

**COOPERATIVE RESEARCH WITH INDUSTRY IN
SUPPORT OF THE PATH GOALS**

**Accelerating the Adoption of Vacuum Insulation
Technology in Home Construction, Renovation,
and Remodeling**

PROJECT FINAL REPORT

COOPERATIVE AGREEMENT NO. H-21173CA

Prepared for
**U.S. Department of Housing
and Urban Development
Office of Policy Development and
Research**

December 23, 2002

Prepared by
**NAHB Research Center, Inc.
400 Prince George's Boulevard
Upper Marlboro, MD 20774-8731**

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Preface

New technologies developed for use in applications unrelated to the residential sector can have the potential to significantly enhance the performance of our housing. While they can eventually find their way into residential construction and remodeling, the lag to adoption and widespread use can be appreciable.

Vacuum Insulation is a technology with the potential to improve the thermal performance of housing. A Vacuum Insulated Panel consists of a core material sealed in an evacuated envelope of some impermeable material. It can yield an insulation value approximately six times that of fiberglass batts. This technology is currently being used in applications outside the home building industry.

In response to the opportunity for gains in residential thermal performance, the U.S. Department of Housing and Urban Development commissioned a program aimed at accelerating the development of Vacuum Insulated Panel products for home construction, renovation, and remodeling. The effort undertaken represents the first attempt under the PATH program to develop a residential product based on technology from non-residential sectors.

This document, *Accelerating the Adoption of Vacuum Insulation Technology in Home Construction, Renovation, and Remodeling*, reports on the progress made toward developing applications that take advantage of the technology. It recounts the identification of alternative products, discusses market potential and design development, and describes the obstacles encountered during the process. It also makes suggestions for future work.

We believe that this report can help guide future efforts aimed at developing Vacuum Insulated Panel products for U.S. homes that provide increased thermal performance and energy savings.

Acknowledgements

This report was prepared by the NAHB Research Center, Inc. under funding from the U.S. Department of Housing and Urban Development. Special appreciation is extended to William Freeborne of HUD for his helpful guidance during the project. We also gratefully acknowledge The DOW Chemical Company for its role in this project. Special thanks go to the DOW INSTILL Vacuum Insulation Core staff. Their participation, assistance, and technical input were indispensable. They include: Slava Grinshpun, Bob Henson, Bruce Malone, Peter Pendergast, Bob Russell, and Kevin Weir. Finally, we wish to acknowledge the following companies for providing valuable information and advice:

- ADO Products
- American Stairways, Inc.
- Nanticoke Homes, Inc.
- Rintal International
- VacuPanel, Inc.
- Wacker-Chemie GmbH

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BACKGROUND

This document reports on research into speeding the adoption of Vacuum Insulated Panel (VIP) applications for the residential sector conducted under a cooperative agreement involving the Partnership for Advancing Technology in Housing (PATH), the Department of Housing and Urban Development (HUD), the NAHB Research Center, Inc., and the DOW Chemical Company (DOW).

The VIP is an advanced insulation product that combines a high R-value¹ with a relatively thin profile. It consists of a special core material enclosed in an evacuated airtight envelope. The envelope is constructed of an air-impermeable thin film such as metal foil or metalized film and serves as a barrier to gas and moisture infiltration. A panel of core material is inserted into the envelope that is then evacuated to a pre-selected vacuum level and sealed. This process can produce a product with a per-inch-of-thickness insulation value that is approximately six times that of fiberglass batt insulation.

The research was conducted between April 28, 1999 and May 31, 2002. The project consisted of two parts. Part One entailed the identification and assessment of a wide selection of potential applications. It concluded with the selection of two applications to be the subject of further work. Part Two focused on the development of alternative design concepts for the two applications, investigation of regulatory issues, and identification and contact with potential manufacturers.

¹ R-value (thermal resistance value) is a property of a material or composite that describes its resistance to heat flow.

PART ONE

I. INTRODUCTION

Until recently, the cost of manufacturing VIPs has limited their use in almost all sectors of industry. The core materials have consisted of some substance such as rigid, open-cell polyurethane foam, silica-based powder, or fiberglass. DOW has been developing a core material intended to provide a less costly option for fabricating VIPs with extremely high insulating capabilities. The trade name of the material is INSTILL² Vacuum Insulation Core.

INSTILL Core material is an extruded, open-celled polystyrene. Tests conducted by the National Institute of Standards and Technology (NIST) and DOW indicate that a one-inch VIP produces the same R-value as six inches of glass-fiber insulation. A typical one-inch thick VIP made with INSTILL Core has an R-value of 25-30, depending on panel size and product grade.

VIPs containing the INSTILL Core are currently being successfully produced to meet the needs of several applications. DOW has developed working relationships with manufacturers to include VIPs in:

- Refrigerators and Freezers
- Insulated Shipping Containers
- Refrigerated Trucks
- Cold Storage Units and Industrial Refrigeration
- Marine and Recreational Vehicle Refrigeration
- Vending Machines.

This document also reports briefly on a VIP that makes use of a silica-based core. It is produced by Wacker-Chemie GmbH (Wacker), a German chemical firm, and may be available shortly in the United States.

² Trademark of The Dow Chemical Company.

II. VACUUM INSULATED PANELS

Conventional insulation systems, such as fiberglass batting, cellulose, and foam panels, reduce heat transfer by trapping gases. Since a VIP is essentially evacuated core material vacuum-sealed in a thin barrier envelope, few gas molecules are present to transfer heat.

A photograph of a VIP made with INSTILL Core and a cross-sectional mockup of the panel are presented in Figures 1 and 2. Figure 2 depicts the components typically found in a VIP – the core material, the barrier film, and desiccants or "getters". Desiccants and getters are components inserted into the VIP to remove moisture and gases to preserve the vacuum.

Figure 1

Finished VIP

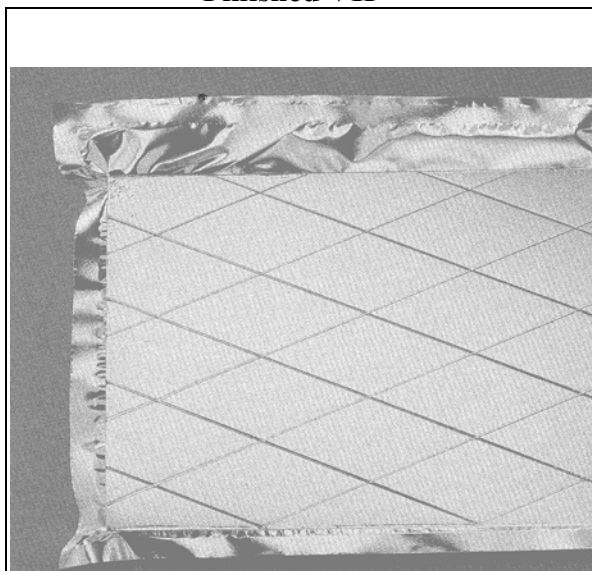
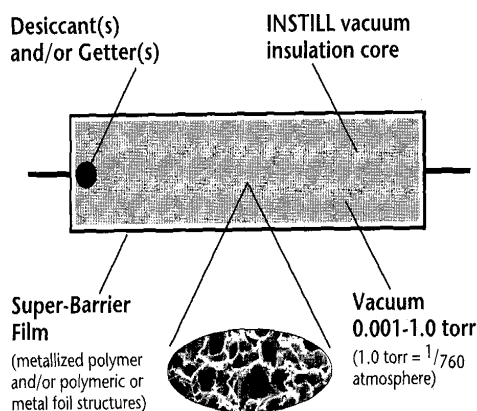


Figure 2

Section Detail of VIP



Foil-based and metalized films represent two alternatives for enclosing the core material. At the outset of this project, metal films that are foil-based rather than deposited or metalized were regarded as the preferred option because they provided the superior vacuum barrier properties needed to support long life. The main cause of vacuum loss, particularly in small panels, is entry of air into the VIP through the metallic envelope seal surrounding the perimeter of the core panel. It is important to ensure flat, close, seal-to-seal contact when joining two plies of the pre-fabricated bag and to achieve a snug fit of the panel within this envelope to prevent deterioration of the vacuum. A seal that is smooth rather than wrinkled and wide rather than narrow helps accomplish this. There are several companies that specialize in the proper manufacture of these panels.

One drawback with the use of a foil barrier film is a process known as thermal shunting or bridging. The metal foil in the laminate provides a path for heat transfer around the panel to its edges. The effect is less in larger panels than in smaller ones. The thermal resistance of a 2' x 4' x 1" VIP could be about R-22 instead of R-30, a 27 percent reduction. In a 1' x 1' panel, a

reduction of 50 percent might be realized. New laminates composed of metalized films, on the other hand, resist the transfer of thermal energy with minimal thermal shunting, but provide only short-to-medium panel life. Barrier film technology appears to be still evolving. New materials that diminish thermal bridging while providing a longer panel life may yet be developed.

Cost of Vacuum Insulated Panels

The cost of one square foot of 1" thick finished VIP using INSTILL Core was between \$4.00 and \$7.00 at the outset of the project, depending on density of the core board and customer requirements. A VIP costs significantly more than conventional insulation. One-inch DOW STYROFOAM³ brand insulation retailed for about \$0.34 per square foot.

About 1/3 of the cost of an INSTILL Core VIP goes for components and materials used to construct the panel. The remaining 2/3 goes for processing and other value-added activities. Total costs are expected to drop with larger volumes and more efficient fabrication.

Table 1 presents estimated breakdowns of the cost of materials for one square foot of 1" INSTILL Core VIP. The costs could be much higher for odd shaped applications or low production volume items.

