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A comparative study of the environmental impact of Swedish residential buildings with vacuum insulation panels

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ABSTRACT

A large part of the energy consumption in the European Union member states is related to space heating, a significant share of which is due to transmission losses through the building envelope. Vacuum insulation panels (VIPs), with unique thermal insulation properties, do therefore provide an interesting alternative for the building industry. This paper presents the results of a life cycle analysis (LCA) study that compares the environmental impact of three hypothetical buildings, a standard residential building, a regular well-insulated building and a building insulated with VIPs. The environmental impact includes the global warming potential (GWP) and the primary energy (PE) use, from the material production stage to the building operational phase (50 years). The cradle-to-gate environmental impact categories of ozone depletion potential (ODP), acidification potential (AP) and eutrophication potential (EP) of all building components are also assessed. The study shows a comparatively lower operational energy for the VIP insulated building and a relatively lower total greenhouse gas emission as well as the possibility to save significant living space. The results also show that the VIPs have measurable environmental impact during the product stage while the core material of the VIPs has considerable impact on the results.

1. Introduction

1.1. Energy and the climatic envelope

The European Union has set three key objectives related to climate and energy [1], a reduction of 20% in greenhouse gas emissions from 1990 levels, a 20% share of energy from renewable resources and a 20% improvement in the energy efficiency of the EU countries. An additional target is a 50% reduction of greenhouse gases until year 2050, compared to 1990.

A significant share of the energy used in the European Union can be related to space heating of buildings, a substantial part of which is the thermal losses through the climatic envelope (about 20%). Improved thermal insulation, of new and existing buildings, is therefore an important part of the efforts toward the reduction of energy consumption. The Swedish responsible agency for energy use in buildings (Boverket) prescribes a value of less than or equal to 80 kWh m^{-2} per year for the energy use of a new multi-family building in Stockholm. While a value of 0.40 W m^{-2} K^{-1} or less, must be reached to attain scope set for an average heat transfer coefficient, U_m, of building [2]. This value contains all heat transfer coefficient of building components and thermal bridges, determined by the SS EN ISO 13789:2007 and SS 24230 (2). The equation is available in the Swedish building regulations [2].

The use of traditional insulation materials will result in a significant increase in the thickness of the climatic envelope that may in turn lead to a significant loss of living space area. As an example, a house in Sweden would need to have a conventional insulation thickness of some 335 mm in the wall and about 500 mm in the roof to meet the Swedish passive house standards of a U-value of 0.10 and 0.066 W m^{-2} K^{-1} for the wall and the roof. Other issues include an increased volume of transport and restrictions on the architectural design.

Vacuum insulation panels, VIPs, with an unprecedented thermal insulation performance do, however, provide the unique opportunity of a slender climatic envelope with superior thermal insulation. Assessment of the environmental impacts of buildings with VIPs is therefore of interest, and is the scope of this study.

1.2. New opportunities with VIPs

VIPs, with a thermal conductivity of 0.004–0.007 W m^{-1} K^{-1} [3], offer a thermal resistance of about 8–10 times that of a conventional insulation material with the same thickness. A regular

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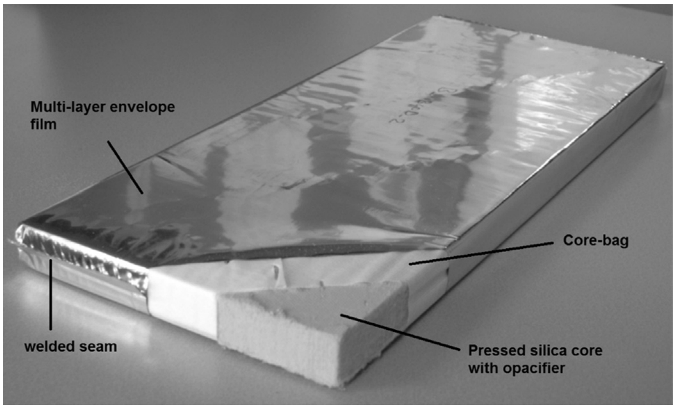

Fig. 1. A regular VIP panel with a fumed silica core.

vacuum insulation panel is made of a gas-tight envelope surrounding a porous core from which the air has been evacuated (Fig. 1). There are, however, vast possibilities of combining different core materials and envelopes in different typologies as described in the literature [4]. The relatively small pore size in combination with low pressure prevents thermal transport through convection of gases in the core. By using a core material with pore size in the range of the mean free path of the gas molecules the conduction through the collision of gas molecules can also be limited. Conduction through the core material is minimized by using materials with a sparse solid matrix while the radiative heat exchange between the interior surfaces of the core material depends on the surface properties that can be improved by the use of additives.

Until now, the application of VIPs has been limited to a small number of buildings. Further description and examples of applications can be found in the report of the International Energy Agency [5] as well as in Ghazi Wakili et al. [6], Schwab et al. [7] and Binz and Steinke [8]. Baetens et al. [9] have also done a review of VIPs in building applications.

