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Use of Vacuum Insulation Panel in Building Envelope Construction: Advantages and Challenges

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ABSTRACT

In Canada, and elsewhere in the world, highly insulated building envelopes are being seen as a potential solution to bring down energy demand for space heating and cooling requirement of built environment. Quite naturally, this has intensified the search for high performance thermal insulation in an unprecedented manner. One of the most promising thermal insulation that can make building envelopes, both new construction and renovation, highly energy efficient is vacuum insulation panel (VIP). Furthermore, use of VIP can generate more living space using less material. The thermal conductivity of VIP is less than one tenth of the same for traditional thermal insulations used in building envelope construction industry. In terms of thermal performance, as indicated by R-value per inch, VIP is undoubtedly the best available thermal insulation. However, for a number of real or perceived reasons, both economic and technical, use of VIP in building construction industry is a rare example at this moment.

This paper will outline the construction and basic physics of vacuum insulation technology, and economic and technical challenges which are keeping VIP away from the building envelope construction industry. At the same time, ongoing activities in Canada and around the world to bring VIP much closer to building construction industry will also be highlighted.

KEYWORDS

High Performance Thermal Insulation; Vacuum Insulation Panel (VIP); Building Envelope

INTRODUCTION

Climate change due to global warming is undoubtedly the most serious environmental threat facing the world today. As a cold northern country, Canada will be one of the most seriously affected countries in the world. Continuous increase of energy consumption by nations around the world (*Statistical Review of World Energy 2010, http://www.bp.com*) and more specifically by the industrially developed parts of the world is believed to be one of the primary concerns that needs to be checked and reversed, if possible, to avoid impending environmental disaster. Hence, reduction of energy consumption in every aspect of our daily life is considered to be the key to tackling the issues related to global warming and its adverse effects on the environment. Buildings consume up to 40% of our total national energy requirement (*Natural Resources Canada, 2005; Pérez-Lombard et al., 2008*) and thermal insulation is a key component that determines the energy efficiency of the built environment.

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Considering these facts, at its July 2008 meeting, the Council of the Federation, which is comprised of Canada's 13 Premiers, issued a statement requesting an energy efficiency improvement of 25% over the levels set by the 1997 Model National Energy Code for Buildings (*MNECB 1997*). As a result, an increased requirement of thermal insulation in buildings across Canada has been mandated in proposed technical changes for the revised National Energy Code for Buildings (NECB), scheduled for publication in 2011 (see *http://www.nationalcodes.ca*). In principle, this new development offers an opportunity for application of innovative or nonconventional high performance thermal insulation materials in existing and new building envelope construction.

One of the most promising types of high performance thermal insulation currently being considered for the building envelope construction by the researchers and practitioners around the world is the Vacuum Insulation Panel or VIP. VIPs can be more than 10 times thermally efficient than conventional thermal insulation materials (Figure 1). Based on the information available to date (*Simmler et al. 2005; Binz et al 2005; Mukhopadhyaya, 2006; Mukhopadhyaya et al. 2008; , Mukhopadhyaya et al. 2009a, 2009b; Mukhopadhyaya, 2010a, 2010b*), it appears that use of VIPs is an attractive technological option for substantially increasing the energy efficiency of built environment. However, in Canada and elsewhere in the world, VIPs are rarely used for building envelope construction or selectively used if space for traditional insulation is too expensive or not available (*Fricke et al. 2008*). Primary reasons behind the lack of real life applications are cost, absence of consumer confidence on the constructability and long-term performance of VIPs. Researchers and manufactures across the world are focusing their efforts at this moment to address these issues and integrate VIPs in the building envelope construction.

