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Vacuum Insulated Panels in a Roofing Application
Camden U.S. Post Office and Courthouse
Camden, New Jersey

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GPG
Green Proving Ground Program

The Green Proving Ground program leverages GSA’s real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

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Table of Contents

Page

List of Figures

List of Tables

I. Executive Summary

A. Introduction

The U.S. General Services Administration (GSA) Public Buildings Service (PBS) acquires space on behalf of the Federal Government through new construction and leasing and acts as a steward for federal properties across the country. PBS has jurisdiction, custody, and control over 9,624 federally owned and leased assets and maintains an inventory of more than 370.2 million square feet of workspace and because of this has enormous potential for implementing energy efficient and renewable energy technologies to reduce energy and water use and associated emissions.

In 2011, GSA created the Green Proving Ground (GPG) program to test and evaluate innovative and underused sustainable building technologies and practices based on their potential to support GSA's programmatic needs and accelerate environmental efficiency in building operations in the context of the GSA Strategic Sustainability Performance Plan and Zero Environmental Footprint vision. The goal of the program is to identify effective building technologies and practices that could be broadly deployed to reduce energy costs and the environmental impacts of GSA site operations through decreased energy and water use and waste creation at GSA sites. Findings from the testing and evaluation of technologies are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program ultimately aims to drive innovation in environmental performance in federal buildings and help lead market transformation through the deployment of new technologies.

The buildings sector accounts for about 41% of the total energy consumed in the United States each year. About 37% of this "building energy" is used by heating, ventilation, and air conditioning systems to heat and cool the facilities (Avdelidis and Kauppinen, 2008). A large fraction of this energy is lost through the building envelope. Continuing advances in building envelope technologies play an important role in reducing overall building energy consumption.

Roofing systems are one facet of the building envelope where significant advances have been made. Better insulating properties and improved solar energy reflectance are two areas that have shown significant gains. One particular technology that has shown potential for improving insulation is vacuum insulated panels (VIPs).

In this project, sponsored by the GSA GPG program, VIPs installed in a retrofit roofing application at the U.S. Post Office and Courthouse in Camden, New Jersey, were evaluated.

VIPs are a type of insulation composed of an interior solid layer of a high R-value material wrapped in an exterior layer of airtight foil. During panel manufacturing, a vacuum is drawn inside the airtight foil wrapper, and the product is used with the vacuum intact. This vacuum increases the insulation R-value to the extent that a panel can have an R-50 insulating value with a thickness of only 1 in.

The main focus of this project was to capture the lessons learned at the Camden U.S. Post Office and Courthouse in one document. Interviews were conducted with key players, including facility operations personnel, the project team and its leader, and the contractor. Another goal of the project was to provide guidance on what would make VIPs economically viable at a site, notwithstanding that individual analysis is still required for each given set of parameters.

B. Results

The VIP installation project presented a challenge because the roof area where the VIPs were installed is less than 15% of the building's total roof area, and no data existed on how much energy that portion of the roof used with conventional insulation. Therefore, it was not possible to measure exactly how much of an impact the VIPs had on overall building energy consumption. To work around this situation, energy modeling was used to simulate the impact of an R-50 roof on the energy consumption of "typical" buildings in the GSA inventory in different climate zones.

This study also looked at lessons learned, such as the following from the construction experience at the U.S. Post Office and Courthouse in Camden.

- The issues that came up during the project and how they were addressed.
- Tasks that should have been done differently.
- Tasks/procedures that worked well and should be incorporated in similar projects.

Finally, thermographic images were taken at the Camden facility to evaluate the current condition of the VIPs that were installed. The images show any places where the panels were compromised during construction and further validate the findings and lessons learned from the construction team's experience.

The following is a synopsis of the report's findings and recommendations.

- VIPs are a technically viable alternative in roofing applications where a higher R-value is desired, but space restrictions dictate a roofing insulation with a thinner profile. There are other insulating systems that can provide a similar R-value at a lower cost of materials, but they require much more space to achieve that R-value. Modifying a roof to provide that space can be costly, at which point the VIP technology can be economically viable.
    - It must be noted that increasing a roof's R-value does not proportionally increase the energy savings from that insulation. See Section IV, C on Page 13 for a more thorough discussion and how it applies to selecting appropriate insulation for a particular application.
- The experience at the Camden U.S. Post Office and Courthouse showed that the panels are more robust than was expected and can withstand the demands of being installed in a field environment provided that certain precautions are taken during constructions. Details of the care required are included in the body of the report.
- The economic parameters of each site must be carefully analyzed to determine the cost effectiveness of VIPs in a roofing application. Factors that contribute to the economically viable use of VIPs include, but are not limited to, the following.
    - High unit costs of energy in terms of dollars per kilowatt-hour of electricity or dollars per thousand cubic feet of natural gas.
    - Extreme climate zones, such as are found in the Arctic or the Southwest.
    - Single story buildings with large, flat roofs, such as office buildings or large maintenance facilities.

- High costs of modifying the building to reach the desired R-value using conventional insulation. Such modifications might include having to change the brick and sills around windows or building up parapets around the roof edges to account for added thickness.

It should be emphasized that a careful analysis must be conducted at each site to determine the overall cost effectiveness of reaching a certain R-value with the roofing system and the viability of using VIPs to reach that R-value.

II. Introduction

The General Services Administration (GSA) is a leader among federal agencies in aggressively pursuing energy efficiency opportunities for its facilities and installing renewable energy systems to provide heating, cooling, and power to those facilities. The GSA Public Buildings Service (PBS) has jurisdiction, custody, and control over more than 9,600 assets and is responsible for managing an inventory of diverse federal buildings totaling more than 354 million ft^2 of building stock. This includes about 400 buildings listed in or eligible for listing in the National Register of Historic Places and more than 800 buildings that are over 50 years old. GSA has an abiding interest in examining the technical performance and cost-effectiveness of different energy-efficient technologies in its existing building portfolio as well as in those buildings currently proposed for construction. Given that most GSA buildings include office spaces, identifying appropriate energy-efficient solutions has been a high priority for GSA, as well as for other federal agencies. Based on the sheer size of the building portfolio, there is a huge opportunity for potential energy savings.

The buildings sector accounts for about 41% of the total energy consumed in the United States each year. About 37% of this "building energy" is used by the heating, ventilation, and air conditioning systems to heat and cool the facilities (Avdelidis and Kauppinen, 2008). Much of this energy is lost through the building envelope. Continuing advances in building envelope technologies play an important role in reducing overall building energy consumption.