Recent studies by Jelle [10] and Kalnæs et al. [11] give a comprehensive account of VIPs while Bouquerel et al. [12] and Coquard et al. [13] put emphasis on the modeling of heat transfer in VIPs. Our previous studies are concerned with simulations of heat and moisture transport across a climatic envelope with exterior VIPs [14], developing new precipitated silica powder material for VIP core [15] as well as improvement of existing thermal measuring methods for testing VIP porous core materials [16].

1.3. Durability and service life prediction of VIPs

The service lifetime of a VIP can be defined as the time at which the required thermal conductivity has been surpassed, while a further account of service life is given in ISO 15686-2 [17]. One of the most important aging mechanism of VIPs is the permeation of gas through the envelope, that may be enhanced at higher temperatures and humidity and is further increased at the edges [18]. The edge effect will increase with the ratio of edge length over area of the panel [19]. It is common to put getters or desiccants in the core material in order to adsorb or entrap residual gas or moisture and thereby secure or prolong the service life of panels [20]. With current technology the gas pressure increase of a 20 mm thick VIP with metalized high barrier envelope is around 1–2 mbar a year giving a lifetime of 25–50 years or more depending on the required performance of the panel [3,18,21]. The problems of gas permeation through the envelope can be solved by using virtually impermeable metal films with a thickness of 10 μm or more, but this can result in thermal losses that are of the same magnitude as the heat flow through the panel [22].

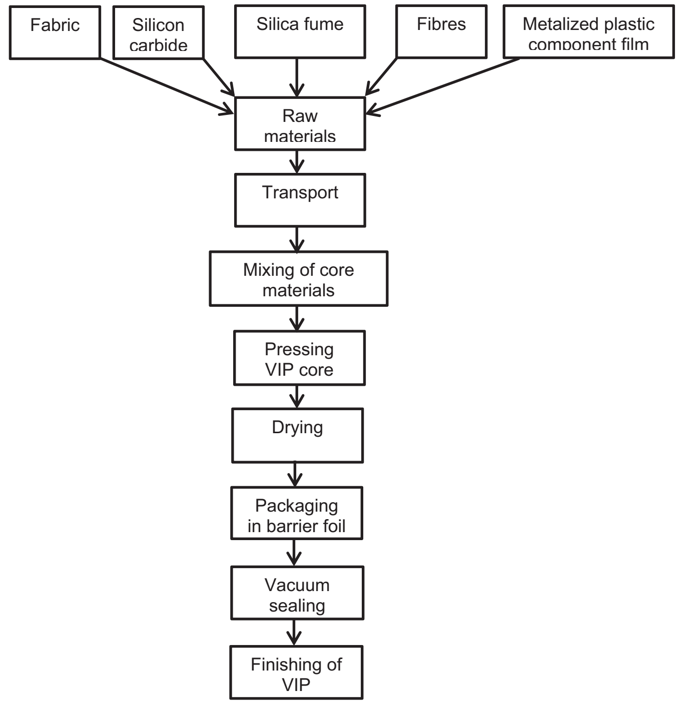

Fig. 2. Life cycle flow diagram of the VIP manufacturing process based on methods described by a VIP manufacturer and previous work [26].

It has been shown that the VIPs can be expected to have an approximate thermal conductivity of 0.007–0.008 W m^{-1} K^{-1} after 25 years while the increment of the thermal conductivity rate depends mostly on barrier properties and panel dimensions as well as boundary conditions [23]. A more recent work shows, however, a significant deviation between measured and predicted thermal conductivity values [24]. The work of Wegger et al. [25] gives an account of four different accelerated aging laboratory tests and the theoretical relationships between VIP properties and the external environment.

It must also be noted that VIP panels may fail due to imperfect production or through mechanical damages during installation [26].

1.4. Manufacturing of VIPs

Vacuum insulation panels consist of a core, typically made of fumed silica (60–90%), silicon carbide (10–40%) and fibers (<5%) and metalized plastic composite film.

In the first step of the manufacturing process the raw materials of the core are mixed and pressed in a hydraulic press to form a panel and then cut to size. The panels are then dried at a temperature between 60 and 150 °C and wrapped in a fabric. The metalized film is then wrapped around the core with one side kept open for evacuation of the air. When the requested pressure range has been reached the panel is heat sealed. The finished product is then packed for delivery (see Fig. 2). The VIP panels are fully recyclable if no damage or contamination occurs during deconstruction. If the VIP is intact the wrapping can be separated from the core and the fabric can be thermally recycled while the metalized film can be sent to material recycling. The core material can be ground and used in the production of a new VIP product [27].

1.5. LCA – life cycle assessment

The LCA method is defined by SETAC, the Nordic guidelines for LCA and within the ISO 14000 series [28]. It can be applied on all