TABLE 1 Estimated Material Cost (Per Square Foot) Of INSTILL Core Vacuum Insulated Panel (Including Waste)		
	Low End	High End
INSTILL Core Material	\$0.98	\$1.43
Metal Foil Film	\$0.23	\$0.23
Desiccant	\$0.05	\$0.05
Getter		\$0.33
Total	\$1.26	\$2.04

Life Span of Vacuum Insulated Panels

The effective life span of VIPs may be much shorter than many insulating materials traditionally used in residential construction, and some degree of uncertainty surrounds estimates of the life expectancy of all VIPs. This is because VIP longevity is tremendously affected by the service environment of the panel. For example, a conservative estimate of the amount of thermal resistance lost over a 30-year period by a 2' x 4' x 1" VIP through moisture and gas penetration is 25 percent. This estimate assumes a temperature of 25 degrees Centigrade and 60 percent relative humidity. Since the rate of loss of thermal resistance is dependent on such variable factors as the temperature or the humidity, the actual life span of two otherwise identical panels could be different. These are not the only factors that can impact the life span of the VIPs, but it

³ Trademark of The DOW Chemical Company.

is this kind of uncertainty over the life span of a VIP that can be a cause for concern in some applications.

The following five factors can influence the life expectancy of VIPs:

- Minimum Performance Requirements
- Panel Size
- Fabrication Quality
- VIP Component Choices
- Use Conditions.

Minimum Performance Requirement

A VIP could be designed to meet at least the minimum insulating requirements for the application throughout its functional life. Thus, a VIP would be over-designed, so that it would retain the minimum desired R-value at the end of its intended service life of the application.

Panel Size

Moisture and gases that degrade the insulating characteristics of a properly prepared VIP enter through two primary routes: the seal and the barrier film. The seal area is the more vulnerable path. Increasing the size of a panel can lessen the impact of seal leaks on the life of a panel. An increase in panel thickness increases the volume of core material, but the length of the panel seal remains unchanged. This means that the rate of moisture and gas infiltration through the seam should be unchanged but their impact on thermal resistance is diluted due to the greater volume of core material. The panel's thermal performance would decrease at a slower rate and the panel life would increase. Much the same can be said for increasing the length and/or the width of a panel, except that the seal length increases but not-at the same rate as the volume of core material.

Although barrier films are not as susceptible to infiltration as the seal, they become more important in larger panels as the impact of the seal diminishes. Given this, more attention must be given to selecting a barrier film for them.

Fabrication Quality

Quality assurance in the fabrication of VIPs is of paramount importance to the life of the panel. Care must be taken in sealing the film so that the seals are not wrinkled. Also the barrier film must not be wrinkled, sharply bent or folded during fabrication. The INSTILL Core material is supplied with a subtle grid pattern imprinted on the surface to take up excess film material in the vacuum process to prevent wrinkling.

VIP Component Choices

Component choices are also important factors affecting panel life. The two primary components that will affect the life of the panel are desiccants and getters that will be incorporated into the panel and the barrier film. During the fabrication of VIPs, it is impossible to evacuate all of the

residual gases from the panel. Desiccants and getters remove both residual gases and those gases that enter through the barrier film and the seal during the service life of the panel. Desiccants remove moisture, and more sophisticated and expensive adsorbents called getters are designed to remove molecules of atmospheric gases. Panels that are required to have long service lives must be fabricated with these materials, but these devices can significantly increase the cost of the finished panel. In recent years, a great deal of research aimed at developing super barrier films that can provide longer service lives for VIPs has been undertaken.

Use Conditions

VIP barrier films are susceptible to both elevated temperatures and humidity. Either condition can accelerate the movement of molecules through the barrier film and seal. To mitigate the affect, panels can be pre-insulated and additional getters can be added to maintain a suitable panel life. Additionally, application and product engineers can minimize panel exposure to these conditions through the use of proper design. While the INSTILL Core material is able to withstand temperatures of 158 degrees Fahrenheit, prolonged exposure to these temperatures is not recommended.

For a more detailed explanation of the INSTILL Vacuum Insulation Core see Appendix A. The discussions of technical issues related to performance are based on information provided by DOW staff. No original tests were conducted by the Research Center to develop or verify the information.

III. POTENTIAL RESIDENTIAL MARKETS FOR VIPS

Determination of Applications for VIP Technology

The goal of the initial phase of Part One of the project was to systematically identify components of the home that could serve as candidates for the integration of VIPs. To this end, the Research Center, HUD and DOW convened a brainstorming session to generate a list of such home components. Participants included those experienced in relevant residential construction issues and in VIP technology.

Methodology

Prior to convening the session, Research Center staff developed evaluation criteria to assess potential applications. The evaluation criteria attempted to rate the performance characteristics of VIPs in areas considered critical to the acceptance of a product in the residential construction market. The potential applications were evaluated based on the following six basic criteria:

- Cost of Manufacturing
- Significance of Impact of VIP on Performance of a Home
- Required Life Span of Material
- Risk of Damage on Jobsite
- Risk of Damage after Construction
- Additional Installation Cost.

Each category was assigned a value of 1 to 5. A value of 1 represented a favorable rating for a specific category, and a value of 5 represented an unfavorable impact for a specific category. The ratings for each of the criteria were averaged to develop an overall rating reflecting the potential of each specific application.

Definition of Decision Criteria

Cost of Manufacturing

Potential applications were evaluated on how easily the product could be manufactured relative to current panel manufacturing processes. Current manufacturing processes are limited to producing flat panels. Applications which may require bending or forming of the finished VIP material could be substantially more difficult to manufacture than applications which incorporate board stock. Additionally, applications that require the use of a new barrier film or evacuation process pose a significant hurdle in the manufacturing process.

Significance of Impact of VIP on Performance of a Home

Applications were evaluated according to the impact that the new VIP product could have on the thermal performance of the entire home rather than at the component level. This strategy was chosen to facilitate significant gains toward the PATH energy efficiency goals, which entails

reducing the energy use and environmental impact of new housing by 50 percent and energy use in existing homes by 30 percent in the future.

Required Life Span of Material

Perhaps the most significant drawback of VIP technology is the uncertainty over the length of the life span of the panels. However, it is believed that further research and development will result in improved barrier films that will reduce this as an issue in the long term. Applications were evaluated based upon the expected life of a material currently used in a specific application. For example, garage doors have a much shorter expected life span than a foundation. The applications were also evaluated on how easily the product could be replaced. For example, wall cavity insulation would be virtually impossible to replace, but attic insulation would be fairly easy.

Risk of Damage on Jobsite

The barrier film currently used in VIP manufacturing is extremely susceptible to puncture. If the film is punctured, the panel loses the vast majority of its thermal resistance. Each application was evaluated on its potential damage during construction.

Risk of Damage after Construction

Potential applications for the VIPs were evaluated on their susceptibility to damage by occupants after installation.

Additional Installation Cost

Applications were evaluated for any expected increase in installation costs. Any need for increased care in handling the panels to reduce the chance of puncture would most likely push installation costs upwards.

Results

Twenty-seven potential applications were evaluated during the brainstorming session. Applications were considered for their potential in both site-built and manufactured housing and for the following areas of the building envelope:

- Foundations
- Floors
- Walls
- Roof/Ceiling
- HVAC
- Appliances
- Miscellaneous.

Table 2 shows the evaluation results produced during the session. Ten of the twenty-seven applications were determined to have potential for use in residential construction and were

chosen for examination in the initial market assessments. They are the shaded applications in Table 2.

TABLE 2 Vacuum Insulated Panels Initial Brainstorming Session							
Potential Applications	Cost of Manufacturing	Significance of Impact of VIP on Performance of Home	Required Life Span of Material	Risk of Damage on Jobsite	Risk of Damage After Construction	Additional Installation Cost	Overall
Foundations							
Under-the-Slab Insulation	1.00	2.00	4.00	4.00	4.00	3.00	3.00
Frost Protected Shallow Foundations	1.00	2.00	4.00	4.00	4.00	3.00	3.00
Precast Concrete Panels (Foundation/Wall)	1.00	1.00	4.00	1.00	3.00	3.00	2.17
Interior Basement Wall Insulation	4.00	2.00	4.00	3.00	2.00	4.00	3.17
Exterior Foundation Wall Insulation	1.00	2.00	4.00	4.00	3.00	4.00	3.00
Floors							
Manufactured Housing Floor Panels	1.00	1.00	2.00	2.00	2.00	2.00	1.67
Floor Panels (above unconditioned space)	1.00	3.00	5.00	4.00	3.00	3.00	3.17
Walls							
Party/Shaft Walls	3.00	4.00	4.00	4.00	2.00	2.00	3.17
Wall Cavity Insulation	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Panels Laminated to Gypsum Board	4.00	2.00	4.00	4.00	4.00	4.00	3.67
Exterior Insulated Finishing Systems	2.00	2.00	5.00	5.00	4.00	4.00	3.67
Window Frames	5.00	5.00	5.00	4.00	5.00	3.00	4.50
Exterior Doors	2.00	3.00	2.00	1.00	3.00	1.00	1.83
Garage Doors	2.00	5.00	2.00	2.00	4.00	2.00	2.83
Roof/Ceiling							
Panels Laminated to Gypsum Board for Manufactured Housing Ceiling	2.00	1.00	3.00	2.00	2.00	3.00	1.50
Cathedral Ceiling Insulation	3.00	1.00	5.00	3.00	3.00	3.00	3.00
Insulated Metal Roofing Panels	1.00	2.00	5.00	2.00	2.00	2.00	2.33
HVAC							
Rectangular Duct Insulation	1.00	2.00	3.00	4.00	2.00	4.00	2.67
Oval/Round Duct Insulation	3.00	2.00	3.00	4.00	2.00	4.00	3.00
Furnace Cabinet Insulation	VIPs cannot withstand the temperatures that would be experienced in these applications						
Prefabricated Fireplace Lining	VIPs cannot withstand the temperatures that would be experienced in these applications						
Appliances							
Refrigerators/Freezers	DOW is currently producing VIPs for this application						
Water Heater Jackets	DOW is currently producing VIPs for this application						
Miscellaneous							
Retrofit Exterior Insulation	1.00	1.00	3.00	4.00	3.00	2.00	2.80
Plumbing Insulation	3.00	5.00	3.00	4.00	2.00	3.00	3.33
Acoustical Ceiling Panels	1.00	4.00	3.00	3.00	2.00	3.00	2.67
Attic Access Panels/Stairway Insulation	1.00	4.00	2.00	1.00	2.00	1.00	1.83

Evaluation of Market Potential

After the 10 most promising applications were selected, estimates of their market shares were developed. The major sources of the data were the Research Center's *Annual Builder Practices Survey* and the Research Center's *Annual Consumer Practices Survey* of Repair and Remodeling Activity. Survey data regarding new home construction and remodeling and repair practices in 1997 were selected as representative of recent activities. Data was either obtained from existing published reports or generated through analysis of survey responses.

