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Mukhopadhyaya, Phalguni; Molleti, Sudhakar; van Reenen, David

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Vacuum Insulation Panel (VIP): An Historic Opportunity for the Building Construction Industry

Phalguni Mukhopadhyaya, Sudhakar Molleti & David van Reenen
National Research Council Canada, Ottawa, Ontario, Canada
Contact address: phalguni.mukhopadhyaya@nrc-cnrc.gc.ca; +1 613 993-9600

What is a Vacuum Insulation Panel (VIP)?

The construction of VIPs is based on the principle of vacuum technology, invented by British scientist James Dewar in 1892. VIPs are made with open porous core materials enclosed in an impermeable gas barrier (Figure 1) and have three major components: 1) open porous core material that imparts mechanical strength and thermal insulating capacity 2) gas barrier/facer foil that provides the air and vapor-tight enclosure for the core material, and 3) getter and desiccant inside the core material that help extend the service life by adsorbing residual or permeating atmospheric gases or water vapor in the barrier enclosure.

Background and Significance

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 requirements, and thermal insulation is a key component that determines the energy efficiency of the built environment. Recent upgrades of energy codes (*NECB 2011, IECC 2012, ASHRAE 2013*) have recommended higher levels of insulation in building envelopes. However, addition of more traditional insulation in new or existing roofs and walls is impractical for various reasons such as very thick layers of insulation increasing the thickness of the building envelopes beyond current practices, loss of usable space, etc. (*Mukhopadhyaya et al. 2011*). These issues have provided a fresh impetus to the search for high-performance thermal insulation for building envelope construction.

Among various nonconventional insulations being introduced to the construction industry as the next-generation thermal insulation, vacuum insulation panels (VIPs) appear to be one of the most promising insulation materials with the highest thermal insulating capacity (up to ten times or more thermally efficient than conventional thermal insulation materials; see *Figure 2*). In North America and elsewhere in the world, the potential to apply VIP in the building envelope construction is enormous, and VIP can play a major role in existing and new buildings to meet the higher insulation requirements of the newly introduced energy codes.

However, the acceptance of VIP in the construction industry is critically dependent on cost, long-term performance, and availability of best-practice guidelines.

The expensive core material (e.g., precipitated silica or fumed silica) is one of the main reasons behind the higher cost of VIPs that offer a satisfactory long-term service life in building envelope applications. To overcome this cost barrier to mass application of VIPs in the building industry, researchers at the National Research Council Canada – Construction Portfolio (NRC Construction) have developed a low-cost, fiber-powder composite core material for VIP (*Mukhopadhyaya et al., 2008, 2014*). Similar ongoing efforts have been reported around the

world to introduce glass fiber and other innovative core materials for VIP (Dia et al., 2014; Alam et al., 2014).

The long-term performance of VIP is governed by two distinct phenomena (Figure 3): 1) aging, and 2) durability. Aging is considered to be a natural phenomenon for VIP, and unknowns are the nature and rate of aging. On the other hand, durability is an issue that is related to manufacturing, quality control, handling, and maintenance of VIP.

Finally, development of best-practice guidelines is one of the most important steps for creating broader market access for VIPs in the building construction industry. Several real-life examples of VIP insulated building envelope systems are provided in literature (Binz et al., 2005; Mukhopadhyaya, 2011; Brunner & Ghazi Wakili, 2013); however, development of technical best practice guidelines is still a job in progress at best.

The following paragraphs will introduce readers to the construction of VIPs, heat transfer fundamentals related to the performance of VIPs, advantages and challenges, and observations from two real-life field constructions. The authors hope that dissemination of the technology behind VIPs and their performance record will stimulate the construction industry in general and the roofing community in particular to exploit the historic opportunity arising from the newly introduced building energy codes and to integrate VIPs in the mass construction market of North America and rest of the world.

Fundamentals of Higher R-Value of VIP

A few eyebrows may be raised over the high R-value of VIPs, which can reach R-60/inch or higher. Considering the fact that the most efficient foam insulation is about R-6/inch, and the most efficient aerogel-based thermal insulation has about R-10/inch thermal resistance, it is important to understand the fundamentals of heat transfer mechanisms that make the much higher R-value of VIP a credible reality.

There are three basic heat transfer mechanisms that control the insulating capacity of conventional thermal insulation materials. These are: 1) conduction (solid conduction and air conduction), 2) convection, and 3) radiation. It should be noted that air conduction 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 (Figure 4), and preventing air movement through air space inside the insulation can eliminate the convective heat flow phenomenon almost entirely. However, air conduction is an independent component and offers a significant opportunity to develop high-performance thermal insulation materials by effectively reducing this component.

