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Assessment of the economic performance of vacuum insulation panels for housing projects

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ABSTRACT

One of the key concerns for achieving a passive house is highly efficient thermal insulating materials. With this in mind, the vacuum insulation panel (VIP) was developed recently to improve the heat transmission efficiency. On the other hand, project owners or managers are often reluctant to apply VIPs to their particular housing projects because of the relatively high installation costs compared to conventional panels. Therefore, this paper evaluated the economic performance of VIPs by life cycle cost analysis (LCCA) including the energy costs during the operation phase of the house adopting the VIPs. The results showed that economic benefits can be earned from the installation of VIPs in terms of energy consumption during the operational phase of the house. LCCA for a 40 year period showed that VIP 30T and VIP 20T could provide as much as 136.923% and 88.28% more economic benefit than conventional insulation panels, respectively. These results show that the project owner or manager can choose VIPs as a thermal material for their housing projects even after considering the high installation costs.

1. Introduction

Environmental problems and energy exhaustion have become major global issues. The annual energy consumption has been increasing every year and the amount of environment pollution is accelerating. Accordingly, many countries have announced a range of policies for environment protection and energy savings along with the relevant laws. In particular, the Korean Government has announced the “GREEN HOUSE” policy and is expected to settle the passive house policy by 2017. Furthermore, environmental friendly housing and sustainable developments were established as the objective through the obligation of a zero energy building by 2025. The passive house standard for central Europe requires a building to satisfy the following criteria: (i) less than 15 kWh/m^2 per year in space heating and (ii) less than 60 kWh/m^2 year of annual primary energy consumption for space heating, hot water and building services [1]. As a result, high-efficiency thermal insulation has become one of the key techniques for achieving a passive house [2–4]. Therefore, a range of insulation materials have been developed recently. Although these insulation materials are intended to achieve ultra high thermal performance, their high production cost has led to a significant increase in construction cost [5].

As the SIP is considered a cost efficient material with good insulation performance, it has become the most widely used insulation panel for multi-family housing construction projects. On the other hand, it is susceptible to water damage, which can decrease insulation capability significantly. In addition, SIPs produce hazardous gases during a fire.

During the 1990s, VIPs were introduced into the refrigeration industry in the USA, Japan and Europe, which was followed by applications to the building industry at the beginning of the 21st century, first in Europe and now spreading to East Asia and North America [6]. VIPs consist of an evacuated core material surrounded by a highly air and moisture tight envelope containing aluminum barrier layers [6]. The internal spaces are under a vacuum of less than 1 mbar to maximize the thermal insulation performance. The thermal conductivity of existing general insulation panels is an average of 0.031–0.045 W/mK, whereas that of VIPs is s low as 0.002–0.0045 W/mK, which is 8–10 times better than general insulation panels. Consequently, VIPs can be manufactured more thinly than conventional insulation materials with the same overall thermal performance, which allows the house to have more available space. Because of these benefits, VIPs are the most actively developed insulation panel for achieving the objective of a passive house with a zero energy [6,7].

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Most studies of high efficiency insulation panels including VIPs focused mainly on the thermal insulation performance of the panels and their physical performance when installed in buildings. Simmler and Brunner [8] analyzed the long-term properties and durability of VIP panels, and suggested aging mechanisms of the panel along with the experimental results. Alam et al. [7] reviewed the thermal insulation performance of VIPs using a range of materials, such as glass fiber, foams and composites. In addition, they suggested a process for the aging of VIPs including the useful life time of VIPs and thermal bridging effect. Similarly, Choi [9] examined the insulation performance of VIPs and conventional insulation panels using a range of scientific methods, and reported the superiority of VIPs in terms of their heat performance. Bouquerel et al. [2] conducted heat transfer modeling in VIPs comprising nanoporous silicas, and they concluded result on four aspects of heat fluxes: radiative transfer, solid conduction, gaseous transfer, and envelope thermal bridge. Jelle [4] provided a potential saving from the application of VIPs in terms of growth of living area, due to reduced wall thickness. According to his research, VIPs have a thermal resistance about 5–6 times higher than traditional thermal insulation panels, i.e. more specifically that 35 cm of mineral wool corresponds thermally to 6 cm VIPs, which can reduce wall thickness finally.

Most studies focused on the insulation and physical performance of VIPs including its application method and useful life time. Nevertheless, more research highlighting the economic benefits of VIPs to the owners or managers of projects is needed.

