A combined life cycle cost and energy analysis of Vacuum insulation Panels (VIPs) in building applications

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Abstract:

In this paper life cycle cost and energy analysis of a domestic and an office building that uses vacuum insulation panel (VIP) as building envelope insulation over the life span of building has been presented. Methodology used for energy and cost analysis takes into account the decrease in performance of VIP over its life time, heating efficiency over the life span of heating energy systems and fluctuating energy prices. The life cycle cost analysis show that financial payback of the VIP insulation in six storey office building in UK is between 2.5-7 years depending on the building rental value while for an average semi-detached UK house financial payback is never achieved. This demonstrates the financial viability of VIPs in non-domestic buildings located in high rental value areas.

Key words: Vacuum Insulation Panel, Cost and energy life cycle analysis, Payback period, Domestic building, Office building

1. Introduction

Vacuum Insulation Panel (VIPs) are being promoted as high thermal performance insulation material which can play a significant role in reducing energy consumption in buildings. However, VIPs are costlier compared to the conventional insulation materials. [1,2]. Their use in buildings requires a comprehensive life cycle cost and energy analysis. This paper presents combined life cycle cost and energy saving assessment of VIPs when applied in a typical domestic (3 bed semi-detached) and an office building (six storey) located in in the UK. The cost analysis calculation employed is based on the net present value method. Methodology for energy and cost analysis consider the decrease in performance of VIP over its life time, heating efficiency over the life span of heating energy systems and fluctuating energy prices [3].The life cycle cost and energy analysis of applying VIPs on two different buildings has been presented in this paper.

2. Methodology

Life cycle cost analysis of application of insulation in building considers the cost of insulation materials, installation and space heating energy savings achieved over life time of building by applying insulation in buildings. This has been achieved by evaluating the financial payback time i.e time period requires to offset the initial investment. For this purpose Net Present Value (NPV) method has been used which considers the time value of money, changing energy prices. Payback period of an investment is reached when NPV zero equals. NPV can be calculated using equation (1): [3]

$$NPV = -C_T + [C_E \times 1/(1+r)^n] + [C_S \times 1/(1+r)^n] \quad (1)$$

where

C_T is the total insulation cost (£) including manufacturing, materials and installation costs, C_E is annual energy cost saving (£),n is the number of year ,r is the annual discount rate, C_S is the annual additional rental income due to space saving (£).

$$C_E = \frac{86400 \times HDD \times \Delta L \times C_F}{H_V \times \eta (1-x)} \quad (2)$$

where

HDD is the heating degree days (°C days), C_F is the cost of fuel (£m^{-3}), H_V is the calorific value of fuel (Jm^{-3}), η is the thermal efficiency of the heating system (boiler), x is the annual rate of decrease of thermal efficiency of heating boiler, ΔL is the difference of total building transmission heat loss coefficient before and after applying insulation (WK^{-1}) which takes into account the U-value of a building element.

Thermal conductivity of a VIP degrades with its life time as the pressure inside VIP rises due to infiltration of gases and moisture through envelope and any off gassing from core material. This degradation in VIP performance should be included in calculating the U-value of any building element comprising of VIP insulation. This effect has been described in equation 3 and 4 [3].

$$U(t) = \frac{1}{R_{si} + (\sum R_e) + R_{vip}(t) + R_{sx}} \quad (3)$$

where $R_{vip}(t)$ is the time dependent thermal resistance of VIP layer in a building element and can be described as equation (4):

$$R_{vip}(t) = \frac{d_{vip}}{\lambda_{vip}(t)} \quad (4)$$

where d_{vip} is the thickness and $\lambda_{vip}(t)$ time dependent thermal conductivity of VIP.

3. Result and discussion

In this study semi-detached two storey example dwelling and a six storey office building in UK have been studied to have VIPs and EPS insulation on all opaque elements. Geometric and thermal features of both building along U-values before and after applying insulation on all buildings considered have been shown in table 1.

Parameter	Semi-detached house	Six Storey Office
Length (m)	7	60

Width (m)	7	15
Height of each storey (m)	2.5	3.7
Air infiltration rate (ach)	0.8	0.25
Wall existing U-value ($Wm^{-2}K^{-1}$)	0.45	0.44
Wall U-value after applying VIP insulation ($Wm^{-2}K^{-1}$)	0.27	0.30
Floor existing U-value ($Wm^{-2}K^{-1}$)	0.45	0.30
Floor U-value after applying VIP insulation ($Wm^{-2}K^{-1}$)	0.27	0.25
Roof existing U-value ($Wm^{-2}K^{-1}$)	0.25	0.37
Roof U-value after applying VIP insulation ($Wm^{-2}K^{-1}$)	0.19	0.18

By applying insulation space heating energy savings can amount to 78.8 MWh and 1395.2 MWh for semi-detached dwelling and six storey office building respectively over the 60 years of life span as shown in figure 1.