Roofing systems are one facet of the building envelope where significant advances have been made. Better insulating properties and improved solar energy reflectance are two areas that have shown significant gains. One particular technology that has shown potential for improving insulation is vacuum insulated panels (VIPs).

VIPs were originally developed for the appliance industry. Their great value in stoves and refrigerators came from their ability to provide very high R-values (R-50 and greater) in a relatively thin sheet (less than 1 in. thickness). This property is provided by two key factors in the construction of VIPs. First, the core of a VIP sheet is a solid material with its own high R-value. Various manufacturers use different proprietary materials in their cores, but they all share the high R-value trait. Second, the core material in the VIP is wrapped in an airtight membrane, and then all air is removed from the panel interior. This combination of high R-value core material plus a vacuum is what gives VIPs their high R-value per inch thickness.

Because of their exceptional insulating properties, there is a lot of technical merit to using VIPs in a roofing application, especially in retrofit applications where space limitations prohibit the installation of several layers of built-up roofing material. Until recently, the manufacturing processes for VIPs made them too expensive for use in roofing applications. However, as more manufacturers have entered the market to provide VIPs for the appliance industry, the unit cost has come down considerably. The lower cost and high R-value per inch thickness have made it possible for VIPs to work in roofing applications. As with any new technology or application, there is a certain amount of risk the first time it is used in field environments.

GSA leadership saw an opportunity for a test case for VIP technology in a roofing application at the U.S. Post Office and Courthouse in Camden, New Jersey. GSA had included the replacement of a leaky section of the roof at this facility in its FY 2010 budget. During this time frame, the American Reinvestment and Recovery Act (ARRA) provided funding for roof replacements at federal facilities, with the stipulation that the new roof have a minimum R-value of R-50. Even though the Camden U.S. Post Office and Courthouse roof project was being funded from GSA's Minor Repair and Alterations budget activity, the decision was made that it should also meet the same R-50 standard as the ARRA-funded roofs.

With a goal of R-50 established, two options were considered for the new roof: Use conventional polyisocyanurate panels, building them up to a thickness that provided the R-50 value, or use a combination of traditional polyisocyanurate insulation and VIPs.

The configuration of the area that needed reroofing presented a major challenge for the first option because the roof was in in a recessed area that covered the interior second floor of the courthouse, and it was surrounded on all four sides by the exterior zones of the building that extended from the third to the sixth floors. (See Figure 1 for photos of the area.) The exterior walls all had windows that faced into the area for the new roof, located within 18 in. of the roof surface. Between the roof and the window sills was a copper flashing system that was integrated into the building brickwork.

Figure 1. Roof Area to be Replaced at the U.S. Post Office and Courthouse, Camden, New Jersey

To reach an R-50 insulation value using conventional polyisocyanurate panels, the new roof would need to be about 15 in. thick. This thickness would have pushed the roof surface up into the flashing system, requiring extensive modification to the copper flashing and the brickwork and windowsills. The roof designer estimated the marginal cost to accommodate these changes to the flashing, brickwork, and sills would be about $300/linear foot above the normal costs of replacing the roof.

The second alternative, using a combination of traditional polyisocyanurate insulation and VIPs, would allow the project to meet the R-50 goal while keeping the roof system thin enough that it would not impact the flashing and brickwork. This option required a higher cost of insulation material, but lower installed cost due to not having to modify the flashing and brickwork.

The second option was selected. The VIPs were custom made by the manufacturer for this application and cost about \$9/ft^2. The total cost of this option was estimated to be $380,000. Considering the additional work that would have been required for the traditional insulation option, the designer estimates about $200,000 was saved by using the VIPs.

Due to the lower overall cost of installation, GSA elected to use the VIP system to provide the R-50 insulation value in the new roof at the U.S. Post Office and Courthouse in Camden, New Jersey.

Figure 2 is a copy of the architectural drawings that shows the layers used in the roof replacements. The “specified insulation board” is the VIP used in the roof.

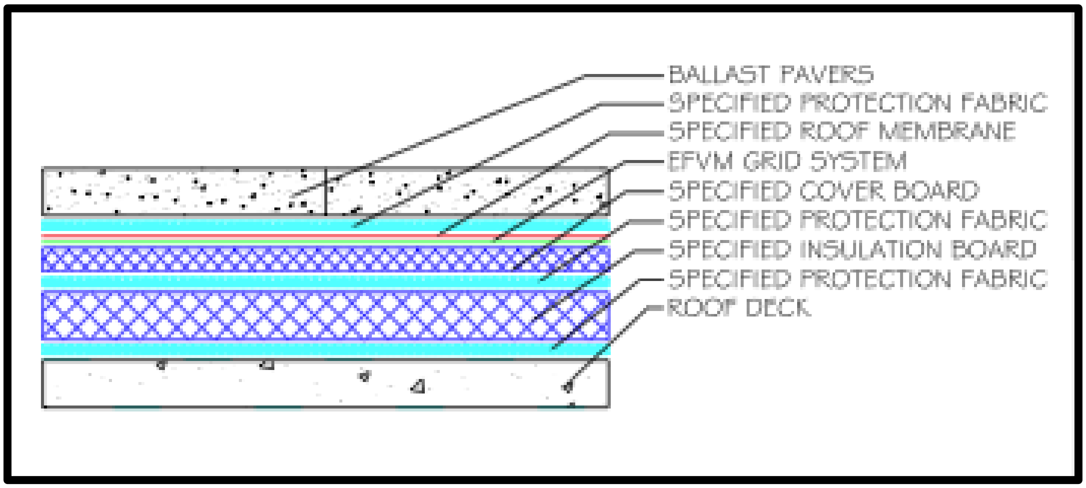

Figure 2. Layers Used in VIP Roof Replacement

III. Methodology

In conventional Green Proving Ground (GPG) projects, every effort is made to quantify what impact the new technology had on building energy consumption. Various techniques are used, but the preferred method is to take measurements that focus on energy flow before the new technology is installed and an identical set of measurements after installation of the new technology. By having both before and after measurements and focusing on the area where the new technology will impact energy flow, an accurate evaluation of the technology’s effectiveness can be made.

At the Camden U.S. Post Office and Courthouse, the conditions did not allow the team to make a direct evaluation of VIP performance. The roof area that received the VIPs accounts for only about 15% of the total building roof area. More importantly, the only measurements that were taken before installation of the VIP roofing material were the building’s overall utility bills; no measurements were taken that focused specifically on the areas that received the VIPs. (It should be noted that the VIP installation was not originally tagged to be a GPG test case that included extensive instrumentation for measuring energy savings. At the time of installation, it would have been an unnecessary expense to install instruments to provide a before and after measure of energy use. The lack of instruments in no way reflects poorly on any decisions by the project team that executed the roof retrofit.) Because of these circumstances, GSA and Oak Ridge National Laboratory (ORNL) elected to take a different approach for the report on this technology.