- Consequently, this study compared the economic performance of ultra high thermal insulation materials with conventional insulation materials, which, albeit important, has been not introduced properly. Two insulation materials were selected for this research; the VIP (vacuum insulation panel), which is a highly efficient insulation panel, and SIP (Styrofoam insulation panel), which is generally adopted for housing construction projects.

The study was performed mainly in three steps. Through a literature review in step 1, the advantages and disadvantages as well as the performance of VIPs and SIPs were examined. In step 2, an economic analysis of the panels was conducted using the life cycle cost analysis (LCCA) technique, which can identify the most cost effective among several alternatives in terms of economics. To apply LCCA, this study selected a prototype house generally used in the Korean construction industry and calculated the LCC according to type of panels installed in the prototype. In addition, the cost data necessary for conducting LCCA, including the initial cost (i.e. installation cost) and operation cost (i.e. energy cost) for each panel, was collected from five panel manufacturing companies (refer to Table 1) and energy simulation techniques, respectively. In the final step, sensitivity analysis was performed to determine how the LCC results were affected by variations in the cost items, in terms of the reduction of uncertainty during the LCCA process.

Table 1
Profile of the companies.

Location	Year of foundation	Employee	Main product
Seoul, Korea	1959	2870	VIP, petro chemicals, renewable energy systems
Seoul, Korea	1947	4123	Interior materials, high functional materials, windows
Seoul, Korea	1958	4766	Building materials, paints, silicone
Busan, Korea	2012	n/a	VIP (board type, film type)
Chungnam, Korea	1979	n/a	VIP, glass fiber, silica fiber, super insulation

2. LCCA of insulation materials for housing projects

2.1. Concept of LCC

The LCC means not only the initial investment costs of a building construction but also the costs during its life time, such as operation and salvage costs. The LCC can be helpful in selecting more cost effective alternatives by considering the costs in the operation of a building, which comprises the largest portion of the LCC of building projects. Therefore, LCCA has been used widely in research into construction engineering and management. Cost items comprising LCC are categorized into the following: (i) initial costs (construction cost, fee costs, etc.); (ii) maintenance and operation costs (energy costs, maintenance costs, alteration/replacement costs, etc.); (iii) financing costs; (iv) salvage value; and (v) others (taxation elements, associated costs, etc.) [10].

To analyze the LCC, it is important to convert the projected cost items for a building project (i.e. including above items) into the equivalent costs [11]. According to Dell'sola and Kirk [10], two conversion methods can be considered according to the user's preference: (i) present worth method (PWM), which allows the conversion of all present and future costs to a single point in time; and (ii) the annualized method (AM), which is used to convert the dollars expended over a range of points in time to an equivalent cost. Both methods account for the time value of money. Hence, they are interchangeable as measures of the life cycle cost. Because future costs are discounted to a smaller value when converted to the present time, it is common practice to use the term, discounting factor, in reference to the real interest rate i [10]. In this paper, PWM was selected for the main analysis method, and Eqs. (1)–(3) were used to conduct PWM. Eq. (1) can be used to determine the present worth (P_F) of a future amount (F) discounted at real interest rate i for n periods. To quantify the impact of the real interest rate in relating dollars spent in the future to dollars spent today, the equation is presented. This formula addresses situation involving a single present sum of money of a single future sum of money, given the real interest rate and the length of time of the cash flow. For instance, if an investor hope withdrawing $197 from the bank after 10 years, earning 7% real interest, he should deposit $100 at present and allow it to remain there. Eq. (2) can be used where a present amount (P_A) at i % real interest is returned in n equal periodic instalments (A). The real interest rate means the time value of money, and can be established as the nominal rate of the increase in the value of money over time (i.e. inflation), as shown in Eq. (3) [10]. For example, if one borrows money from the bank at 8% per annum (nominal rate) and the inflation is 2%, the real interest rate is 2%.

$$P_F = F\frac{1}{(1+i)^n}, \tag{1}$$

where P_F = the present worth of a future amount, F = a future amount, i = the real interest rate, and n = the analysis period.

$$P_A = A\frac{(1+i)^n - 1}{i(1+i)^n}, \tag{2}$$

where P_A = the present value, A = n equal periodic installments.

$$i = \frac{(1+j_1)}{(1+j_2)} - 1 \tag{3}$$

where j_1 = nominal rate of increase, and j_2 = the inflation rate.