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Energy and economic analysis of Vacuum Insulation Panels (VIPs) used in non-domestic buildings

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HIGHLIGHTS

- A novel methodology for payback analysis of vacuum insulation panels was proposed.
- The methodology considers the variation of techno-economic parameters with time.
- Space heating energy and emission savings were calculated.
- Longer lifespan vacuum insulation panel achieved a shorter payback period.
- Fumed silica VIPs are economically viable for adoption into non-domestic buildings.

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ABSTRACT

The potential savings in space heating energy from the installation of Fumed Silica (FS) and Glass Fibre (GF) Vacuum Insulation Panels (VIPs) were compared to conventional expanded polystyrene (EPS) insulation for three different non-domestic buildings situated in London (UK). A discounted payback period analysis was used to determine the time taken for the capital cost of installing the insulation to be recovered. VIP materials were ranked using cost and density indexes. The methodology of the Payback analysis carried out considered the time dependency of VIP thermal performance, fuel prices and rental income from buildings. These calculations show that VIP insulation reduced the annual space heating energy demand and carbon dioxide (CO_2) emissions by approximately 10.2%, 41.3% and 26.7% for a six storey office building, a two floor retail unit building and a four storey office building respectively. FS VIPs had the shortest payback period among the insulation materials studied, ranging from 2.5 years to 17 years, depending upon the rental income of the building. For GF VIPs the calculated payback period was considerably longer and in the case of the typical 4 storey office building studied its cost could not be recovered over the life time of the building. For EPS insulation the calculated payback period was longer than its useful life time for all three buildings. FS VIPs were found to be economically viable for installation onto non-domestic buildings in high rental value locations assuming a lifespan of up to 60 years.

1. Introduction

The combustion of fossil fuels to generate energy is recognised as the major cause of anthropogenic climate change. To mitigate this, the international community has agreed to collectively endeavour to limit global temperature rise to within 1.5 °C above pre-industrial levels by reducing emissions of greenhouse gases through the use of cleaner energy sources and increased energy efficiency [1]. In 2013, emissions from space heating energy use in UK buildings accounted for 98 million tonnes of carbon dioxide (CO_2), constituting 17% of total UK greenhouse gas emissions [2]. Energy efficiency requirements for UK buildings are continuously improved through stricter stipulations in the building regulations. The aim is to reduce overall UK CO_2 emissions by at least 80% from the 1990 level by 2050 as set in the Climate Change Act 2008 [3]. With over 60% of the energy consumed in the buildings used for space heating [4], the development of building fabrics with sub-

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stantially improved insulation properties are essential for the UK to achieve its long term carbon reduction goals.

To reduce heat losses from building fabric using conventional insulation products, such as Expanded Polystyrene (EPS), will require prohibitively thick layers, which may not be feasible in existing or even new buildings. Alternatively, thinner layers of advanced insulation products, such as VIPs, could be used due to their thermal resistivity being 5–8 times greater than conventional insulation [5–9].

A VIP is a composite rigid sheet comprising an evacuated (pressure ⩽0.5 mbar) inner core board laminated inside an outer barrier envelope [10]. VIPs can be installed on opaque building surfaces (externally or internally) and on hot water storage cylinders to improve their thermal resistance. For façade applications, transparent insulation materials [11,12] are under development.

In 2014, only 10%of the VIPs production were used for insulating buildings, refrigeration and transportation industry were the main users of this technology consuming 30% and 60% of the annual production of VIPs respectively [13]. The uptake of VIPs for building applications has not achieved its full potential due to their high installed cost compared with other insulation products. Presently, VIP use can only be justified in a few construction scenarios; for example, heritage and narrow city centre buildings with unique architectural features or limited usable indoor space.

The high cost of VIPs is due to the materials required for manufacturing, necessitating the development of lower cost core and envelope materials with similar or improved thermal insulation properties than those currently in use. Previous research on VIP core materials has focused mainly on Fumed Silica (FS) due to its excellent thermo-physical properties [14]. But, FS is expensive and several studies, as shown in Table 1, have proposed alternative core materials.

Published research on the materials listed in Table 1 have primarily focused on the thermo-physical performance of VIPs neglecting the potential for energy savings and the associated economic analysis. Cho et al. [21], Alam et al. [10] and Tenpierik [22] published economic analysis of VIPs but only considered domestic building applications. Kucukpinar et al. [11] demonstrated that VIP insulation reduced annual energy consumption by 25% for two mock-up rooms situated in Poland and Spain.