Reducing Air Conduction in Thermal Insulation

The reduction of thermal conduction through air (i.e., air conduction) can be done in three ways:

- 1) Replacing the air with a gas that has a 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 above is the key for development of closed-cell foam insulation where gaseous blowing agents with thermal conductivity lower than air replace the air inside the closed cells.

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 (e.g., aerogel).

In the third approach—reducing the air pressure inside the insulation material to increase the thermal resistance—the air pressure inside the open porous structure of an insulating material is brought very close to zero (*Figure 4*), and the resulting insulation product is a VIP.

Application of VIPs in Building Envelope Construction: Advantages and Challenges

VIPs offers a number of advantages and challenges for application in the construction industry.

Advantages

- (1) Higher thermal resistivity than any known thermal insulation used in the construction industry (*Figure 1*).
- (2) Reduced thickness of building envelopes/components, providing increased indoor space and optimization of land use.
- (3) Constitutive materials may be recycled after the service life.

Challenges

- 1) More expensive than traditional thermal insulations used for building envelope construction, but becoming 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 vapor 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.
- 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 traditional thermal insulation boards (e.g., rigid foam or high-density mineral fiberboard). Thermal bridge effect at edges in a VIP system is a justifiable technical concern.
- 5) As VIPs cannot be drilled or cut on the construction site, unlike traditional insulation materials, special design considerations must be developed to deal with penetrations through roofs and walls. VIPs with predetermined holes are available at a higher price.

However, significant progress has been made to address these issues globally, and initiatives are in progress to mitigate the challenges associated with the application of VIPs in the construction industry (*Binz et al, 2005; Mukhopadhyaya, 2011; Brunner & Ghazi Wakili, 2013*).

EXAMPLES OF FIELD APPLICATIONS

VIPs in wall (Ottawa, Ontario)

VIPs were installed in a purpose-built test hut (*Figure 5*) at the NRC¹ Construction campus in Ottawa. The indoor environment of the test hut was controlled, and exterior weather data were monitored. The VIPs were installed on east-facing wall of the test hut. In the test area of the existing wall, three 1150 mm x 750 mm x 12 mm (45 inch x 30 inch x 0.5 inch) VIPs were installed in an edge-overlapped formation (*Figure 6*). The test area was equipped with temperature, heat flux, and humidity sensors to gather both external and internal data (*Figure 6*). The performance of VIPs installed in the test hut wall has been monitored since the winter of 2009-2010. The recorded thermal performance of VIP under dynamic temperature conditions is shown as a function of time in *Figure 7*. In general, there appears to be no evident significant thermal performance degradation of VIPs during four years of field exposure. The monitoring of thermal performance of VIPs installed in the test hut will continue.

Performance of VIPs on a Roof (Ottawa, Ontario)

The in-service low-slope roof was a 15-year-old built-up system on an NRC office building (*Figure 8*) undergoing reroofing with the new-generation rigid roofing system (*Molleti et al., 2011*). The cross-sectional layout of this new roof comprised a concrete deck, vapor barrier, 75 mm (3 inch) rigid polyisocyanurate (also known as polyiso or iso) insulation, 6 mm (0.25 inch) asphalt cover board, modified-bituminous membrane base sheet, and a modified-bituminous membrane cap sheet (*Figure 9*). This was a mod-bit roofing system, and all the roofing components are integrated with solvent-based roofing adhesive. A 1.2 m x 2.4 m (48 inch x 96 inch) iso-VIP composite was installed, replacing one of the 75 mm (3 inch) iso boards. The 75 mm thick, adhesive-bonded composite VIP comprised of two layers of 12 mm (0.5 inch) thick 450 mm x 560 mm (18 inch x 22 inch) VIP, staggered to minimize the effects of thermal bridging, sandwiched between two layers of 25 mm (1 inch) thick iso board on the top and bottom.

Figure 10 shows the performance of VIP in a week of February 2011, 2012, and 2013, respectively. These data clearly indicate that thermal performance of VIP has not gone down in any significant way over the three years of real-life field exposure in a roof construction.