Using VIPs to achieve R-50 roofs is being considered at other GSA facilities. This technology also is being considered for non-GSA buildings. To provide the best value to potential future users of VIP roof systems, a three-pronged approach was selected for this evaluation.

First, the project team looked at the lessons learned from the construction team. The team considered the following questions.

- What factors drove the decision to use VIPs, and why were VIPs not used on other roofing projects during the same time frame?
- What challenges were presented due to using VIPs in this project?
- What characteristics of the panels were perhaps not as difficult as originally expected?
- What lessons would the current project team like to pass on to the next project team that uses VIPs?

Second, the ORNL staff took infrared (IR) images of the roof installation. These images can indicate any panels that were damaged during installation and, therefore, are not providing the ultrahigh R-values expected.

Third, the ORNL staff conducted energy and economic modeling to determine what impact an R-50 roof would have on overall building energy consumption compared to a standard roof, as dictated by ASHRAE Standard 90.1. This modeling helps to identify what parameters must be present in a building to justify going to an R-50 roof, as well as when the use of VIPs would be justified to reach the R-50 threshold. These parameters will be useful to building managers who are considering this modification in the future.

IV. Report Findings

A. Lessons Learned

Factors that “Drove” the Decision at the Camden U.S. Post Office and Courthouse Compared to Other GSA Buildings: Two other GSA reroofing projects were done at about the same time as this project. Both were funded by ARRA, so R-50 roof insulation was required.

The first building was in Wilkes Barre, Pennsylvania, and was a traditional design-bid-build project. The second project was the Veterans Benefits Administration Building in Germantown (Philadelphia), Pennsylvania, and was a ballasted ethylene propylene diene monomer (EPDM) roof. For both projects, extra insulation was needed to meet the R-50 requirement. However, neither project had any constraints on the roof height. Thus, extra layers of conventional polyisocyanurate insulation could be added at a very low cost because no significant modifications were needed to the surrounding brickwork or window sills like at the Camden U.S. Post Office and Courthouse.

The GSA leadership team selected the Camden U.S. Post Office and Courthouse roof for the VIP demonstration. It was an ideal candidate for a VIP technology demonstration because the recessed area of roof was surrounded by walls with windows within a few inches of the existing roof deck. These brick walls had integrated copper flashing that would have to be rebuilt if the roof level were raised to accommodate a traditional insulation system with an R-value of R-50. The added cost of modifying the brickwork, flashing, and window sills made VIPs more economical than using traditional insulation to reach the R-50 threshold. The old roof was replaced with the VIP roof in November 2011.

Handling VIPs During Construction: A VIP achieves much of its insulating properties due to the airtight foil surrounding the panel core material. If this foil is punctured, much of the panel’s insulation, or R-value, is lost. Also, the core of many VIPs is actually a loose material. Panel rigidity is the result of the vacuum seal of the foil coating, much like a vacuum-packed bag of ground coffee is rigid until the bag seal is broken. This being the case, extra care was taken during installation to ensure the foil seal remained intact.

To protect the VIPs from potential damage due to job-site activity, palletized packages of panels were kept in a warehouse off-site and brought to the site only on the day they were expected to be installed. In hindsight, the contractor believes that this extra care was not really needed. In his opinion, the panels were much more durable than they were originally expected to be. On the few occasions when a panel was bumped or hit in a manner that they thought could puncture the foil seal, detailed inspections showed that there was, in fact, no puncture. Thermal images taken by the ORNL evaluators confirmed that no installed panels were compromised in this fashion. The contractor observed that the only panels discovered to be compromised were two panels that had been damaged during shipping. They were simply laid to the side and not used in the project.

The contractor believes that in future projects using VIPs the palletized panels could simply be stored at the site, covered with a tarp, in a place where they would be protected from impact by a vehicle or similar incident. The ORNL team concluded that storing the panels off-site at a warehouse and trucking pallets daily to the job site was an unnecessary expense.

Preparing Roof Surface for Panel Installation: Another step taken to preserve the foil covering's integrity was to make rigorous inspections of the roof surface before laying down panels. Metal fasteners were used to hold insulation panels to the concrete roof deck of the previous roof. Upon removal of the insulation, many of the fasteners stuck in the concrete and protruded above the deck. These fasteners would have easily punctured the foil had they not been accounted for.

To mitigate risk from the remaining fasteners, thorough inspections were done to find any that protruded upward by any amount. These stubs were marked with orange paint and were ground flush to the concrete with an angle grinder. (See Figure 3 for a photo of the roof with fasteners marked.) The contractor did not feel that the few hours needed for the inspections and grinding contributed to the overall project cost, but it ensured that the panels would not be compromised during installation.

Figure 3. Fasteners from Old Roof, Marked for Grinding

Job Site Cleanliness: Another step taken by the contractor to ensure no punctures to the foil wrap was rigorous job-site cleanliness. Area cleanup was continuous, and debris was always removed from the roof—good practice for all roof jobs.

Worker Footwear: To prevent debris from reaching the roof work area, each individual worker was required to have a pair of work boots that was carried to the site, inspected for cleanliness, and then put on their feet before they entered the roof area. In fact, the crews found that they could carefully walk on the panels without damaging them due to their clean footwear. This increased the ease with which panels could be installed throughout the roof area.

Selecting a VIP Vendor and Ordering VIPs: Because the use of VIPs is still new to the roofing industry, not all VIP vendors were comfortable working with the project team for this application. The VIP vendor Thermal Visions was selected because it was willing to work with the project staff and produce VIPs to their specifications within the needed time frame. To be cost effective, VIPs for buildings must be able to provide useful service for a much longer period than VIPs more typically sold for packaging or appliance applications. Also, the VIPs for this job were larger than VIPs typically produced for the appliance industry. Carefully selecting a vendor that can meet the job requirements will contribute to project success.

Panel Arrangement and Size: For this project, identically sized panels were ordered. When they were installed, the panels had to be fit together like a jigsaw puzzle to maximize the coverage around vent pipes and edge areas. This presented challenges and led to gaps in the insulation that had to be filled with conventional insulation or overlaps of the VIPs.

On the next VIP project, the contractor will preplan how panels will be arranged on the roof. He also plans to order a variety of sizes for the panels so that smaller areas can be covered without having to resort to overlapping panels. Preplanning the panel arrangement and ordering custom sizes will require added time up front, but the extra time should help the project go more smoothly during installation.