Data on annual housing starts were used in conjunction with the survey response information to generate national level market estimates. Sources of additional information included NAHB's *Housing Market Statistics* and *Factory and Site-Built Housing - A Comparative Analysis*, published by the U.S. Department of Housing and Urban Development, Office of Policy Development and Research.

Selection of Five Candidate Applications

Table 3 summarizes the estimated annual market for each of the 10 candidate applications. The results of the assessment were reviewed by HUD and DOW to develop a list of applications for further analysis. The five applications found to be the most promising are shaded in the table.

TABLE 3	
Estimated Size of Current Annual Market Potential for VIP Applications	
Application	Estimated Annual Potential
Precast Concrete Panels (Foundation/Wall)	1.4 million square feet current market share. Could greatly expand if share of basements increases
Manufactured Housing Floor Panels	489 million square feet
Exterior Doors	100 million square feet
Garage Doors	33 million square feet
Manufactured Housing Ceiling Panels	489 million square feet
Insulated Metal Roofing Panels	4 million square feet
Rectangular Duct Insulation	40 million square feet
Retrofit Exterior Insulation	65 million square feet Could greatly expand if it replaces or is used in conjunction with other sheathing
Acoustical Ceiling Panels	Potentially large commercial building market
Attic Access Panels/Stairway Insulation	Approximately 1 million access panels

A description of all ten applications, their benefits, limitations and market potential are contained in Appendix B. A discussion of the five selected applications follows.

Attic Access and Folding Stair Panels

Access to attic spaces is frequently provided through a ceiling hatch located in the conditioned spaces of a home. Sometimes a pull down stair is installed to facilitate entry. Installing and

maintaining insulation on the hatch with an R-value comparable to that in the attic can be difficult. Sometimes batt insulation is attached to a piece of gypsum board that serves as the hatch panel. Over time the insulation can loosen and become detached. While some attic access stairs are insulated with foam board, the insulation is usually less than one-inch thick since the space between the panel and the stairs is limited. This constraint on the thickness of the insulation greatly limits the R-value that can be achieved with conventional insulation. A more common approach with the pull down stair is to stuff batt insulation between the treads in the stair. This method has problems of its own, most notably, severe compression of the batts and loosening or loss of the batts over time during use. VIPs built into the stairs or attic hatch could result in a more permanent method of insulating these areas.

Exterior Doors

While most insulated exterior entry doors are either steel or fiberglass, insulated steel doors dominate the residential market due to their relatively low cost. Some manufacturers use fiberglass or polyurethane insulation, but most frequently the core material is extruded polyisocyanurate. Generally, an exterior entry door is about 1-3/4" thick. The R-values of insulated exterior doors range from about 5 to 7. VIPs could be used to replace some or all of the more conventional foam insulation materials in exterior doors.

Garage Doors

Even though most garages are not conditioned, insulated garage doors are becoming more common. It is estimated that approximately 1/3 of the garage doors installed in new houses are insulated steel. Insulated steel doors are stiffer and easier to install and use. They operate quieter than one-layer doors, and they provide some degree of sound insulation. In some climates, like Alaska, garages are intentionally conditioned. Finally, some homeowners use space heaters when they work in the garage, and the added insulation contributes to thermal comfort. VIPs could replace some of the conventional insulation in garage doors.

Manufactured Housing Floors

The floor insulation in manufactured homes is often located in the space between the floor framing and a bottom board that is installed at the level of the chassis. The bottom board provides protection for the underside of the unit during transport. VIPs could be installed above the bottom board to serve as the floor insulation for the unit, or they may be manufactured as part of the bottom board.

Panels Laminated to Gypsum Board for Manufactured Housing Ceilings

The gypsum board used on roof/ceiling panels in manufactured housing is frequently attached to the roof frame using adhesives rather than mechanical fasteners. In this application, VIPs could be laminated to the gypsum board to produce a composite product that provides attic insulation and a ceiling finish. The VIP side of the composite assembly would be attached to the roof frame with adhesives to produce a ceiling identical in appearance to conventionally insulated ceilings.

Estimated Cost of VIPs for Candidate Applications

Project staff developed preliminary estimates of the range of costs of the INSTILL Core VIP for each of the five selected candidate applications. They are presented in Table 4. The costs were based on a \$4.00 to \$7.00 price range and a rough estimate of the size of the VIP required for each application. It should be noted that these estimates did not include any additional expenses associated with manufacturing the entire assembly or selling it.

TABLE 4 Estimated Cost Added to Candidate Applications		
	Low End	High End
Attic Access Panels/Stairway Insulation	\$15	\$55
Steel Entry Door	\$50	\$125
One-Car Steel Garage Door	\$210	\$420
Manufactured Housing Floor Panels*	\$5,000	\$10,000
Manufactured Housing Ceiling Panels*	\$5,000	\$10,000

**28 x 50 Double Wide*

Industry Input

Two focus groups were held in November 1999 with remodelers and builders during the Remodeler's Show/Custom Builder's Show in Philadelphia to explore their reaction to the exterior door, garage door and attic hatch/stairs applications. Individual interviews were held with manufactured/modular producers during December 1999 and January 2000 to obtain their input regarding the floor and ceiling insulation concepts. This research sought their perceptions regarding the construction feasibility of the chosen applications and attempted to uncover and explore the advantages and disadvantages of the applications that buyers or occupants may discern.

Floor and Roof/Ceiling Systems

Staff from the Research Center and DOW visited the Nanticoke Homes, Inc. production facility in Greenwood, Delaware to get the reaction of a producer of manufactured and modular homes to VIP panels for floor and ceiling insulation. They met with Mike Younous, Vice-President of Sales and Micky Hitchens, Operations Manager at the Greenwood plant. During the session, it was discovered that Nanticoke does not install bottom boards in their manufactured houses, so VIPs installed beneath the floor trusses would be vulnerable to damage during transport to site. This practice is not conducive to the use of VIPs as floor insulation. Nanticoke was not deemed a good candidate for partnership for the floor insulation application.

Research Center and DOW staff also discussed laminating VIPs to gypsum ceiling panels for both manufactured and modular housing. Although a sister plant of Nanticoke's attaches ceiling

panels in manufactured homes, the ceiling panels in the units manufactured at the Greenwood plant are attached with nails and glue. Attaching the ceiling panels with nails could pose a significant puncture risk for the VIPs. This practice made Nanticoke less than optimal for this application. The Nanticoke people felt that some of the larger producers might be interested.

Research Center staff subsequently sent product literature to Fleetwood Enterprises, Inc., Champion Enterprises, Inc., and New Era Building Systems and conducted follow-up interviews to assess their reaction to the use of DOW INSTILL Core VIPs. Both Champion and Fleetwood homes are among the top five producers of manufactured homes in the United States. New Era is a smaller manufacturer of HUD-Code and modular housing with a reputation as an innovative company.

Fleetwood exhibited no interest in the product. Product cost and workability were cited as major concerns. Champion cited penetrations and the life span of the panels as issues. Of the three producers, only New Era exhibited any interest, but cited concerns regarding susceptibility to penetration.

Attic Access, Exterior and Garage Doors

Research Center staff conducted two focus groups sessions in Philadelphia on November 5th and 6th, 1999. These sessions were timed to coincide with the Remodeler's and Custom Builder's Shows so that a large, diverse set of potential attendees was available. During these sessions, project staff explored the use of VIPs in garage doors, exterior doors, and attic access panels. (A summary of the focus group findings can be found in Appendix C.)

The comments of the participating builders and remodelers toward the attic stairs/hatch were more favorable than their comments on the exterior entry door and garage door applications. Most of the attendees thought that the level of insulation in entry doors is not an important issue. Even if the VIP door was used, the seal around the door could still be a significant source of energy loss.

Participants stressed that garage spaces are not typically conditioned. An important reason that insulated garage doors are used is that they are more rigid than uninsulated doors and thus easier to install. The insulation material used in such doors is inexpensive and does not add much to the cost of the garage doors. VIPs could add substantially to the cost.

Attic access panels were seen as a problem area in houses. Current solutions for insulating these areas were viewed as temporary. The attendees thought that the VIP panel could provide a solution.

Results of Industry Input

The results of interviews with focus groups of remodelers and custom home builders and producers of manufactured housing subsequently led to the elimination of exterior doors, garage doors and the manufactured home applications from the list of potential products.

As a follow-up to DOW's interest in manufacturing the attic hatch, the team developed a conceptual design. DOW then constructed a prototype based on the concept design. The design sandwiched a 1-inch VIP within a layer of DOW STYROFOAM ("blue board"). The finished product was intentionally oversized to allow for cutting to exact size at the construction site. Markings on the top of the panel indicated how much of the panel could be field cut without damaging the VIP core. The panel was finished on the top and bottom with a fiber reinforced synthetic covering designed to make the product more durable.

Additional Focus Group Input on Attic Access Panels and Pull-Down Stairs

An additional set of focus groups was conducted in March 2000 to obtain feedback on the attic access panel and pull-down stair concepts from those who would likely be installing them. Do-It-Yourselfers (DIYs) and carpentry contractors were the targeted participants for the focus groups. Since the VIP insulation would not be visible in the final product, no mock-up of the pull-down stairs was prepared for the focus groups. In addition, the Research Center team felt comfortable that participants in the focus groups would already have a good understanding of pull-down stair products. A summary of the March 2000 focus groups is presented in Appendix D. It includes the following findings:

- Participants generally reacted positively toward the use of VIPs for attic hatch and pull-down stair applications.
- Most participants stated a preference to purchase VIP products if they were the same price or only slightly more expensive than current products.
- Participants stressed the importance of the attic entryway being sealed to reduce air infiltration for the full benefits of the VIP technology to be realized.
- DIYs were less concerned with code and appearance issues than contractors. It appeared that it might be appropriate to develop several different strategies for marketing products to these groups. It also appears that developing different finishes or grades of product for each market may also be appropriate.