Summary

The information and discussion presented in this paper can be summarized as follows:

- Based on sound principles of the basic physics of heat transfer, it is realistic to expect five to ten times higher R-value/inch from VIP than traditional thermal insulation materials used in building envelope construction.
- Use of VIP in energy-efficient building envelope construction is a real possibility and an attractive proposition for the roofing industry.
- Recent upgrades of building energy codes in North America offer an historic opportunity for the construction industry to integrate VIP in building envelope construction.

¹ National Research Council, Ottawa, ON, Canada

- Available field performance evaluation results provide encouraging indicators for the long-term thermal performance of VIP in both roof and wall constructions.
- 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.
- Researchers across the world, including those from the National Research Council Canada, are working with construction industry stakeholders to exploit the advantages and addressing the challenges.

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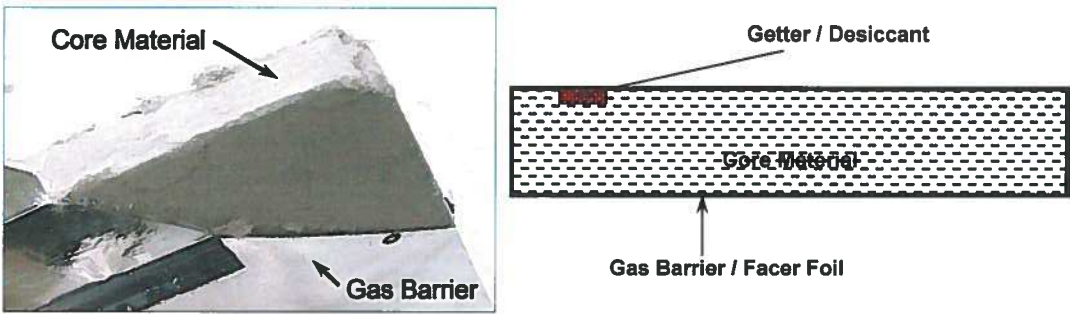


Figure 1: Vacuum insulation panel (left) and schematic construction of VIP (right)

