the variation of the service life of aerogel glazing are performed. Results from the calculation of the annual energy use and the greenhouse gas emissions performed in the sensitivity analyses are also presented.

3. Method

3.1. The case study

An apartment building near Oslo, Norway, the Myhrerenga Borettslag (a housing cooperative), is used as a case study 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 [14]. The building 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. The facades consist of a timber frame with mineral wool insulation. The load bearing structure consists of concrete walls that run orthogonally from the East façade to the West façade [15]. Such a structural system allows a high degree of modification of the openings placed on the East and West facades, as it is proposed in this study (Fig. 1). The apartment building was renovated in 2010, and a description of the upgrading design is to be found in Ref. [16]. In the performed renovation of the building an additional layer of 200 mm of mineral wool was placed externally to the facades of the buildings [16]. In this study, however, the addition of an external layer of 250 mm of mineral wool is considered for all the facades. This results in an after-retrofitting U-value of the external walls of 0.10 $W/m^2 K$. A description of the layers of the retrofitted facades according to this study is shown in Table 1. Table 2 lists the materials used in the renovation of the building (excluding the facades), the layers thickness, the materials service lives, and the transportation distances.

The variation of the window-to-wall ratios aims at studying to what extent the ratio of the glazed surfaces to the opaque surfaces influences the building energy use for heating for an apartment building located near Oslo. In a well-insulated building, windows are the components of the building envelope where most of the heat losses and gains occur, and it is interesting to evaluate the drawbacks of a large glazed area in terms of energy use for space heating. Table 3 shows the values of the window-to-wall ratios used in this work. The 0.24 glazing ratio is the value of all the current facades of the Myhrerenga Borettslag. The 0.50 glazing ratio is set as the maximum value, since larger fenestration areas would have compromised the availability of wall surfaces for placing furniture and domestic appliances. The 0.33 glazing ratio has been set as an intermediate value between the two above.

3.2. Glazing alternatives

The variation of the fraction of the aerogel glazing of the total number of windows aims at understanding the full potential of the employment of such technologies in residential buildings, in terms of both energy savings and greenhouse gas emissions abatement. The quantities of windows with aerogel are shown as percentages in Table 3. The alternatives named “standard” (with the *_s* suffix) have an increasing portion of windows with aerogel for an increasing total window-to-wall ratio. On the other hand, the alternatives named “full” (with the *_f* suffix) have the same portion of windows with aerogel regardless of the total window-to-wall ratio. In this last case, the small number of windows with argon in the “full” aerogel alternatives refers to the windows used in the basement walls, which are not considered in the analyses but still contribute to the building energy use and greenhouse gas emissions.

The variation of the replacement schedule, which determines when a product has reached the end of its service life, aims at studying to what extent a shorter service life of the aerogel glazing influences the total building greenhouse gas emissions. The maintenance schedules of the windows and the other building components used in this work are extracted from Ref. [17]. As above mentioned, the thermal insulation of the windows with monolithic aerogel is achieved by both vacuuming the gap between the two glass panes and filling it with monolithic aerogel, which has a very low tensile strength [18] and is a very fragile material. It is assumed, then, that the service life of such windows cannot compare to that of standard triple-glazed-with-argon units. However, specific information on the service life of windows with monolithic aerogel has not been found in literature. It has been decided then to use a service life that is half of the triple-glazed units, as a base case. To present coherent results between the two glazing products with aerogel, their service life has been set the same. The values of the replacement schedules of the different glazing technologies are shown in Table 4. It is worth noticing that the service life of the triple-glazed units with argon varies between 60 years for the long maintenance schedule and 20 years for the short maintenance schedule. The service life of the double-glazed units with aerogel insulation varies between 30 years for the long maintenance schedule and 10 years for the short maintenance schedule. Since the building service life is 50 years, the service life of the triple-glazed units with argon is limited to 50 years by the building service life.