IV. DISCUSSION

The initial activities of Part One of the project consisted of an identification of components of the home that could serve as candidates for the integration of VIPs. The Research Center, HUD and DOW convened a brainstorming session to generate a list of such home components. Participants included those experienced in relevant residential construction issues and in VIP technology. The brainstorming session identified 27 potential applications for VIP technology in residential buildings. Each was evaluated using preselected criteria. The 10 most promising applications were selected for further evaluation.

Project staff developed information related to the market for each of the applications. The results were reviewed with DOW and HUD to develop a list of potential applications for further analysis. Five applications were identified as holding the greatest promise and recommended as candidates for further exploration. They were:

- Attic access panels (hatches and pull-down stairs)
- Bottom board panels for manufactured homes
- Ceiling panels for manufactured or modular homes
- Exterior doors
- Garage doors

Further analysis resulted in a narrowing of the list of potential applications. The activities included interviews with producers of manufactured housing and focus groups of remodelers and custom home builders. The results subsequently led to the elimination of the exterior doors, and garage doors, and manufactured home applications from the list of potential products. The findings included:

Effective use of VIPs in exterior doors could require that thermal shorts through the lock block area and wood rails be reduced. Similarly, garage door thermal performance could be low because of the use of nearly continuous aluminum skin around the edges of the panel. Considering the focus group reaction to the exterior door and garage door applications, the higher costs of using them with VIPs, and the possible need for potentially costly redesign, it was recommended that no further work on the exterior entry door or the garage door applications be undertaken.

Members of the manufacturing housing industry that were contacted exhibited only mild interest, at best, in either the floor or ceiling application. Preliminary cost estimates indicated that each of these applications could add between \$5,000 and \$10,000 to the cost of a new home. Given these conditions, it was recommended that neither of the applications be pursued at that time.

Focus group participants made up of builders, remodelers, finish contractors, and do-it-yourselfers indicated a need for improved performance of attic access panels. Currently attic hatches generally consist of gypsum board or wood panel. Typically, a piece of batt insulation is tacked to the hatch by the builder, but it usually loosens shortly after occupancy and is often discarded by the owner. At this point, the insulation value of the hatch is negligible. The insulation on the proposed VIP hatch would stay in place and would be less obtrusive.

Participants also indicated a willingness to use VIP-based attic hatches and pull-down stairs if the products were available at the same price as current products or at a slightly higher price.

V. CONCLUSIONS

The forgoing indicated that Part Two of the project should emphasize the attic hatch and pull-down stair assemblies exclusively. Prototype development of these two products was to continue.

Anticipated Part Two activities included identification of manufacturers to produce the VIP-enhanced assemblies and initiation of field trials. Upon establishment of manufacturer relationships, issues related to the design and manufacturing the applications could be more fully explored. The applications should be designed to take full advantage of VIP's insulative properties.

PART TWO

VI. INTRODUCTION

Part Two activities built on the prior findings and centered on developing two selected applications of VIPs - an insulated attic hatch and an insulated attic stair. The activities included the development of potential designs, determination of relevant code and regulatory requirements, estimating the impact on energy use, examination of issues related to manufacturing methods, and identification and liaison with potential partners in the manufacturing industry.

During the course of Part Two, DOW indicated that it had scaled back its participation in building and construction related VIP projects to focus on thermal packaging and refrigeration applications. Nevertheless, the results of the investigations are still valid and other producers exist. Wacker is a globally active German chemical firm that produces silica-based VIPs. The firm is in the process of establishing distribution arrangements for their VIP product in the United States. Representatives of the company indicated interest in this project and expressed a desire to visit the Research Center for further discussions. Unfortunately, this project ended before a joint effort could be undertaken. While no representative of Wacker has visited the Research Center, they appeared to remain interested.

VII. APPLICATIONS DEVELOPMENT

Multiple prototypes were developed in the course of the project as regulatory requirements and production constraints were identified. The details of the design concepts as they evolved are discussed below.

Attic Hatch

Attic hatches in new homes are, for the most part, fabricated on-site of gypsum board or some similar material. Manufactured attic hatches account for a very small share of the hatches installed in new homes. The hatch panel is generally installed so that it rests on the lip of molding nailed around the perimeter of the attic opening. It is slightly undersized so that it can be easily slid upward between ceiling joists to give the homeowner access to the attic. Frequently, a sheet of fiberglass batt insulation is attached to the upper side of the panel. Over time, it can detach and fall on the occupants. This problem can lead to the homeowner discarding the hatch insulation. The VIP offers a more permanent solution.

Project staff identified one producer of manufactured insulated ABS plastic attic hatches, ADO Products (ADO), and arranged a visit to discuss integrating the VIP into their hatch. The shell of the assembly is ABS plastic. The main portion of the assembly is a 1-inch deep "pan", open at the top, which incorporates a 1-inch sheet of fiberglass batt insulation. The assembly is attached to the underside of the ceiling with mechanical fasteners that pass through slots in a flange around the edge of the panel. The fasteners are turnable to allow removal of the hatch for attic access. During the session, several serious impediments to producing a hybrid product using the INSTILL Core VIP and the producer's panel were identified. The INSTILL Core VIP needs to be protected from flame and puncture hazards. Both the International Residential Code (IRC) and the International Building Code (IBC) require that foam plastic be separated from the interior of residential units by an approved thermal barrier, such as a one-half-inch sheet of gypsum board to limit the amount of temperature rise if a fire should occur. Additional sheathing can be required for the attic side to afford protection from ignition. Sheathing also provides puncture protection. A VIP must retain its vacuum to maintain its high-insulation performance. Even a small hole in its envelope will rob the panel of its vacuum and drop the R-value to that of the core material.

Gypsum board was seen as an effective means of providing both types of protection. Unfortunately, the manufacturer saw several problems with the material. Gypsum board would be difficult to incorporate into the attic hatch manufacturing process because of the dust, etc. produced during the cutting process. Additionally, the rounded corners of the ABS plastic hatch panel would be difficult to match with the gypsum board. Finally, the weight of the gypsum board in the panel would be a factor. Estimated weight of 3/8" gypsum board and VIP panel would be about 10 pounds. The ABS panel did not provide the required flame spread or fire protection for the VIP. These obstacles were regarded as serious and the concept was not pursued further at that time.

Project staff, with help from several members of the VIP industry, developed a series of panels and panel design concepts as construction and regulatory issues were identified, culminating in panels 5, 6, and 7 listed in Table 5. A discussion of the development of the listed products follows.

TABLE 5
Attic Hatch Development
1. INSTILL Core VIP sheathed in fiberglass-cloth coated foam sheathing
2. INSTILL Core VIP w/ 3/8" ceiling-side gypsum board sheathing, flexible foam on attic side and around perimeter.
3. INSTILL Core VIP as in #2, with a soft foam around perimeter to allow panel to accommodate variation in the dimensions of attic openings
4. INSTILL Core VIP encapsulated in polyurethane with gypsum sheathing on both sides
5. INSTILL Core VIP with ceiling side gypsum sheathing and attic-side plywood sheathing
6. Wacker VIP with ceiling side gypsum sheathing and attic-side plywood sheathing
7. Wacker VIP enclosed in ABS panel

The first design concept was a prototype attic panel (developed in Part One of the project) that could be trimmed to size. It consisted of a 20" x 20" x 1" VIP sandwiched between two 24" x 24" x 1/2" layers of blue foam faced with fiberglass cloth. A 1" thick strip of foam was inserted between the foam layers on two sides of the panel to lend structural support. A dotted line, inscribed around the perimeter of the foam panels, 1" from the edge, was used to distinguish the trimmable area. While the design was flexible, the foam sheathing did not provide a suitable ceiling surface in terms of flame spread. (See Figure 3.)

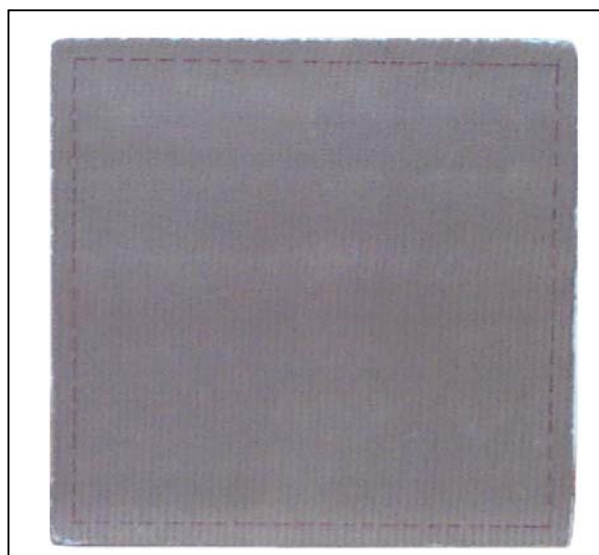


Figure 3
Trimmable Attic
Hatch Concept

The second design concept consisted of a VIP sheathed on the ceiling side with 3/8" gypsum board to enhance flame spread performance, and a sheet of flexible foam plastic attached on the attic side and along the perimeter of the panel. The foam plastic was intended to provide protection from puncture on the attic side, while serving as a flexible gasket around the perimeter.

Project staff constructed an easily modifiable ceiling/attic hatch opening assembly and subjected the panel to a series of tests to assess its ability to accommodate variations in attic hatch opening dimensions. The foam proved to be too stiff, accommodating only a small degree of variation. A follow-on design embodying a softer cushion type around the perimeter of the panel was developed and fabricated by DOW. The improved design succeeded in accommodating a wider range of opening sizes. (See Figure 4.)



Figure 4
Attic Hatch with
Perimeter Cushion

Based on these results, a modified design was submitted to the National Evaluation Service (NES) for informal evaluation (See Figure 5). NES is an independent, not-for-profit organization that conducts a voluntary and advisory program of evaluation for building materials and products. It issues National Evaluation Reports of these technologies indicating code compliance. The reports facilitate the review and approval by regulators of the product covered by the report. In support of PATH, NES provides preliminary evaluations of technologies to identify issues related to compliance with relevant model building codes.