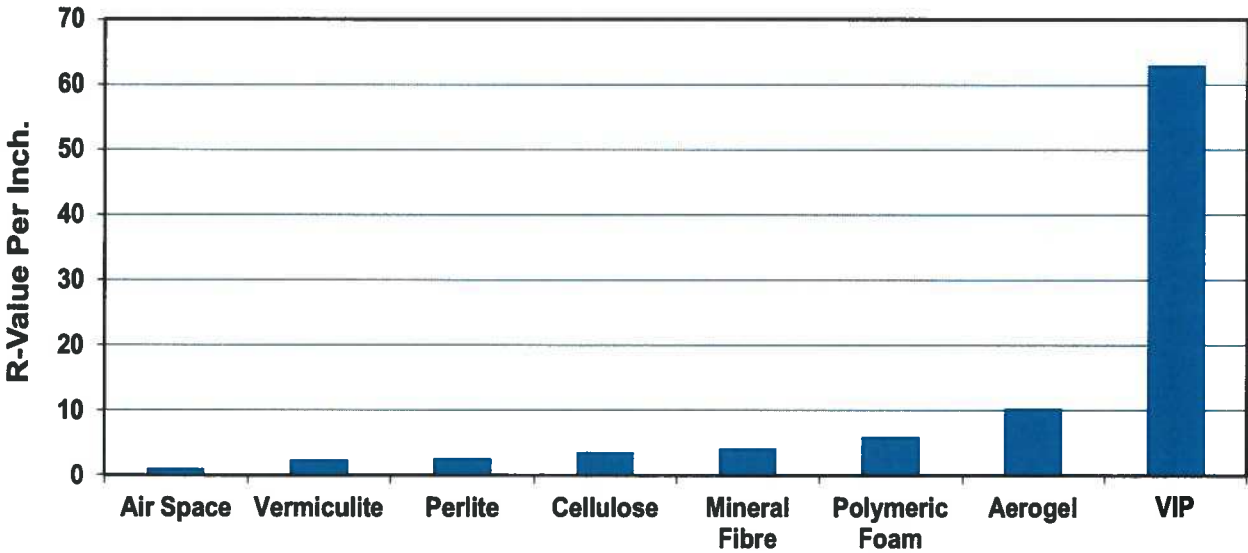


Figure 2: R-value of VIP compared with other insulation materials

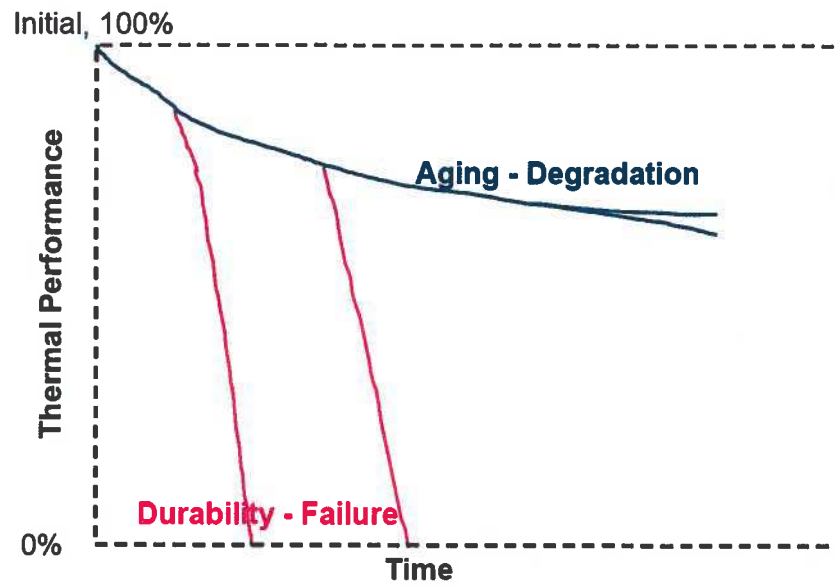


Figure 3: Aging and degradation of VIP

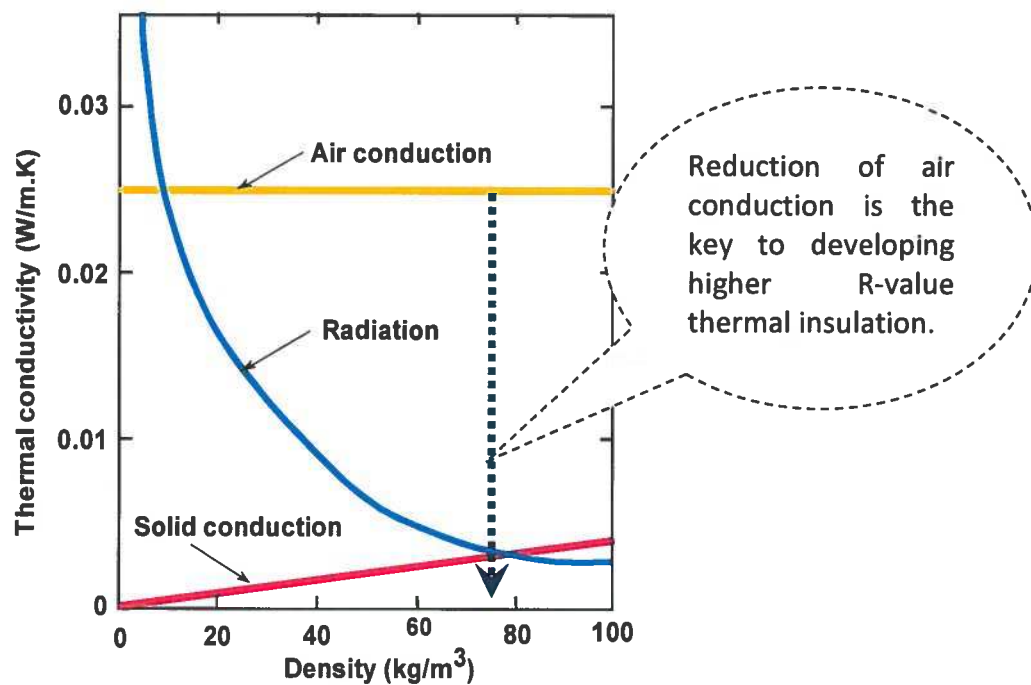


Figure 4: Heat transfer mechanisms through insulation materials