B. Infrared Thermographic Inspection

The second step of this project was to evaluate the post-installation condition of the panels using IR thermographic inspection. VIP fragility was the greatest concern during construction. Even after taking great care during installation, the possibility remained that the panels might have been damaged or the foil seals broken while installing the ballasted pavers. As there was no way to visually inspect the VIPs after installation, IR imagery was used to determine their post-installation condition. Any damaged panels would show up as distinct hot spots in the images as heat from the building interior was conducted to the roof surface through the compromised panels.

Nondestructive IR thermography is a relatively easy and quick means of inspecting building envelopes for thermal bridging, insulation imperfections, and air leakage by measuring the IR radiation emission from objects. The measured radiation is displayed in the form of a detailed two-dimensional, apparent-temperature map of the object surface, which allows visual identification of any irregularities or damage. A FLIR ThemaCAM S65 HS model IR camera was used for this work. The S65 HS model has a spectral range of 7.5 to 13 µm and has an accuracy of ±2°C (±3.6°F) or 2% of reading. The detection temperature range of the camera was set to −40°C (−40°F) to 120°C (248°F).

The IR inspection was conducted on January 25, 2013, between midnight and 1:00 AM. ASTM standard C1060 (ASTM 2011) recommends a minimum temperature difference of 10°C (18°F) between interior and exterior surface or ambient air temperatures for a period of 4 hrs prior to testing. Further, for light frame construction, a period of 3 hrs of no direct solar radiation on the inspected surfaces is recommended; temperature differences greater than 18°F reduce the no-solar-radiation time period. Weather data from wunderground.com (Weather Underground, 2013) indicate that the ambient temperature during that time period was about 20°F. Also, sunset on January 24, 2013, was at 5:11 PM, and the ambient temperature varied from 21°F to 24°F between sunset and midnight. The thermostat set point inside the building during this period was 70°F; therefore, the weather and indoor conditions on the day of the inspection were deemed satisfactory.

Figure 4 shows an IR image of the roof sections of interest (left) and a visual image (right) taken from the same vantage point, for reference. It should be noted that the IR images are only used for qualitative evaluation of the VIP coverage on the roof areas. No corrections were made to the apparent temperature maps for surface emissivity, distance, etc. Figure 4 shows the view of the second floor roof with its VIP coverage from the west fourth floor roof. The southern half of the roof showed certain patterns of warmer and cooler areas in the IR apparent temperature map. (For illustration, the apparent temperatures at two locations are indicated.) The yellow rectangles are the cooler areas. Their shape follows the dimensions of the VIPs as they were installed under the pavers.

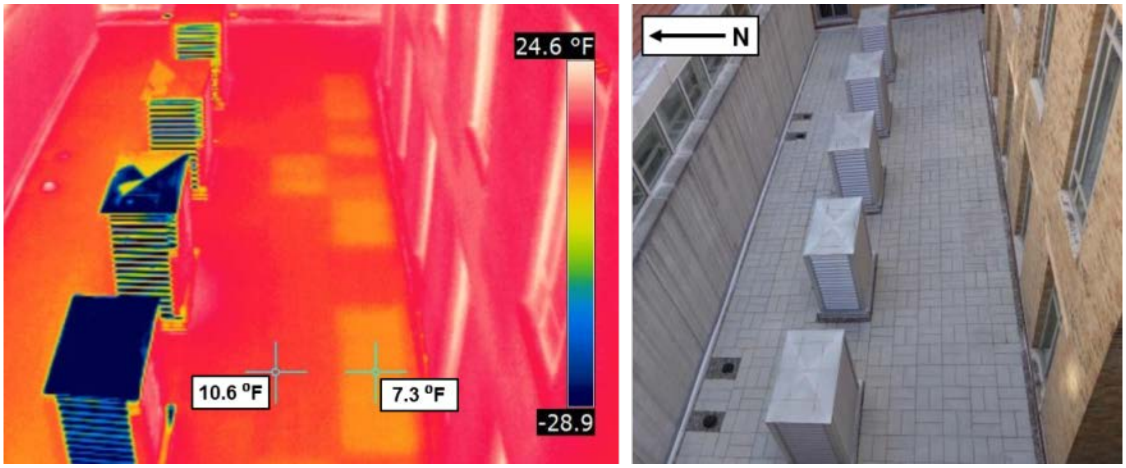

Figure 4. View of the VIP Coverage on the Second Floor Roof from the Fourth Floor West Roof

The cooler sections indicate that the panels in these areas have a slightly higher R-value than the adjacent red panels. The higher R-value prevents heat from the space below from migrating to the roof, which gives the cooler temperature signature. Because the yellow panels show a consistent color, which indicates a consistent temperature, their R-values are consistent with each other. Similarly, the red panels show a consistent color and temperature, indicating they also have consistent R-values.

This consistency in the red and yellow areas indicates that the R-value variations are most likely caused by slight manufacturer variations between lots of panels. They do not indicate that a panel was damaged. A panel that was punctured would show up in this image as a pink or white area, such as seen around the windows.

Figure 5 shows the northern half of the second floor roof. This area shows a more consistent red color across the entire roof, with no apparent damage to the VIPs. Also, there are no rectangular panels showing through, as in the images in Figure 4. This indicates that the VIPs used on the north area most likely all came from the same lot and have very consistent R-values. If one looks closely at the right side of the IR image in Figure 5, one can see the yellow panels of the different lot that were first seen in the IR image in Figure 4.

The photograph and IR images in Figure 6 focus on the bridge area between the old and new sections of the courthouse. No significant discrepancies were observed in the VIP coverage. The vents on the roofs appear as hot spots.