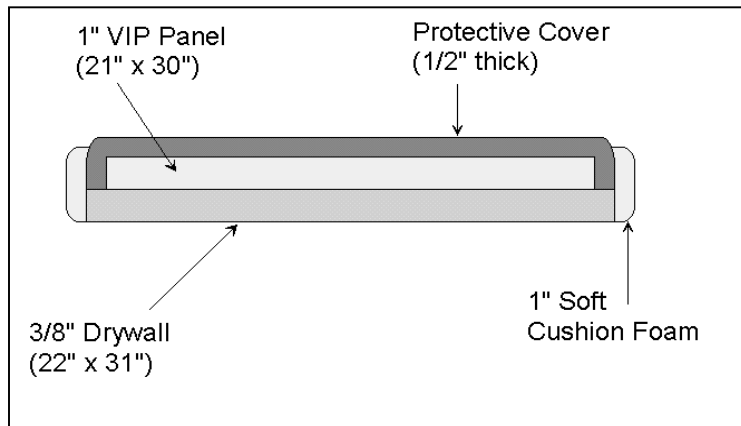


Figure 5
First Hatch
Design Sent to
NES

The resulting NES Letter of Analysis (See Appendix E.) indicated, among other things, an IBC requirement that the INSTILL foam core material and the foam cushion each be submitted to ASTM E84 testing to determine if they met flame spread and smoke development requirements as separate components in accordance with Section 2603.3 of the code. This interpretation did not allow the panel to be tested as a single assembly.

In response, 24 feet of 24" x 1" AF Grade INSTILL Core VIP, provided by DOW, was submitted to ASTM E84 testing performed by SGS, U.S. Testing Company, Inc. The test results indicated that the VIP failed to meet the required standards. The Flame Spread Index results of 125 exceeded the 75 required by the IBC and the Smoke Developed Value of 565 exceeded the 450 maximum allowable level.

These results prompted another reassessment of the design. Project members arranged a visit with VacuPanel, a fabricator of VIPs, in an attempt to explore alternative product designs. The alternatives discussed included:

- Polyurethane: It was generally thought that a polyurethane panel would perform better in fire tests than the polystyrene panel. The VIP with polyurethane would likely be more expensive because the panels would need to be cut with a hot wire saw. It is also more difficult to pull a vacuum. Finally, getters would be needed.

Cutting the panel and installing getters would add steps to the production process. This option would also eliminate INSTILL Core. Although the process seemed more difficult and the material probably would have to come from Europe, VacuPanel could do a polyurethane panel, both as a mock-up for testing and for the prototype panels.

- Silica composition panels: These panels were seen as more difficult to work with, as well. The silica panels are manufactured in Europe also. (They were later evaluated when Wacker expressed interest in the project.)
- Panel coating: VacuPanel had been working with some spray-on polyurethane coatings that might provide increased flame spread performance. A polystyrene (INSTILL Core) VIP encased in polyurethane which could be planed or sanded to the desired thickness was suggested. This coating would be dual-purpose: providing fire protection and providing

some puncture protection. If NES determined that the unit could be recognized as a single cohesive foam plastic unit, then there would be no need for the VIP to undergo separate testing.

As a result of the VacuPanel visit, project members developed a modified panel design with a polyurethane-encapsulated INSTILL Core VIP (See Figure 6.) and submitted it to NES. The design consisted of a 19-1/2" x 19-1/2" x 1" VIP encapsulated in a 1/4" layer of polyurethane foam on all sides. An attic side 20" x 20" layer of 3/8" gypsum board provided ignition protection while a slightly larger (24" x 24") ceiling-side layer of gypsum served as a thermal barrier and could be trimmed to fit smaller openings.

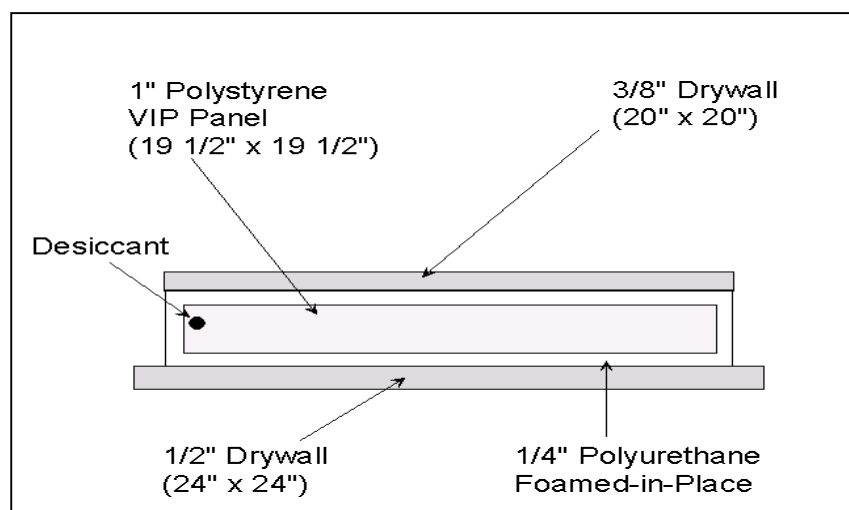


Figure 6
Second Hatch
Design Sent to
NES

A second NES Letter of Analysis (See Appendix F) indicated that, despite the polyurethane cladding, the INSTILL Core VIP would need to be submitted separately to ASTM E84 testing per the IBC.

A follow-up telephone conference with NES was conducted to determine if the Specific Approval provisions in Section R318.3 of the IRC would allow the use of an "end-use configuration" test in lieu of the separate ASTM E84 test of the core material. The provisions appeared to allow such a substitution. NES participants indicated that they were bound by internal policy to use the IBC and not the IRC and that the IBC did not allow a substitution for ASTM E84 testing.

The Research Center petitioned NES to change its procedures so that IRC provisions could be used to assess products meant for use only in one- and two-family houses. NES subsequently approved the change. In response, project staff developed a modified VIP design and submitted it for evaluation (See Figure 7). The submittal indicated a desire to have the panel evaluated using the IRC and to take advantage of Section R318.3 (Specific Approval).

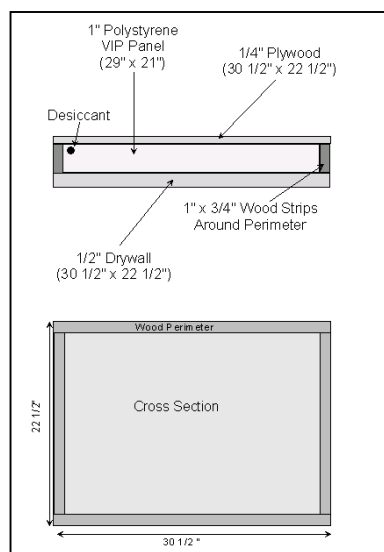


Figure 7
Third Hatch
Design Sent to
NES

NES responded in a Letter of Analysis (See Appendix G) that the design could take advantage of the Specific Approval provisions. The panel assembly, as a whole, could be tested in its end-use configuration in place of separate ASTM E84 testing of individual components. Unfortunately, NES did not think any of the existing tests listed in the provisions were adequate. While a test along the lines of UL1715 had been anticipated, an NES staff member indicated in a follow-up conversation that the test was not designed to test ceiling components as small as the access hatch panel. A custom-designed test or a modification of an existing one, along with supporting justification, would likely be required.

Research Center Staff arranged a meeting with members of the Fire Research Division of the National Institute of Standards and Technology (NIST). The discussion revealed some important issues.

- The development of a custom test to satisfy the cited requirements would not likely be quick or inexpensive, but not all of the NIST personnel were convinced that testing of this type was necessary.
- While the sheathing of the panel seemed adequate, several NIST staff thought that the joints between components could pose a problem. The potential for styrene fumes was the main concern.

Since the concerns voiced during the session focused on the performance of the seams between panel components, the problem was one that manufacturers could address through product design, such as through the elimination of seams. Given this, no further fire testing of polystyrene-based VIPs was undertaken.

Project staff initiated an effort to identify other VIP-core materials that could be more easily adapted for use in attic-closure applications. Wacker, a globally active German chemical firm, was contacted and expressed interest in the project. They indicated that they are in the process of establishing distribution in the United States.

Wacker's core material is Wacker WDS®, a microporous thermal insulation material. It is enclosed in an evacuated envelope fabricated from either a polyethylene-polyamide film system

or an aluminum foil system. The Wacker core material consists of inorganic oxides. The main component is Wacker HDK® fumed silica. This material accounts for no more than two-thirds of the amount of the core material. The remainder of the material consists of opacifiers, for reducing infrared radiation, and silicates. Wacker WDS® is incombustible, rated A1 based on DIN 4102 (Deutsches Institut für Normung – the German Institute for Standardization) Fire Behavior of Building Material and Building Components. Product literature claims that Wacker WDS® has been industrially certified as harmless to health.

A potential disadvantage is that it may not be quite as easy to work with as foam-insulation-based VIPs. Foam cores are stiff and easy to handle and the core material can be cut with relative ease. The Wacker core material is composed of silica-based powder, so the resulting VIPs lack the same stiffness as the DOW INSTILL Core material. This could present a problem when handling larger panels. Admittedly, our exposure to the material is limited, so how much difficulty this can cause is not known at this time. A one-inch thick Wacker VIP in the United States was estimated to be around \$7.00 per square foot.

Project staff subsequently submitted a new hatch design concept to NES that was a modification of the prior design revised to be based on the Wacker VIP. (See Figure 8.)

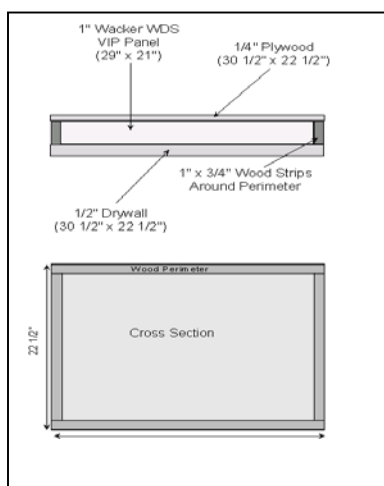


Figure 8
Fourth Hatch
Design Sent to
NES

NES indicated in another Letter of Analysis that the Wacker VIP must be submitted to ASTM E84 testing. This does not appear to represent a major obstacle. (See Appendix H.)