Figure 5: NRC test hut, Ottawa, Ontario, Canada

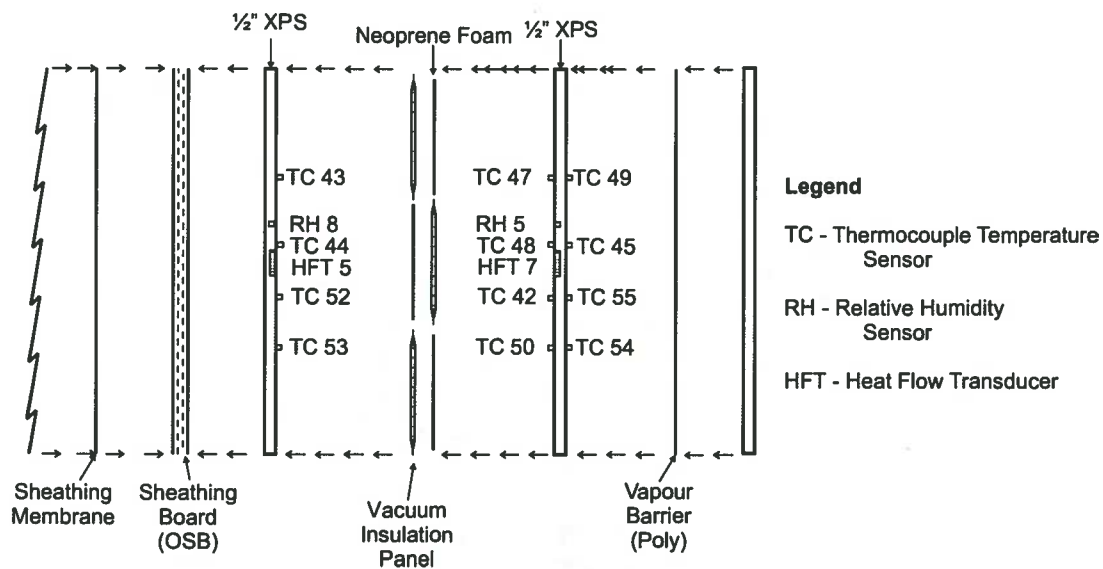


Figure 6: Construction details - VIPs in wall (Ottawa, Ontario, Canada)

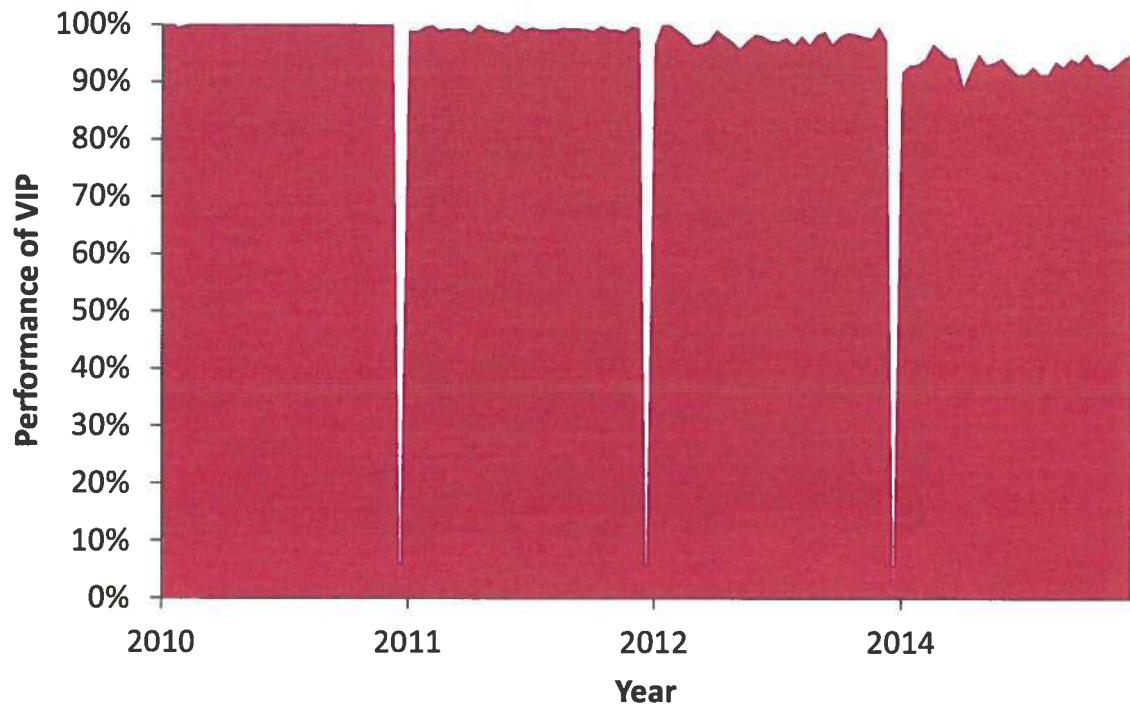


Figure 7: Thermal performance of VIP during a typical winter month in 2010, 2011, 2012 and 2014