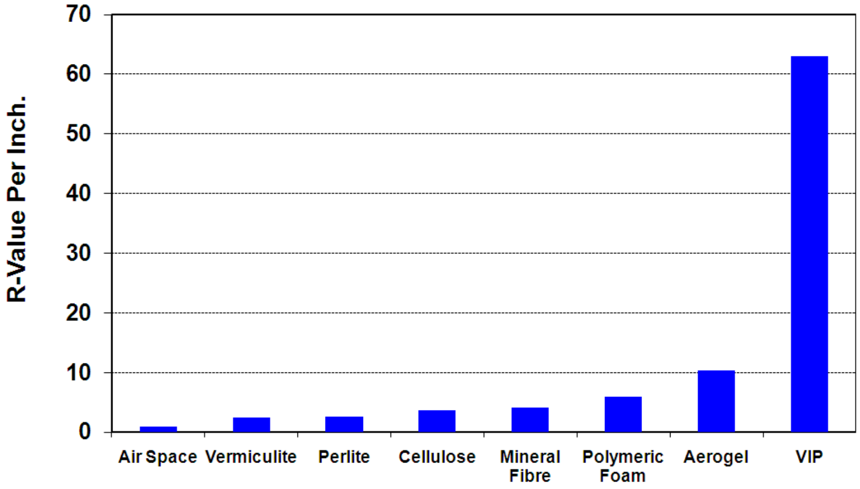

FIGURE 1: R-VALUE OF VACUUM INSULATION PANEL (VIP) COMPARED TO THOSE OF OTHER INSULATING MATERIALS

WHAT IS VIP? IS IT REALLY CREDIBLE?

It may raise a few eyebrows when one hears about the high R-value of vacuum insulation panel (about R60/inch or higher). Considering the fact that the most efficient foam insulation is characterized by about R6/inch and the most efficient aerogel based thermal insulation has about R10/inch thermal resistance, the possible application of VIP in building envelope construction could certainly be a major step forward and probably the most exciting development in the history of thermal insulation in the construction industry. Hence, it is important for professionals and engineers associated with building envelope designers to understand the fundamentals of heat transfer mechanisms in thermal insulation and more specifically the fundamental physics that makes very high R-value of VIP a credible reality.

Heat Transfer Mechanisms in Thermal Insulation

There are three basic heat transfer mechanisms that control the insulating capacity of conventional thermal insulation materials (Figure 2) and these mechanisms are: (1) Conduction (solid conduction and air conduction), (2) Convection, and (3) Radiation. It is to be noted here that air conduction component of heat transfer happens in still air due to random movement of air particles and collisions among them. The solid conduction and radiation components are functionally related to the density of the insulation materials, and no air movement through air space inside the insulation can eliminate the convective heat flow phenomenon almost entirely. However, the air conduction is an independent component and offers a significant opportunity to develop high-performance thermal insulation materials by effectively reducing this component.

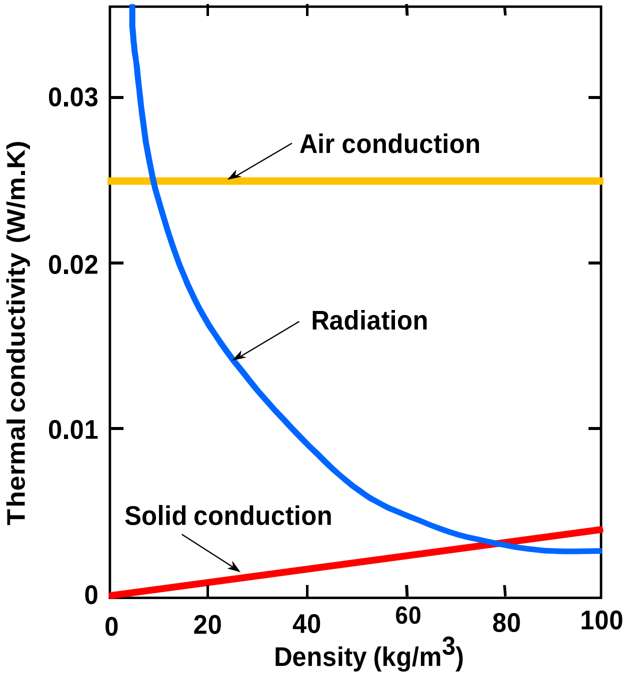

FIGURE 2: HEAT TRANSFER MECHANISMS THROUGH INSULATION MATERIALS

Reducing Air Conduction in Thermal Insulation

The reduction of thermal conduction through air (i.e. air conduction) can be done in three different ways:
(1) Replacing the air with a gas that has thermal conductivity less than that of air,
(2) Reducing the pore size in insulation materials to nano-scale, and
(3) Reducing the air pressure inside the insulation material.