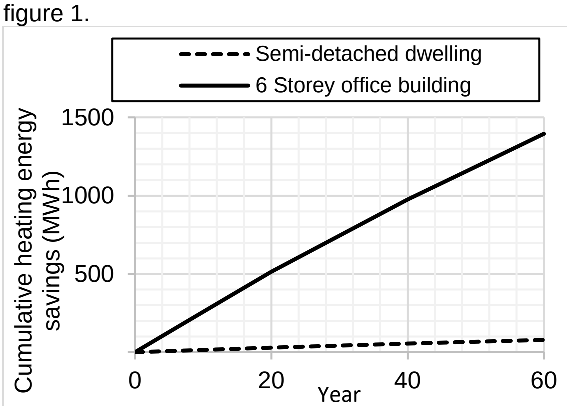

Fig 1. Space heating energy savings

Results of the payback period using methodology described in section 2 have been shown in figure 2 and 3. It has been shown in figure 2 that in case of applying VIP on a semi-detached dwelling the cost of insulation cannot be recovered over the 60 years of life time of the dwelling.

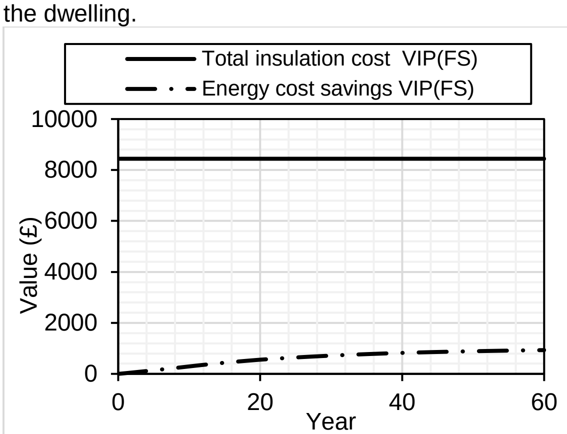

Fig 2. Cost analysis of applying VIP insulation in a semi-detached dwelling

This is due the fact that energy cost savings achieved by applying VIP insulation cannot offset the cost of the VIP insulation. Also, there are no commercial gains associated with any space saving of applying insulation in domestic buildings. However, in case of commercial buildings, economic benefit of space savings due to small thickness of VIP insulation can be used to pay off the insulation cost of VIPs. Results of cost analysis over the life of a six storey office building (60 years) has been shown in figure 3. VIP is shown to have reasonably shorter payback period of 7 years, 5 years, 3 year and 2.5 years with rental values of £400 m^{-2}, £600 m^{-2}, £800 m^{-2} and £1000 m^{-2} respectively [3].

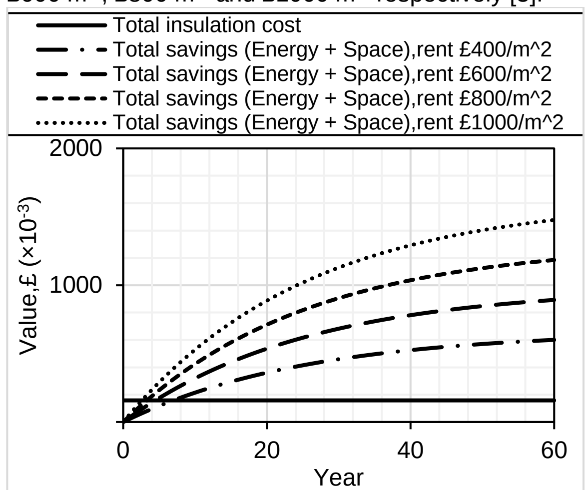

Fig 1. Cost analysis of applying VIP insulation in a six storey office building

Conclusions

Results have shown that VIP insulation can reduce the annual space heating energy demand by approximately 78.8 MWh and 1395.2 MWh respectively for semi-detached house and six storey office building. The life cycle cost analysis show that financial payback of the VIP insulation in six storey office building is between 2.5-7 years depending on the building rental value between £400-1000 per square meter and for average semi-detached house financial payback is never achieved. Life cycle cost analysis has revealed that it is not likely that at current cost, VIPs will be widely accepted in domestic building applications. However, it is economically feasible to use VIP in office buildings despite their higher initial cost which is offset by the economic space gain.

References

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