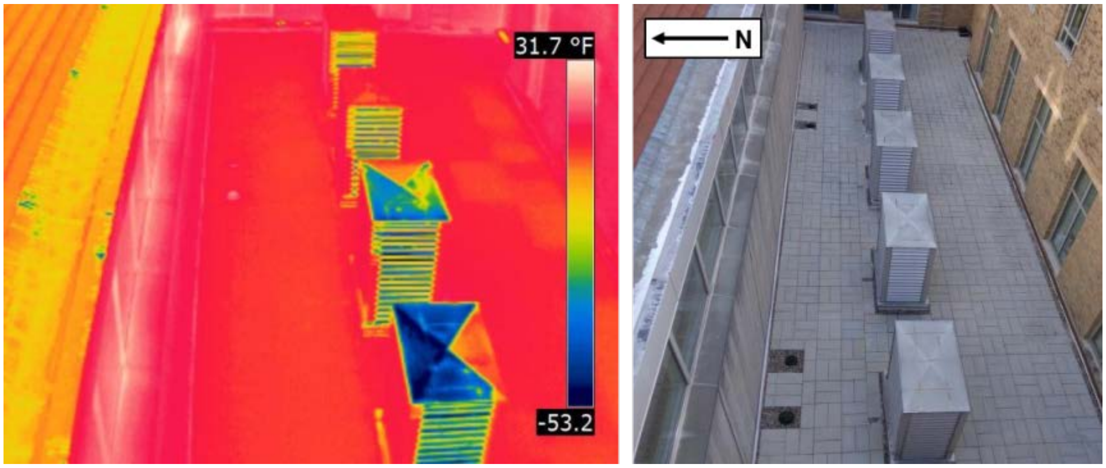

Figure 5. View of the VIP Coverage on the Northern Half of the Second Floor Roof

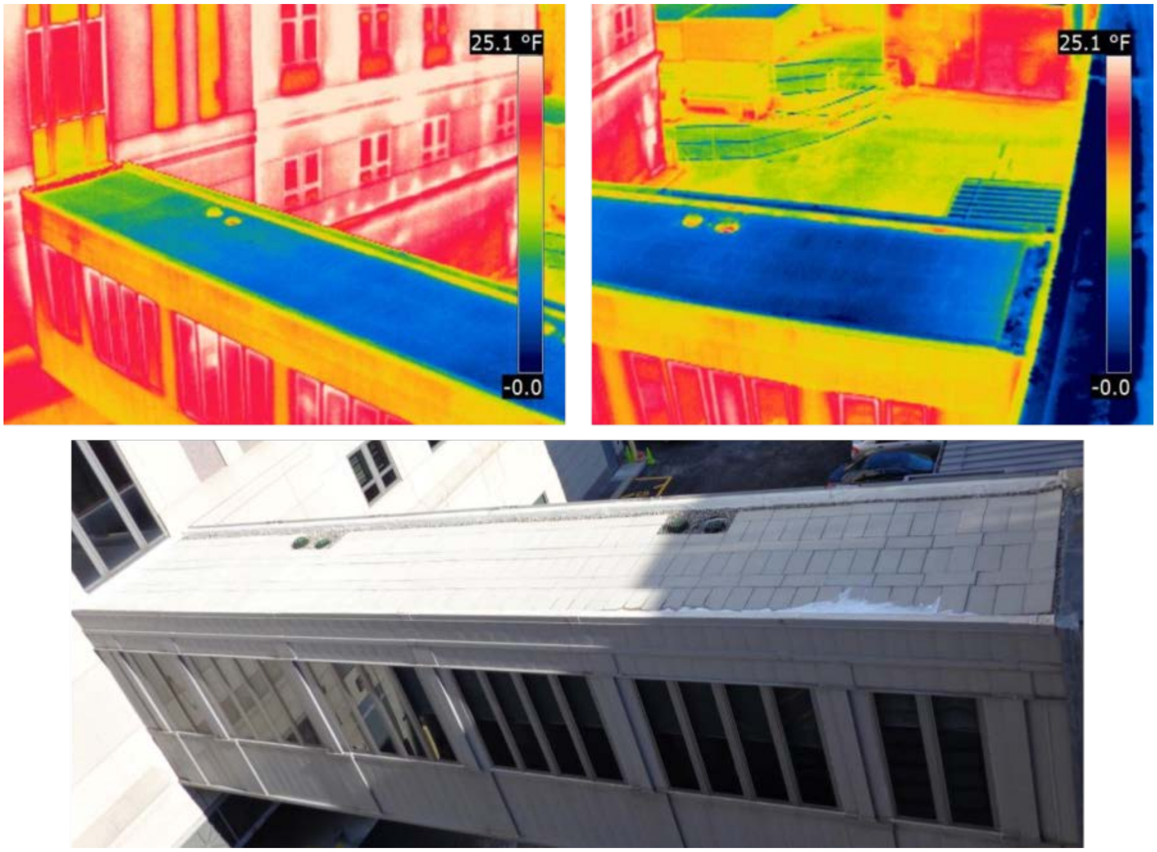

Figure 6. View of the Bridge with VIP Coverage on Its Roof

Figures 7 and 8 show the west and east ends, respectively, of the second floor roof. These photos were taken while standing on the second floor roof itself as opposed to being taken from the roof of the fourth floor. Because of the lower angle of these photos, roof areas near the walls tend to show up as warmer due to the reflection of heat from the warmer walls rather than due to conduction through the roof.

The important thing to note about these areas is that temperature variations are only slight and that they show up in consistent rectangular areas as in Figure 4. This shows that the temperature variations are most likely caused by lot-to-lot variations in the panel R-values. If the temperature variations were caused by punctures in the panels, they would have shown up as greater variations in temperature and would have been round or irregular in shape where moisture had entered through the puncture.