The first approach is the key for the development of closed-cell foam insulation where the gaseous blowing agents having thermal conductivity lower than air replace the air inside the closed cells (*Mukhopadhyaya et al. 2009*).

The increase of thermal resistance with the decrease of effective pore size of the insulation material is a well known physical phenomenon particularly for nano-pore structured insulation materials (*Kistler, 1935*). Hence, the second approach is the basis for the higher thermal resistance value of aerogel board or blanket insulation (*Simmler et al. 2005*).

The third approach of reducing the air pressure inside the insulation material to increase the thermal resistance is a relatively new area of applied insulation research though the fundamental concept had been known to the researchers for a long time (*Verschoor et al. 1952*). In this approach the air pressure inside the open porous structure of an insulating material is made very close to zero (i.e. very few air particles are left to transfer heat through conduction).

Construction of VIP

A VIP consists of an open-pored core material able to withstand the external load caused by atmospheric pressure and has three major components (Figure 3): (1) core material, (2) gas barrier, and (3) getter/desiccant.

> Core Material: The core material is open-pored (and therefore evacuation-capable) and needs to be able to withstand the external load caused by atmospheric pressure. Ideal core materials should have an open cell structure, very small pore diameter, and resistance to compression due to atmospheric pressure. Nano-structured materials have been found to require the least magnitude of vacuum that has to be maintained.
>
> Gas Barrier: The gas barrier/facer foil provides the air and vapour-tight enclosure for the core material. The long-term performance of the VIPs is very much dependent on the performance of the gas barrier of facer foil.
>
> Getter/Desiccant: A getter/desiccant is added inside the core material to adsorb residual or permeating atmospheric gases or water vapour in the VIP enclosure. The addition of getter/desiccant increases performance and longevity.

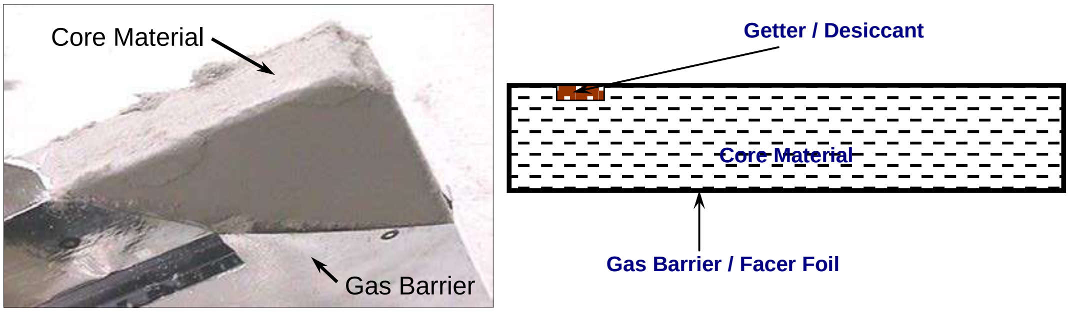

FIGURE 3: (A) VACUUM INSULATION PANEL (LEFT), (B) SCHEMATIC CONSTRUCTION OF VACUUM INSULATION PANEL (RIGHT)

APPLICATION OF VIP – ADVANTAGES AND CHALLENGES

Vacuum technology and its ability to thermally insulate the environment are well known to modern scientists and engineers for more than a century. While most Canadians use vacuum technology based thermos flask (brainchild of British scientist James Dewar, 1892) to keep their hot drinks warm throughout the year, the vacuum technology based vacuum insulation panel (VIP) is still waiting on the sideline to be adapted effectively in the energy efficient sustainable built environment construction. VIPs offers a number of advantages and challenges for its application in the construction industry.