Mujeebu et al. [23] predicted using ECOTECT software that VIPs fixed to the roof and external walls would reduce annual energy consumption by 0.62% for a single office building and 0.79% for a multi-storey office building compared to EPS.

Clearly, the energy saving potential of VIPs is dependent on the type of building and its location (climatic and economic factors) thus further research to clarify the energy saving potential of VIPs is required. Mujeebu et al. [24] predicted the simple payback period of VIPs to be 5.3 times longer than that of EPS if installed in a multi-storey office building in Saudi Arabia. The, simple payback method used by Mujeebu et al. [24], did not consider the impact on energy savings from the deterioration of the VIP thermal performance with time, the economic value of space savings due to thinner section of VIPs and the varying time value of money. These factors significantly influence payback periods and must be considered to enable a more accurate calculation to be made of the cost effectiveness of VIPs compared to other insulation materials.

Table 1
Core materials other than FS and glass fibre reported in previous studies.

Core Material	Initial Centre of Panel Conductivity (W m^{-1} K^{-1})	References
Melamine-formaldehyde Fibre fleece	0.0023	[15]
Expanded perlite and fumed silica composite	0.0074	[16]
Open pore melamine formaldehyde foam	0.006	[17]
Granular Silica	0.014	[18]
Phenolic foam	0.005	[19]
Fumed silica/rice husk ash hybrid mixture	0.0055–0.0062	[20]

The objective of this paper is to calculate the payback period of VIPs through a discounted economic analysis whilst simultaneously accounting for the other identified factors which affect it. To investigate this, an energy saving and economic payback analysis of FS and GF VIPs installed on three representative non-domestic buildings situated in London (UK) was undertaken. A novel methodology which considered the change of VIP thermal performance over time, fuel price variability, heating system efficiency degradation with time and the economic value of space savings realised from using comparatively thinner VIPs was developed. No such information currently exists in the peer reviewed literature. Cost and density indices linked to the thermal conductivity of FS and GF VIPs were calculated. The discounted payback period for VIPs was then compared to that of conventional expanded polystyrene (EPS) insulation, to assess the cost effectiveness of each.

2. Cost and density indices for VIP types

VIPs are classified by the type of main core materials used in their manufacturing, which includes FS, expanded perlite (EP), FS and EP composites (FS+EP), glass fibre (GF) and polyurethane foam (PU) along with opacifiers, getters and desiccants. VIPs with diverse core materials have different expected life times, which determines their suitability for specific applications. The cost of VIP core materials can account for 45% of the total cost.

The price, initial (measured at the time of manufacturing) centre of panel thermal conductivity (λ) design thermal conductivity (thermal conductivity including the thermal bridging effect and ageing effect) and density of VIPs made with different core materials are shown in Table 2.

Cost and density indices for the materials shown in Table 2 were derived. The cost index, was the product of cost and initial centre of panel thermal conductivity. The density index, was the product of density and the initial centre of panel thermal conductivity. VIPs with smaller values of these indices are more desirable. Fig. 1 shows the calculated cost and density index of the materials listed in Table 2.

Calculating the cost and density index of VIPs allows the relationship between cost and thermo-physical properties to be observed. From Fig. 1, GF VIP returned the smallest cost index of 4.10 (best performance) followed by FS, FS+EP composite, PU and EP in that order. Comparing the values of density index shown in Fig. 1, GF VIPs have the lowest calculated value of 0.49, whilst EP VIPs the highest value of 3.77. FS VIP, with a comparatively lower initial thermal conductivity and density, has 2.4X and 1.5X lower cost and density indices respectively than that of FS+EP composite VIP. FS VIP had a calculated cost and density index 2.48X and 1.57X greater respectively than GF VIPs. However, GF VIPs have a significantly shorter life time, of 10–12 years, compared to the lifetime of 50–60 years expected for FS VIPs.

3. Payback period calculation

The discounted payback period is the time taken for an investment, such as the installation of VIPs, to repay the initial capital through the realised savings taking into account fuel cost savings and other accrued benefits. It is a critical factor in the choice of the most cost effective insulation and was quantified by calculating