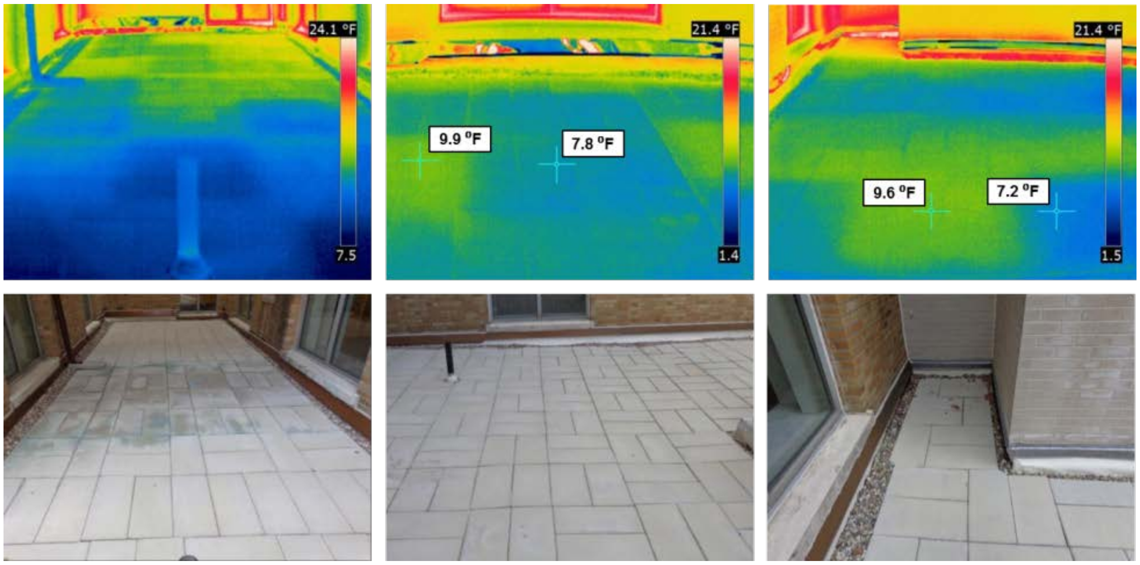

Figure 7. West End of the Second Floor Roof

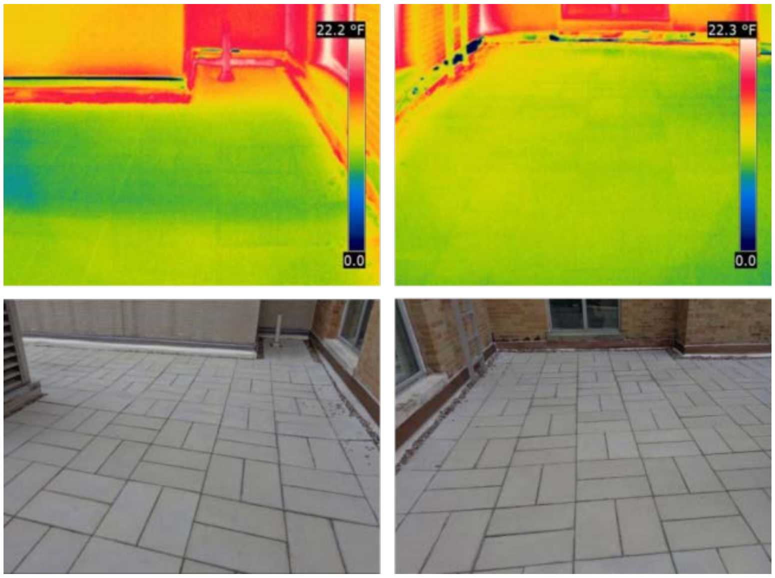

Figure 8. East End of the Second Floor Roof

C. R-Values, Heat Transfer Rates, and Energy Savings

Before beginning the next report section, which looks at simulations comparing energy savings between buildings that have code-compliant roofs (*i.e.,* R-9 to R-16) and the same buildings with R-50 roofs, it is important to address a common misconception about R-values and energy savings.

People incorrectly assume that there is a direct, proportional relationship between R-values and energy savings; that is, if by increasing the R-value from R-10 to R-20, one can save $10,000 per year on energy bills, then by increasing from R-20 to R-30, one can save an additional $10,000, and so on. Unfortunately, R-values and energy savings do not have such a direct correlation. It is true that increasing the R-value by adding insulation will reduce energy costs, but the two are not directly proportional. In fact, the energy savings from each increase by 10 in R-value are less than the energy savings from the previous increase by 10 in R-value.

To understand this concept, one must understand that energy cost savings and heat transfer rates are truly proportional. If the overall building heat transfer rate is cut in half, then the utility cost needed to heat or cool that building also will be cut in half.

The following equation shows the relationship between heat transfer rate and R-value:

$$\text{heat transfer rate} = (1/\text{R-value}) * (\text{surface area}) * (\text{temperature difference across the surface}) \; .$$

The following abbreviations are commonly used to identify these variables.

Q = heat transfer rate
$1/R$ = 1/R-value
A or area = surface area
dT = temperature difference across the surface

Using the abbreviations in place of the previous equation, we get the following:

$$Q = 1/R * \text{area} * dT \; .$$

Figure 9 shows a graph of heat transfer rate as the R-value changes. The four lines represent temperature differences of 10°F, 20°F, 30°F, and 40°F, with the surface area (Area) being held constant at 100,000 ft^2.

Looking at the red line, which represents a temperature difference of 10°F, going from an R-10 to an R-20 insulation will reduce the heat transfer rate by 50%, from 100,000 Btu/hr to 50,000 Btu/hr. This equates to the cost of energy also being reduced by 50%. Suppose that it costs a building owner $100/month to cool the building when the heat transfer rate is 100,000 Btu/hr; it now only costs $50/month, for a marginal savings of $50/month.

However, when moving from R-20 to R-30, the heat transfer rate only decreases from 50,000 Btu/hr to 33,333 Btu/hr. Continuing the cost analysis from above, the monthly utility cost has now gone from $50/month to $33/month, for a marginal savings of only $17/month.