Advantages

(1) VIPs offer higher thermal resistivity than any known thermal insulation used in the construction industry (Figure 1).
(2) Use of VIPs in building envelope construction results in reduced thickness of building envelopes/ components, increased indoor space and optimization of land use.
(3) At the end of service life, in most cases, re-vacuuming of VIP can be done to recycle the constitutive materials.

Challenges

(1) VIPs are more expensive than traditional thermal insulations used for building envelope construction in Canada. For the next five to ten years, it is expected that VIPs will remain more expensive than conventional insulating materials with the same R-value. For conventional insulation this cost advantage is partly due to 'Economies of Scale' (i.e. reduced cost as the scale of output is increased). With time, it is expected the cost of VIPs will decrease and become more economically attractive as a result of improved research efforts, automation of manufacturing processes and increased volume of production.
(2) Aging of VIPs due to slow permeation of gases/water vapour through gas barrier, and/or off gassing of core material can be very slow but is an undeniable reality. Hence, it is very important for designers and engineers to know the long-term thermal performance of VIPs. Researchers across the world are trying to address this issue through laboratory investigation, numerical modeling and field investigation (*Pool 2009; Brunner and Simmler, 2008; Caps et al, 2008, Schwab et al. 2005; Simmler and Brunner, 2005, Simmler et al., 2005; Binz et al. 2005, Mukhopadhyaya et al 2005*). It is hoped that eventually a standard test method will be developed to predict the long-term thermal performance of VIP.
(3) Durability or more specifically the handling of VIP on the construction site is a significant concern considering the fact that any damage in the vacuum system (even a small pinhole) will destroy the thermal insulating capacity of VIP.
(4) In general VIP has a highly conductive gas barrier/foil facer and VIPs are currently available in sizes that are much smaller than thermal traditional insulation boards (e.g. rigid foam or high density mineral fiberboard) and thermal bridge effects at edges in a VIP insulated system is a justifiable technical concern (Figure 4).