While the submitted design was fully functional, it did not take full advantage of the VIP's performance because it contained components that are not likely needed. Since the VIP does not contain any foam plastic, it is exempt from many of the provisions that influenced the design and testing requirements of the INSTILL Core VIP. Thus the gypsum and wood attic hatch components, which add a lot of weight, might be replaced by lighter synthetic pieces.

The material could also make a modified ADO attic hatch application more feasible. Project staff sent ADO written notification of the possible availability of the Wacker VIP and its

potential fire-related performance. In a follow-up phone call, an ADO representative requested a sample of the material and costing data. The request was relayed to Wacker.

Project staff also developed an alternative drop-in hatch design concept (See Figure 9). The assembly was designed to include a bottom enclosure that would contain a VIP. A close fitting "lid" would be attached either mechanically or with adhesive to enclose the VIP. Project staff contacted a plastic component fabricator who indicated that such an enclosure could be fabricated for approximately \$27.00, excluding the initial cost of the mold.

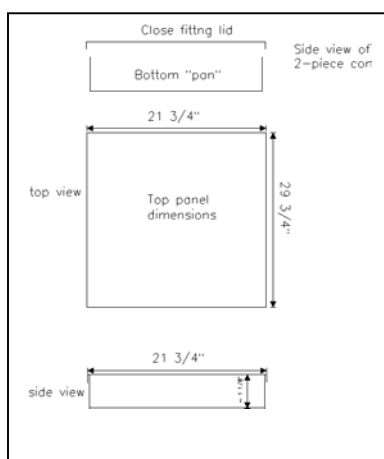


Figure 9
Drop-In Hatch
Design

To recap, four design concepts were eventually developed.

- One version, using a 1-inch DOW INSTILL Core VIP, was sheathed on the ceiling side with 1/2-inch gypsum board and on the attic side with 1/4-inch plywood. A 3/4-inch by 1-inch strip of wood enclosed the edge of the VIP. This design concept was submitted to NES for evaluation. A Letter of Analysis from NES indicated that the assembly could be submitted to end-use related fire testing in lieu of separate ASTM E84 testing of the VIP, but a custom designed test procedure might be required. The cost of the non-VIP material used in fabricating the panel is about \$8.00. The overall cost including labor of these panels is estimated to be around \$60.00, assuming a \$5.00 cost per square foot of VIP.
- A slight modification of this design replaced the INSTILL Core VIP with a Wacker product. While this change eliminated foam-related requirements, ASTM E84 testing of the core would be required. Since product literature indicates that the core material can pass European testing, it is likely that it will pass United States requirements. The overall cost including labor of these panels is estimated to be around \$70.00, assuming a \$7.00 cost per square foot of Wacker VIP.

One potential disadvantage of this assembly is its weight, around 15 pounds. Since the sheathing is not necessary when non-foam insulation is used, alternative, lighter-weight designs are possible. One such design concept could combine a lighter ABS type plastic shell with the Wacker VIP.

- The third design was based on an existing ADO hatch, which consists of an ABS shell and fiberglass insulation. A Wacker VIP would be substituted for the fiberglass batt. The hatch would be attached to the ceiling with bolts that can be turned to release the hatch for attic entry.
- The fourth design was a two-piece ABS assembly. A Wacker-type VIP would be inserted into the bottom "pan" that would surround the VIP on all but the top side. A close-fitting lid would fit over the lips of the pan so that the VIP would be completely enclosed. Discussions with a plastic component fabricator indicated that the shell would cost in the neighborhood of \$27.00, excluding the expense of producing the molds.

Neither of the ABS-based designs was submitted to NES for evaluation. One of the products is based on a hatch currently in production and both designs are still at the initial concept stage. Until panel manufacturer interest can be secured and designs finalized, specific testing would be premature.

Attic Stairs

Phone calls to most major U.S. attic stair manufacturers indicated little interest in discussing integrating VIPs into their stair assemblies. The reasons cited included cost, susceptibility to puncture, and lack of market demand for the greater insulating capacity. Contact with American Stairways, Incorporated (ASI) revealed some interest in the project.

Project team members visited with ASI and discussed integration of the VIP into the company's stairs. Two design concepts were discussed:

- Fitting a 3/4" VIP into the recess between that panel and the treads and providing some type of protection.
- Fitting a VIP into a sliding stair with a 1-3/8" VIP.

The following concerns were expressed by ASI:

- The first ladder is an inexpensive unit and the cost of the VIP would prohibit sales.
- Construction details of the second stair appeared to be an impediment. Also, stair production is limited due to low demand for a high end product.
- Any size changes in the products would affect packaging, shipping and related costs.

Prototype stair mockups were subsequently produced. A VIP was fastened to the ceiling side of the bottom panel between the runners. Such a layout left a significant proportion of the panel uninsulated. Since the panel had no protection against an occupant's foot striking the panel, it was also vulnerable to puncture. A major redesign of the stair assembly was indicated.

Subsequently, project staff developed an alternative design based on one of the ASI assemblies and contacted ASI to determine their reaction. The design made use of the Wacker VIP with its promise to resolve fire-testing-related requirements. Figure 10 shows the details of the completed prototype design developed at the Research Center.



Figure 10
Prototype Stair
Design

Originally, a 3/4" INSTILL Core VIP was fastened to the ceiling access panel in the space located between the two runners that extended along each side from the "spacer" near the bottom of the panel to the piano hinge at the head of the panel. This design meant that the VIP was significantly smaller than the ceiling-side access panel. The areas that remained uninsulated represented a further opportunity for energy conservation gains.

The modifications to the stair assembly design were fairly straightforward. First, the VIP, both "runners", and the bottom "spacer" members were removed. This made it possible to install a wider, longer, and thicker (1-inch) Wacker VIP panel to provide a higher overall R-value. In place of the runners and spacer, small, predrilled wooden dowels or blocks could be located close to the edge of the panel at intervals along the perimeter. The blocks provide a means of attaching a second sheet of plywood located on the attic side of the VIP using small bolts and nuts. This upper sheathing protects the VIP from impact-related damage that can occur when occupants use the stair.

The new design caused the attic stairs to rest at a slight angle when the assembly is closed. Increasing the height of the hinge tabs attached to the ladder would raise its pivot point and allow the ladder to rest horizontally on the upper plywood panel.

These modifications made it possible to use a 21-1/2" x 49" x 1" VIP which represents an increase in surface area of over 25 percent over the original design. The new VIP occupied almost 85 percent of the area of the attic stair bottom panel compared to the former 67 percent. Increasing the thickness, width and length of the VIP caused an increase in the effective R-value of the VIP of approximately 65 percent.

The cost to produce this unit was estimated to be around \$140, including approximately \$60.00 for the attic stair and the labor needed to modify it. This estimate is based on a \$7.00 per-square-foot VIP cost. The cost of the modification came to a little over \$80.00.

Project staff also identified and contacted representatives of two European producers of attic stairs. One produces a gasketted, insulated stair in which the insulation is sealed into the bottom panel assembly. This stair is currently available in the United States. They declined to participate. The second company is Rintal International (Rintal). Representatives of Rintal in the U.S. indicated interest in the concept and discussed it with their home offices in Italy. While a new insulated attic stair scheduled for sale in the U.S. market might be a future candidate for VIP insulation, it was not available in time for examination.

Another Rintal attic stair model, currently available in the states, was examined for use in one of the field evaluation sites, but the dimensions of the available versions were a concern. The width of the access opening in both assemblies was inconsistent with the attic framing so extra modifications would be required. Given this, no prototype was developed.

Research Center staff also explored designs that would allow the integration of VIPs into an attic stair retrofit. Some of the designs developed are presented below, along with potential concerns.

- An enclosure could be built to surround the stair assembly in the attic. The enclosure would be capped with a VIP assembly. The design is pictured in Figure 11. Optimally, the VIP would be located below the upper edge of the attic insulation to diminish thermal shorting.

A potential issue is the amount of on-site labor needed to construct the unit. Framing the enclosure requires additional carpentry work that translates into higher costs.

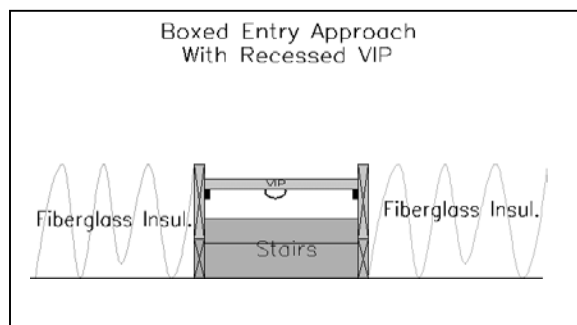


Figure 11
Retrofit Stair Design
Drawing One

- A VIP, covered with gypsum or some other finish, could be attached to the bottom of the stair assembly. The VIP and finish would be supported by trim boards fastened around the perimeter of the stair bottom-board. Additional molding could extend out from the assembly to cover any seams in the ceiling and give a more finished appearance.

A potential problem is that the bottom of the assembly would not be flush with the ceiling. Homeowners may find this objectionable. Also, the assembly would need to be carefully designed so that the weight of the panel would not cause it to detach. The molding and mechanical fasteners would need to support the weight of the VIP and gypsum for many years.

- The third design would entail recessing the attic stairs, so that a hinged attic cover containing a VIP could be mounted flush with the ceiling. This cover would be hinged independently of the stairs and would be swung aside when opened.

A potential problem is that a separate, possibly spring-loaded, assembly would need to be developed. Otherwise, the hatch could present a hazard as it swings down, unimpeded. The use of a spring-loaded or a similar descent control assembly would add cost.

- The existing attic stair could be left in place. A VIP-equipped panel would be held against the ceiling by two rails - one on each side of the panel. The panel would slide forward to expose the attic stairs. When the stairs are closed again, the homeowner would slide the panel back into place.

The appearance of the assembly could be an issue. Much of the assembly is exposed and the occupants may not like its unorthodox appearance. The construction of the rail assembly would add to the cost of the stairs.