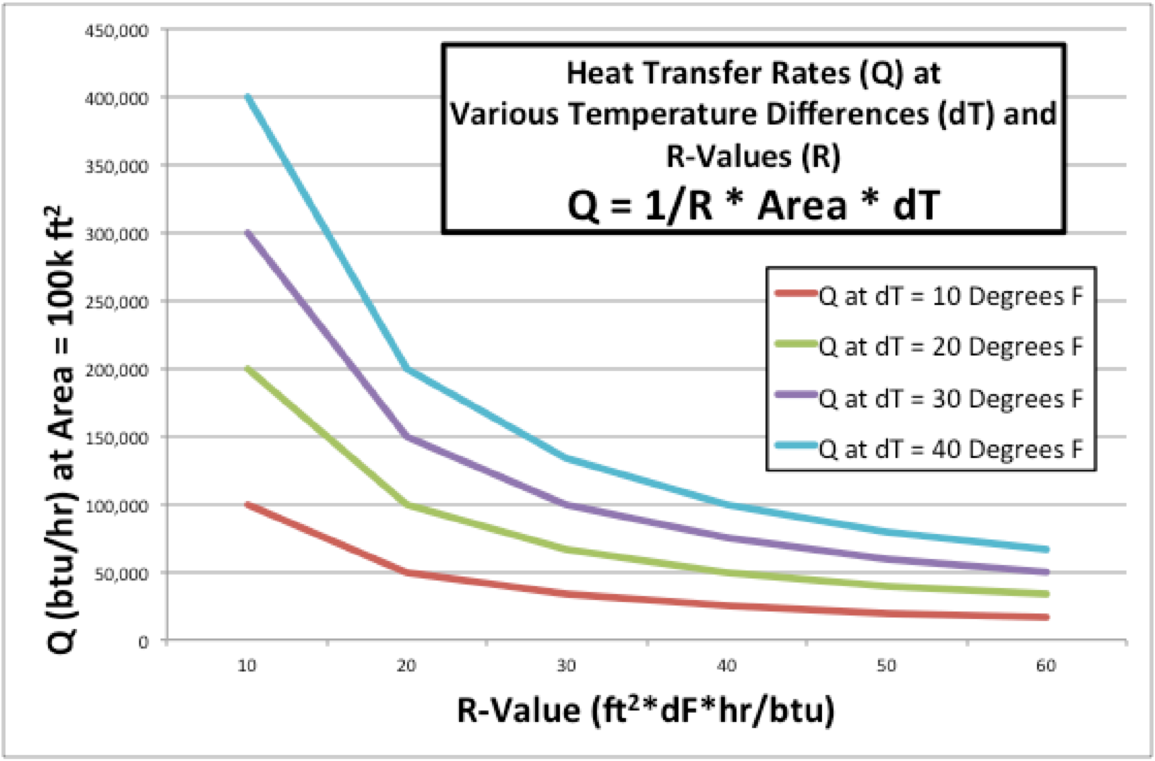

Figure 9. Graph of Heat Transfer Rate Versus R-Value if All Other Factors Remain Constant

The first R-value jump of 10 results in a marginal savings of $50/month. The second R-value jump of equal size results in just a $17/month marginal savings. Each jump of 10 in the R-value will result in a marginally smaller amount of monthly energy savings. This is a fact of physics and heat transfer that cannot be changed.

Because the marginal decrease in utility costs shrinks with each increase of 10 in the R-value, careful attention must be paid to the marginal cost of increasing the R-value by 10. Each building will be unique as far as what the marginal cost will be, but it must be carefully considered so that the cost of each additional layer of R-10 insulation is justified by the potential energy savings that will be realized over the life of the project.

D. Prototype Building for VIP Simulation Study

The third facet of this project used energy modeling to determine the effects of an R-50 roof on building energy consumption. The goal was to develop a set of parameters to guide building energy managers when making the decision as to when it would be economically feasible to go from a building that meets current GSA and ASHRAE standards for roof R-values to an R-50 roof and when would it be justifiable to use VIPs to reach the R-50 value.

The modeling looked at three types of buildings common in the GSA inventory: small, medium, and large office buildings. These buildings were selected from a suite of 16 prototype buildings based on the DOE prototype commercial building models (Deru *et al*. 2010). These prototype building models contain inputs consistent with the type of requirements in ASHRAE Standard 90.1 for various climate zones. EnergyPlus (EnergyPlus, 2011) models of all of the prototype buildings are available.

Table 1 provides the characteristics of the three building types.

Table 1. Building Characteristics

Building Type	Area	Floors
Small Office	5,500 ft^2	1
Medium Office	53,630 ft^2	3
Large Office	498,500 ft^2	12

The building geometry is shown in Figure 10. The roof type for the base case is a built-up flat roof with the insulation entirely above the roof deck. The insulation level in base case buildings varies from R-9 to R-16 depending on the location. The location and insulation levels are given in Table 2.

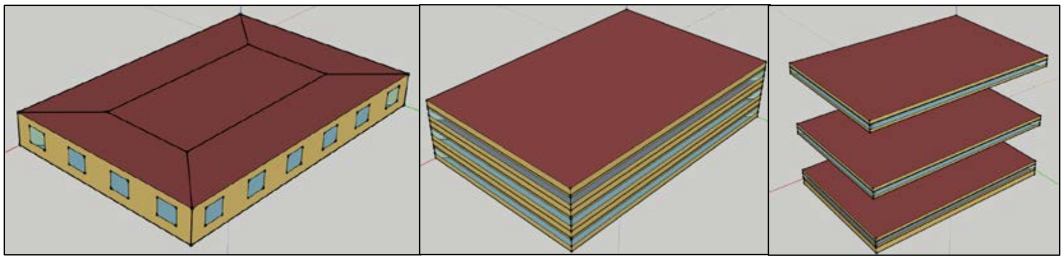

Figure 10. Prototype Buildings(left to right): small office, medium office, and large office. Source: Pacific Northwest National Laboratory

These buildings were simulated for the set of climate zone locations given in Table 2. Figure 11 shows the climate zone map.

Table 2. Climate Zones and Representative Locations
(http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_climateguide_7_1.pdf)

Climate Zone	Climate Zone Type	Representative Location	Base Roof Insulation
1A	Very hot-Humid	Miami, Florida	R-9
2A	Hot-Humid	Houston, Texas	R-9
2B	Hot-Dry	Phoenix, Arizona	R-9
3A	Warm-Humid	Atlanta, Georgia	R-9
3B	Warm-Dry	Las Vegas, Nevada	R-9
3B	Warm-Coast	Los Angeles, California	R-9
3C	Warm-Marine	San Francisco, California	R-9
4A	Mixed-Humid	Baltimore, Maryland	R-10
4B	Mixed-Dry	Albuquerque, New Mexico	R-10
4C	Mixed-Marine	Seattle, Washington	R-10
5A	Cool-Humid	Chicago, Illinois	R-13
5B	Cool-Dry	Boulder, Colorado	R-13
6A	Cold-Humid	Minneapolis, Minnesota	R-16
6B	Cold-Dry	Helena, Montana	R-16
7A	Very cold	Duluth, Minnesota	R-16
8A	Subarctic	Fairbanks, Alaska	R-16