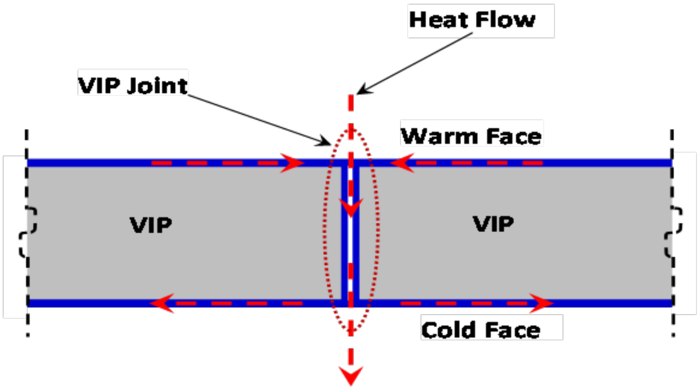

FIGURE 4: SCHEMATIC OF THERMAL BRIDGE IN VIP INSULATED SYSTEM

ADDRESSING CHALLENGES – TECHNICAL STATUS UPDATE

Cost of VIP is probably the most important barrier for mass applications of VIP in the construction industry. As mentioned earlier, 'economies of scale' and productivity play very important roles on this issue. However, it is also known that cost of core materials (precipitated or fumed silica, nanogel or silica aerogel, etc.) commonly used for VIP construction has significant contribution in determining the overall cost of VIP (*Fricke 2009*). Core materials currently being used are usually nanoporus in structure and not always traditional thermal insulation materials but they are least sensitive against pressure increase (Figure 5). Hence, nanoporous core materials generate optimum thermal and service life for VIP. Efforts are on to find out alternative insulating core materials that will be inexpensive and nanoporus. Recent study at the National Research Council – Institute for Research in Construction indicate that fiber-powder composites made with traditional fibrous insulation materials and volcanic powder can be alternative core materials for VIP (Figure 6). Even the possibility of using bio-fiber based core materials for VIP construction are being considered by the researchers from NRC-IRC (*Mukhopadhyaya et al. 2009*) and elsewhere (*MIT*, *2009*). These research advancements when successfully integrated in VIP manufacturing process can have the potential to produce cost-effective and sustainable VIPs.

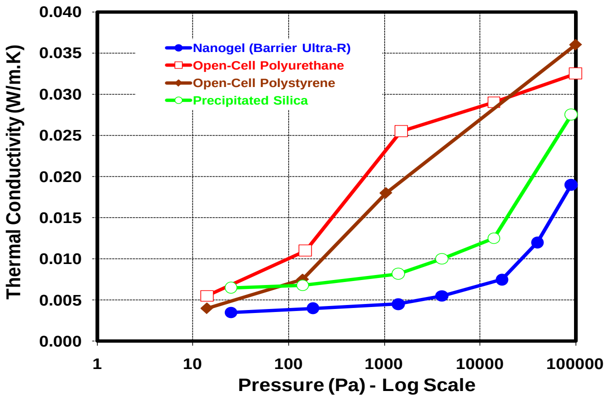

FIGURE 5: CHANGE OF THERMAL CONDUCTIVITY OF CORE MATERIAL WITH THE PORE PRESSURE (SOURCE HTTP://WWW.GLACIERBAY.COM/VACPANELINFO.ASP)

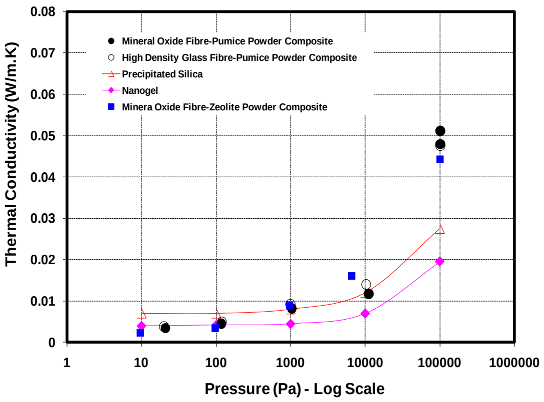

FIGURE 6: THERMAL PROPERTIES OF ALTERNATIVE FIBER-POWDER COMPOSITE CORE MATERIALS.

Aging or long-term performance of VIP is a real concern and a very complex issue (*Simmler 2005*). There are a number of factors that govern aging characteristics of VIP and they are: (1) gas and vapour resistance properties of barrier materials, (2) thermal sensitiveness of core materials against pressure increase, (3) integrity of seam joints, (4) effectiveness of getter/desiccant etc. At this moment there exists no universally accepted practical method to predict the long-term performance or thermal resistance of VIP that can be conducted in the laboratory in a short duration and compare various available products. However, researchers have proposed numerical models to predict the long-term service life of VIP. Efforts are also on across the world to monitor the long-term performance of VIP through field applications. Canadian researchers based at NRC-IRC have been also active in this initiative (*Kumaran et al. 2004; Mukhopadhyaya et al. 2005*). Thermal performances of a set of VIPs, procured from a single source in 2003 (*Mukhopadhyaya et al. 2005*), are being monitored at regular intervals and percentage changes of R-values with the time are shown in Figure 7. These VIPs were stored primarily in ambient laboratory conditions (RH ≈ 50% and temperature ≈ 20°C) and only 4 panels were exposed initially for 60 days to 90% RH and 32°C temperature. More investigations will be carried out on these panels that will aid towards the development of an integrated test procedure that can predict aging characteristics of VIPs.