- The attic stairs could be recessed and a VIP would be attached to the bottom surface. The VIP would be offset 1" from the hinge end of the assembly to allow for clearance as the stair pivots around the hinge. A section of flexible "h" channel would be inserted so that it obscures the gap created by the offset. It would flex when the stair is lowered. Similar strips could be attached around the perimeter of the assembly to reduce air leakage. The design concept is pictured in Figure 12.

Potential issues associated with this design include ensuring a dependable source of functional, durable h-gaskets. The gasket would need to be produced in acceptable colors and/or be paintable.

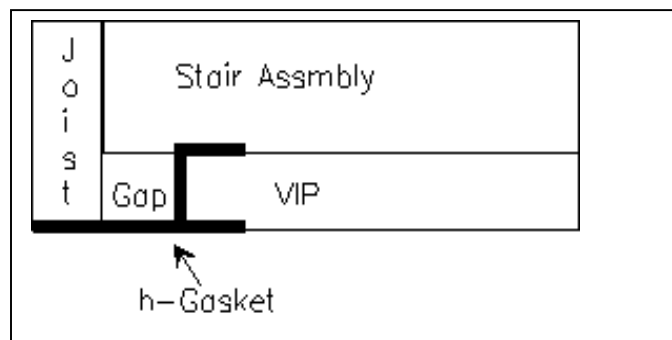


Figure 12
Retrofit Stair Design
Drawing Two

VIII. THERMAL PERFORMANCE MODELING

An analysis of representative stair and hatch assembly designs was conducted to develop estimates of their potential impact on thermal performance and energy savings.

First, the effective R-value for each of the assemblies was estimated by computing the effective R-values of the insulated and non-insulated portions of the assemblies and assigning an R-value to the assembly based on their relative portions. The analysis was based on the parallel path method which makes a simplifying assumption that heat travels in a straight line through a building component.

The baseline stair was a commercially available uninsulated wood folding stair for use with a 22 1/2" x 54" opening. Project staff modeled a similar stair with a 1" VIP sandwiched between two plywood panels that are supported by a wood framework around the edges and another with a 2" VIP. The overall R-value, based on the effective R-value of the insulated and uninsulated portions of the assembly, was estimated at R-18 for the 1" VIP and R-26 for the 2" VIP. The R-value of the uninsulated stair was estimated at R-0.6. The R-Values do not include the effect of surrounding framing because it would be present in any case.

A separate set of comparisons was conducted to assess the attic access hatch. The baseline case consisted of a bare 22-1/2" x 30" x 1/2" gypsum panel with no insulation. While many design alternatives were developed and explored during the project, none were fully code-approved final designs. For the purpose of thermal testing, the following design was assumed. The first VIP alternative consisted of a 20-1/2" x 28" x 1" VIP panel fully encapsulated in 1-inch XPS foam insulation to produce a 22-1/2" x 30" assembly. A 1/2" thick section of gypsum board was adhered to the bottom of the resulting assembly. The second alternative employed an encapsulated 2-inch VIP.

The results of the thermal performance analysis are presented in Table 6.

TABLE 6		
Overall R-Values		
Configuration	Description	Overall R-Value
Attic Pull Down Stair		
#1	Baseline stair (No insulation)	R-0.6
#2	Sandwiched 1" VIP folding attic stair	R-18
#3	Sandwiched 2" VIP folding attic stair	R-26
Attic Hatch		
#1	Baseline access hatch (No insulation)	R-0.45
#2	Foam enclosed 1" VIP access hatch	R-27
#3	Foam enclosed 2" VIP access hatch	R-32

Project staff used the resulting R-values to estimate the potential heating-related energy loss associated with each application. The analysis used the "degree day" approach along with

simplifying assumptions and computational methods approved by ASHRAE⁴ and ACCA⁵. It entailed a comparison of each VIP application to its "base case" assembly located in a house in a 6,640 heating-degree-day region of the upper Midwest, such as Chicago. Fuel prices are derived from Energy Information Administration data for the state of Illinois during 2001 and 2002. Data on natural gas and fuel oil prices for the last two years showed noticeable variations, so low and high range prices were used.

Depending on the type of heating equipment, its efficiency and fuel choice, the estimated annual heating fuel savings for a 1-inch VIP-insulated attic stair ranged between \$5.00 and \$18.00. The estimated annual heating-related savings for the 1-inch VIP-insulated hatch were between \$3.00 and \$12.00. These savings were compared to the costs of the 1-inch VIP-equipped attic stair and hatch to produce an estimate of the payback periods for each. The savings for each fuel/price category are presented in Table 7.

TABLE 7			
Fuel Prices and Annual Savings			
Fuel Type	Unit Price	Annual Savings	
		Stairs	Hatch
Natural Gas – Low Price	\$5.14 / 1,000 Cu. Ft.	\$ 4.53	\$ 2.93
Natural Gas – High Price	\$10.88 / 1,000 Cu. Ft.	\$ 9.60	\$ 6.19
Fuel Oil – Low Price	\$1.16 / Gal.	\$ 6.15	\$ 3.58
Fuel Oil – High Price	\$1.34 / Gal.	\$ 7.32	\$ 4.72
Electric Resistance	\$0.077 / Kwh	\$ 18.36	\$ 11.85
Average		\$ 9.19	\$ 5.85

The cost to produce the VIP stairs by modifying a typical attic access stair was estimated at around \$83.00, in addition to the cost of the stair. Estimates of the cost for the time and materials were based on a one-time trial modification of an uninsulated stair and assumed a VIP cost of \$7.00 per square foot. Addition of sales tax brought the price to about \$88.00. The length of the payback period ranges from five years to over thirty years, based on the fuel savings in Table 7. It is possible that the actual cost to produce such a stair could be less. The VIP might cost as little as \$4.00 per square foot. The installation of the VIP and additional sheathing could be integrated into the production process, and economies of scale in labor and material costs are possible. If we assume a \$4.00 per square foot cost and a fifty-percent reduction in other costs, the price including tax of the assembly falls to around \$45.00. The payback period would fall to between three and twelve years.

⁴ ASHRAE Handbook Fundamentals, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329

⁵ ACCA Manual J Residential Load Calculation, Air Conditioning Contractors of America, 1712 New Hampshire Ave., NW, Washington, DC 20009

The estimated cost of producing the attic hatch was developed using costs from the 2002 R. S. Means Residential Cost manual and local sources. The total price of the assembly, assuming a \$7.00 per square foot VIP cost and 5 percent sales tax, was about \$46.00. The length of the payback period ranges from four years to over twenty years. Based on a \$4.00 per square foot cost for the VIP, the after-tax price of the hatch was about \$32.00, which would require a three to fourteen year payback.

The costs of the assemblies used in the above computations were based on a bare labor rate marked-up 70 percent to cover worker's compensation insurance, overhead and profit. Material costs were marked-up 10 percent for profit and 5 percent to reflect sales tax for purchases of material components. This approach reflects cost estimation practices found in the R. S. Means Residential Cost Data manual and was adopted based on the similar use of wood framing materials and techniques.

It is possible that some potential fabricators of these VIP applications would want to make higher mark-ups for overhead and profit. To explore the impact of higher markups, a sensitivity analysis of the impact of raising overhead on the length of the payback period, assuming the \$4.00 per square foot cost base, was conducted. The length of the payback period was computed for mark-ups of twenty-five percent, fifty percent, and seventy-five percent.

The impact for the stair assembly was as follows: an increase of twenty-five percent raised the payback period to between three and sixteen years; an increase of fifty percent raised it to between four and twenty-one years; and an increase of seventy-five percent raised it to between five and twenty-nine years.

The lower ends of each of the three payback ranges above are based on the price of electric resistance heating. The higher ends of the payback ranges represent the low price for natural gas from Table 7. If the high price for natural gas from the table is used, the length of the payback period would range between six and ten years, depending on the level of markup. Payback periods based on fuel oil prices would be between the high and low prices for natural gas.

For the attic hatch, sequential raising of the overhead produces payback period ranges of: four to nineteen years for a twenty-five percent increase; four to twenty-seven years for a fifty percent increase; and five to thirty-seven years for a seventy-five percent increase. Again electric resistance heat produces the shorter payback periods and natural gas, at its lower price level, produces the longer payback periods. The higher natural gas price produces payback periods between seven and eleven years. Payback periods based on the fuel oil prices would be between the high and low prices for natural gas.

These results indicate that, even with markups, short to moderate length payback periods are possible with VIP core priced near the \$4.00 per square foot level. Manufacturers who are able to operate with a lower overhead and profit rate, or those that are willing to take lower markups to sell more hatches or stairs to boost total profits, could be able to produce VIP-equipped assemblies that allow lower, more attractive payback periods. However, firms with structures that require higher overhead-related markups could be at a disadvantage relative to those with lower rates.

An alternative analysis compared potential energy savings for each application to the selling price of the VIP alone, based on the \$4.00 per square foot cost. The results indicated that the payback period for the attic stair VIP would be between two and nine years and the attic hatch VIP would be between two and seven years. The cost of material and labor (including additional applicable overhead and profit) needed to integrate the VIP into an attic hatch or stair assembly will determine any added time needed to recoup the entire cost.

These results indicate that VIP-equipped attic stairs and hatches may be able to achieve short to moderate payback periods in cold weather locations similar to that modeled. Designs that minimize the cost associated with the integration of the VIP into the attic hatch or stair assemblies are key to keeping the length of the payback period short. Lower markups for overhead can also contribute to shorter payback periods.

IX. FIELD TEST

A trial installation of the INSTILL Core VIP drop-in hatch assembly was performed at a home under construction in the NAHB Research Center Home Park in Bowie, Maryland. The hatch used a 1" DOW INSTILL Core VIP, sheathed on the ceiling side with 1/2" gypsum board and on the attic side with 1/4" plywood. A 3/4" x 1" strip of wood was installed around the perimeter of the assembly. The same panel could be modified to accept a Wacker VIP instead of the DOW product. One potential disadvantage of this type of assembly is its approximately 15 pound weight.