Figure 8: Re-roofed NRC office building

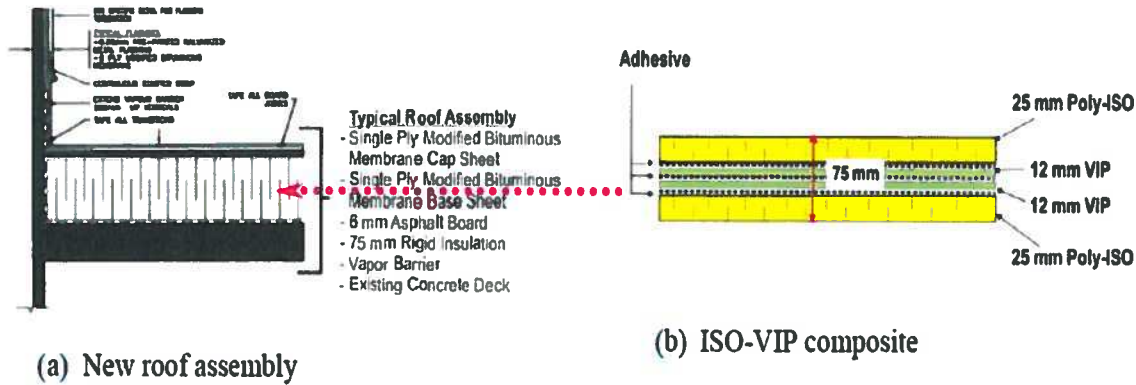


Figure 9: Construction details - VIPs in roof (Ottawa, Ontario, Canada)

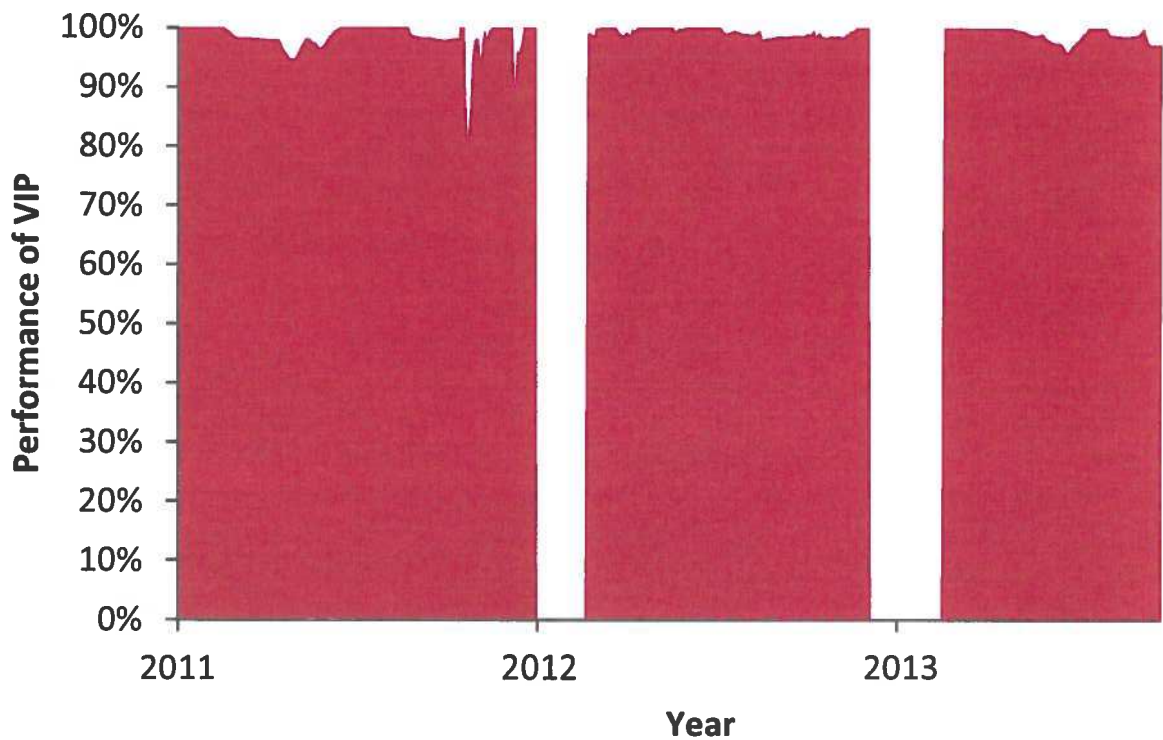


Figure 10: Thermal performance of VIP during a typical winter week in 2011, 2012 and 2013