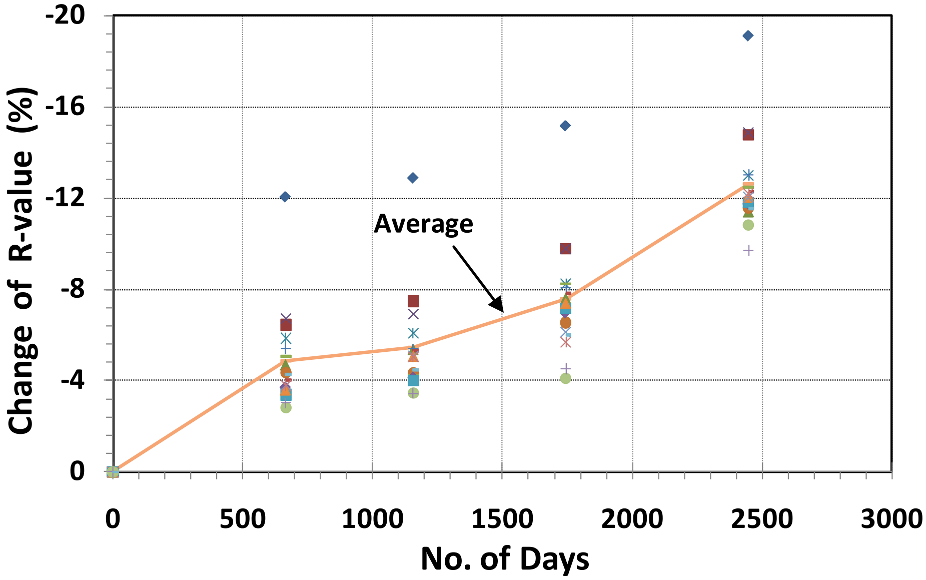

FIGURE 7: PERCENTAGE CHANGE OF VIP R-VALUE (DATA FROM NRC-IRC)

Durability issues related to handing of VIP on the construction site and its interaction with other components of building envelopes are of major concern considering the fact that even a small pinhole will destroy the thermal insulating capacity of VIP. Various design techniques have been developed by architects and engineers (*Binz et al. 2005*) to protect VIPs from any extreme mechanical impact and manufactures have also come up with higher impact resistance barrier/facer foil materials and better sealing techniques for seams/joints. These developments are all positive steps to address the durability concerns related to field performance of VIP.

Thermal bridges at joints can significantly reduce thermal effectiveness of VIP with highly conductive barrier (Figure 4). However, there are various ways to reduce heat loss through thermal bridges. Use of larger panels, overlapping of panels, use of multiple insulation layers, and filling gaps at edges with airflow resistant insulating materials are all proven methods that can reduce heat loss through thermal bridges significantly and effectiveness of these methods have been demonstrated through a series of field investigation projects conducted under IEA/ECBCS Annex 39 initiative (*Binz et al. 2005; Thorsell, 2006*). Researchers across the world are also using numerical modeling tool and conducting laboratory investigation to come up with various VIP configurations that will achieve optimum thermal performance in building envelope applications (*Grynning et al. 2010*).

CONCLUSIONS

The information and discussion presented in this paper lead to following observations:

(1) Construction of vacuum insulation panel (VIP) is based on sound principles of basic physics of heat transfer and it is realistic to expect 5-10 times higher R-value/inch from VIP than traditional thermal insulation materials used in building envelope construction.

(2) Use of VIP in energy efficient building envelope construction is a real possibility but rare at this moment.

(3) However, application of VIP as highly efficient thermal insulation in building envelope construction is advantageous (e.g. higher thermal resistance, reduced thickness of building components, recyclable etc.) and challenging (cost, aging, durability, thermal bridge etc.) at the same time.

(4) Researchers across the world, including researchers at the National Research Council Canada – Institute for Research in Construction (NRC-IRC), are working to exploit the advantages to its maximum and addressing the challenges to optimum at the same time.

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