The following photographs show the steps in the installation process. After a proper size rough opening was cut through the ceiling drywall, molding was attached around the perimeter. Two and one-quarter inch finger-jointed colonial casing was mounted through the ceiling surface into the attic framing using 2-1/2" trim head screws. The molding provided edge support for the panel. (See Figures 13 and 14.)



Figure 13
Attic Hatch Opening

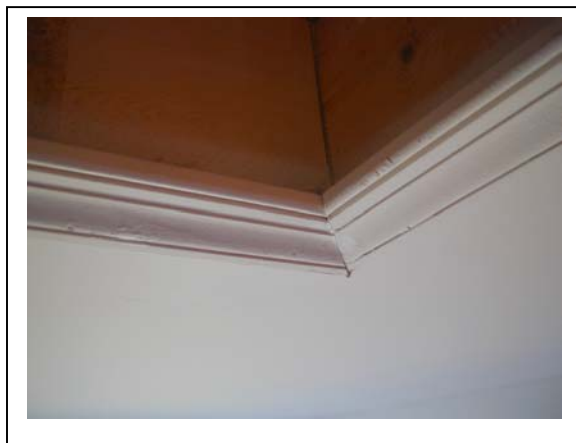


Figure 14
Colonial Casing Detail

Strips of 3/16" x 7/8" wide adhesive-backed foam gasketing were attached to the attic-side of the casing around the perimeter of the attic opening. The gasket provided a seal to minimize energy loss due to air leakage around the panel. (See Figure 15.)



Figure 15
Gasket in Place

Next, the hatch was painted and put in place. The finished hatch's appearance was no different than that of a conventional attic hatch. (See Figure 16.)



Figure 16
Finished Hatch
in Place

Less than an hour was needed to install the hatch. The time would not likely differ from that needed for a typical attic hatch. The addition of gaskets around the perimeter of the assembly takes around five minutes and would likely add less than \$2.00 to the cost. Tables 8 and 9 present material and labor usage data.

TABLE 8 Attic Hatch Installation Labor Break-Down	
Activity	Estimated Installation Time
Cut and install casing	20 minutes
Add gasket	5 minutes
Paint panel	15 minutes

TABLE 9 Attic Hatch Installation Material Usage	
Casing	\$3.85
Gasket	\$1.70

X. DISCUSSION AND RECOMMENDATIONS

DOW's involvement in this project dates back to its initiation, but during Part Two they decided to reduce their direct involvement in construction-related VIPs. Nonetheless, the results of the work performed under this project are still valid and can provide a foundation for pursuing the further development of residential-construction VIP applications.

Representatives of Wacker have indicated that the firm intends to bring its VIP product to the United States market and they seem interested in pursuing construction-related uses. The company's representative in the United States has expressed an interest in visiting the Research Center to discuss our work, and we have discussed their product with multiple attic stair producers. Additionally, product concepts, based on our understanding of the Wacker VIPs, have been developed and circulated to industry members. The preliminary indications are positive. One firm has requested a product sample and costing data. Two other firms have asked how to contact Wacker.

DOW will not actively develop this market in the near term, but they have indicated that technical developments in this field can be handled through its network of fabricators, who manufacture finished VIPs and design systems for using them. One possibility is that building component producers could work directly with members of the network using development agreements. DOW's network of VIP fabricators includes the following companies:

- Advantek Incorporated
- Energy Storage Technologies
- SAES USA
- Thermal Visions Incorporated

While the product concepts have drawn interest, considerable work remains if new applications are to reach the market. This work will need to proceed at a pace that accommodates the requirements of all firms involved. New products often involve new technologies, new markets and new obstacles that firms need to research and understand thoroughly since substantial funds can be at stake. Adjustments and readjustment of product designs can require the participation of both component and application producers, so effective communication between the firms will be vital.

The work under this project represents an important contribution to the state of knowledge about VIP applications for residential construction. The research has explored the potential for thermal performance gains, anticipated costs of attic hatch and stair applications, regulatory barriers, existing industry attitudes and market potential. Much of the uncertainty regarding the suitability of VIPs has been diminished. Multiple prototype concepts that capitalize on our increased understanding have been developed. They can serve as starting points for attic hatch and stair manufacturers, allowing them to economize on their R&D efforts.

Manufacturer Reluctance

Earlier, both DOW and Research Center staff contacted attic stair producers in an effort to solicit participation in this project. Both domestic and foreign producers were contacted. For the most part, the responses indicated little interest in partnering in the project. One domestic producer expressed cynicism, indicating that customers don't seem to be begging for a product that provides greater insulating capacity. Also, the attic stair market was depressed and margins were almost negative. Another pointed to puncture hazard and the increased cost. A foreign producer expressed concerns regarding the VIP's ability to perform superior to that of other insulating materials given the overall nature of the stair assembly and over the total cost of incorporating the VIP into the attic-stair assembly.

Domestically produced residential attic stairs are, for the most part, fairly simple wooden assemblies. A set generally consists of a hinged ladder-like assembly enclosed in, and attached to, a wooden frame that is mechanically fastened to the ceiling framing. A ceiling-side door panel, generally some type of treated plywood or particleboard, is attached to the wooden frame with a piano or similar hinge and serves to conceal the folded stairs when closed. A spring assisted metal arm assembly provides stabilization when the stair is opened and closed. Some variations include the use of a set of sliding stairs in place of a folding set, and the use of an aluminum ladder assembly.

Only a very small number of stairs are insulated, so a sizable retrofit market for VIP-insulated stairs may exist. The United States housing stock is comprised of slightly more than 115 million units. About 60 million of them are either detached or attached owner-occupied homes. A five-percent share of this homeowner market would represent 3 million homes. While this represents a small portion of the housing stock, it could correspond to around 20 million square feet of VIP. The ultimate share of the market could be much larger.

Most domestically produced attic stairs can be bought for several hundred dollars or less. Low-end wooden models can sell for around \$60.00. Many wooden models sell for under \$200.00, but prices can range higher. Prices go up as weight capacity and ceiling height increases. Aluminum construction, insulation and other features can push the price up. The cost of a VIP appears to be a major obstacle to its acceptance since it could represent a major increase in the cost of inputs. Unless the producers are able to earn the same rate of return on the installed cost of the VIP, the product represents a reduction in margin to the stair producer. In a market where margins are seen as narrowing, this appears to be a very serious impediment, especially for the more inexpensive U.S. stairs.

Most domestic attic stair producers are not inclined toward exploring new technologies and changing their designs unless they see credible indications of interest from their customers. What the home builder wants is a matter of great importance to these firms. Given this, expressions of interest in VIP-equipped stairs from members of the building industry could spur an increased level of interest in the technology and help speed its diffusion. The PATH Industry Steering Committee could play an important role by expressing their desire for products that incorporate VIPs to the producers of stairs installed in their homes.

XI. CONCLUSIONS

The study produced several key findings. They include:

- While many potential applications of VIPs in residential construction were identified, attic hatches and stairs offered the best opportunity and were selected as the initial VIP applications.
- Incorporating VIPs into attic hatches and folding attic stairs is feasible, but certain barriers must be surmounted before these applications can be commercialized. Several alternative VIP core materials are currently available and the technology is still evolving. Currently, open-cell polystyrene, polyurethane and silica are the major alternatives. Each offers a different set of advantages and disadvantages.
- Marketing research indicates a sizable market potential for attic-related and other applications exists. The pre-sales-tax cost for a VIP-insulated hatch was estimated to be roughly \$30 to \$44. The pre-sales tax cost of a VIP-insulated folding wooden stair was estimated to be about \$43 to \$80 more than an uninsulated one. While these figures are approximations, an energy analysis indicated that payback periods could range from only a few years to well over 20 years, depending on prevailing fuel costs and climate. Designs that minimize the cost of integrating the VIPs into the assemblies are key to producing shorter payback periods. Lower manufacturer overhead can also contribute to shorter payback periods.
- A custom-designed fire-test procedure may be needed for foam insulation-based VIP attic opening applications. Silica-based VIPs are not subject to the same fire-related provisions and will probably need to satisfy only ASTM E84 flame-spread and smoke-generation requirements.
- The \$4.00 to \$7.00 per square foot cost of VIPs means a relatively large first cost. Fairly energy-intensive items with small surface areas were targeted so that initial costs could be kept to a minimum. At this time, applications that entail larger surface areas would be prohibitively expensive due to large initial outlays. Applications that add value in other ways, like a permanent means of insulating attic hatches and stairs, make VIPs more attractive.
- While our investigation indicates that a large potential market exists, it is not sufficient to motivate stair manufacturers to adopt VIP technology. Domestic manufacturers already sell a lot of stairs profitably. If VIPs were added, costs would certainly rise. Perhaps total revenues would also increase, but margin rates could fall because of a lower rate of return on the added costs. Indications of interest on the part of builders could encourage these stair producers to look into using VIPs. An effort to educate and inform manufacturers about VIPs and their potential uses could reduce some of the uncertainty and motivate them to develop viable applications.

- The NES's preliminary evaluation reports were very helpful in identifying the regulatory requirements for the attic hatch and stair assemblies. The Research Center recommended a change in the NES's Rules of Procedure to allow the use of the IRC to evaluate products destined only for one- and two-family dwellings, and the NES has adopted the change. It should help reduce the cost of entry for such products and speed their adoption. This was a positive development.

The following three activities constitute the next steps needed to facilitate the introduction of VIP insulated folding attic stairs and hatches and other applications into the domestic housing market.

- Information Dissemination - VIPs and their potential for energy savings are not widely understood or appreciated in the U.S. When industry members, such as attic stair manufacturers, see a demand for VIP-equipped stairs, they will develop products for the market. Educating builders on the advantages of VIPs to the homeowner so that they ask stair producers for a VIP option could motivate more industry participation.
- Technical Support - Some of the domestically used VIPs are likely to be produced by foreign firms, such as Wacker. In fact, they may play important roles in the early development of VIP markets; however, they are not as likely to understand the United States residential construction market as well as some of the domestic producers. Providing them with information on the United States housing market, building methods and regulations could speed the development of the market.
- Product Identification and Development - Attic hatch and folding stair insulation is only the first VIP application for the residential sector. As these applications become more widely known, other uses are likely to be developed.