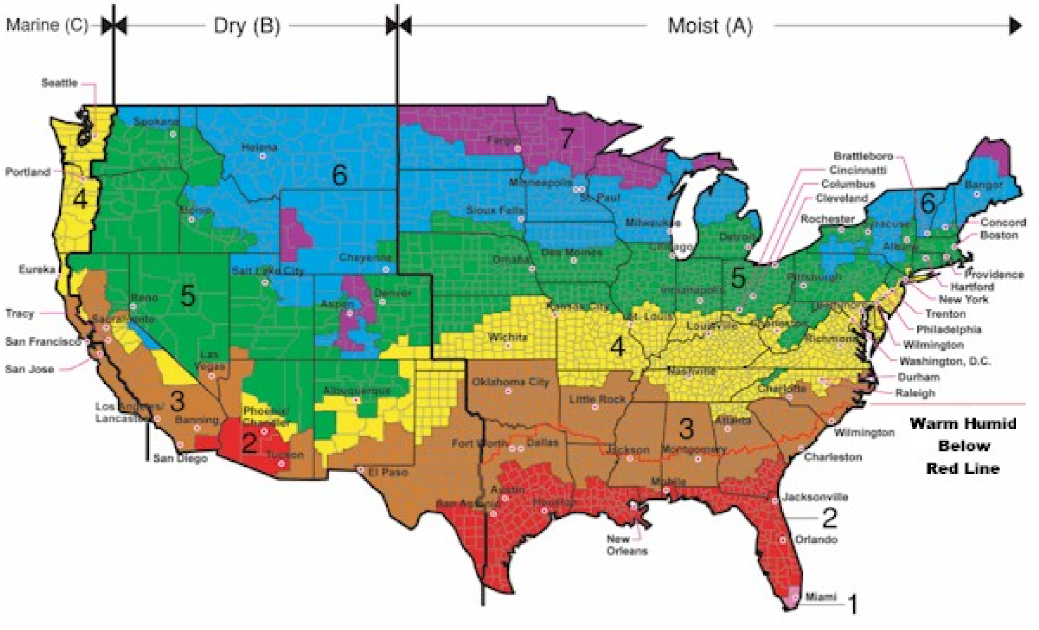

Figure 11. Climate Zone Map

For the energy modeling, the roof insulation was replaced by a 1 in. thick VIP of R-50. The thermal conductivity, specific heat, and density of the VIP used in the simulation were 0.020 Btu-in/ft^2-hr-F, 0.20 Btu/lb-F, and 16 lb/ft^3, respectively. The size of the panel used was 3 ft. by 4 ft. The roof area that could not be covered by VIPs was replaced by 1 in. thick roof insulation of R-3. Figures 12 through 14 show the annual electricity and gas consumption savings due to the replacement of existing roof insulation with VIPs in the three types of office building. The results also are presented in Appendix Tables A1–A6.

The results show that the VIP insulation can save up to 8% (*i.e*., from 1,500 to 9,400 kWh) electricity and 10% gas (*i.e.,* from 0.5 to 60 MMBtu) in small office buildings, up to 2% electricity (*i.e*., from 1,500 to 2,200 kWh) and 4% gas (*i.e*., from 0.2 to 110 MMBtu) in medium office buildings, and up to 0.2% electricity (*i.e.,* from 370 to 17,000 kWh) and 1.4% gas (*i.e.,* from 9 to 344 MMBtu) in large office buildings.

Assuming an average cost for electricity of $0.1/kWh and an average cost for gas of $1.1/THERM, the maximum annual cost savings would be $900 in electricity and $3,800 in gas. These energy savings would probably justify adding enough insulation to reach an R-50 value using a conventional insulation system with its relatively low installation and product costs. Careful attention must be paid to the total first cost and savings present at each site to determine the exact payback period and justification for the R-50 insulation.

However, if site conditions such as those at the Camden U.S. Post Office and Courthouse exist, such as extensive brickwork, windowsills, and flashing which must be modified to create space for a conventional R-50 insulation, the economics change. The material cost of a VIP insulation system is higher, but at the Camden site the added material cost was offset by not having to modify the windowsills, brickwork, and flashing if a conventional insulation were used. Because of the added cost of the panels, careful consideration must be given to the marginal cost of installing VIPs and to the utility savings before deciding to go ahead with a VIP installation.

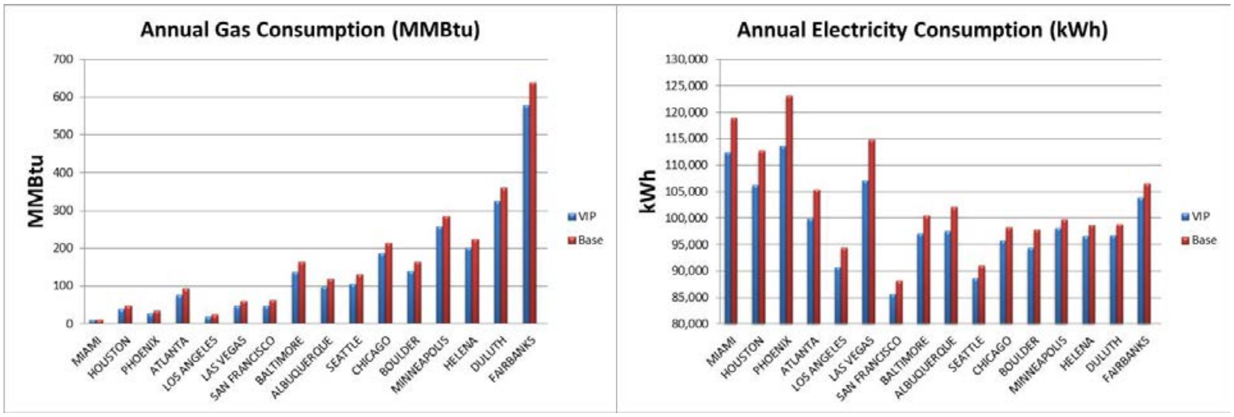

Figure 12. Annual Gas (left) and Electricity (right) Consumption in Small Office Buildings

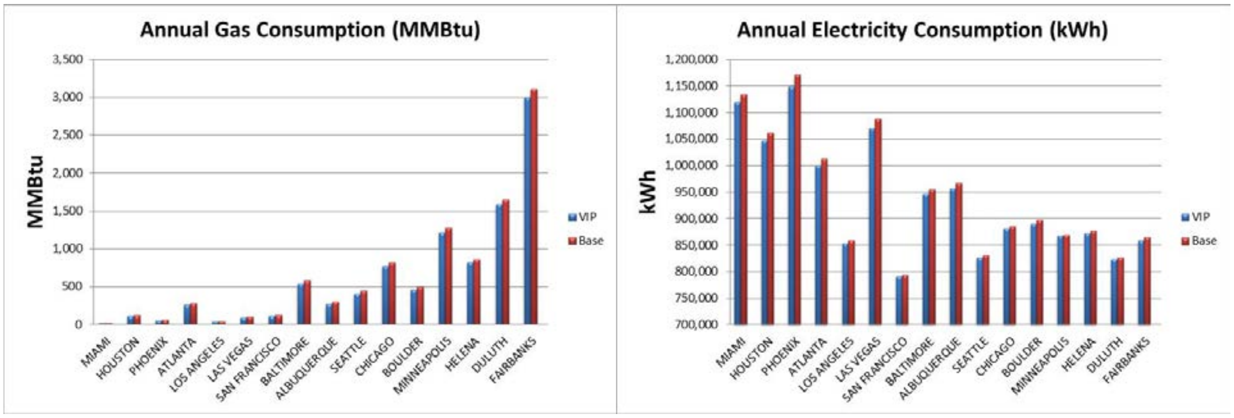

Figure 13. Annual Gas (left) and Electricity (right) Consumption in Medium Office Buildings

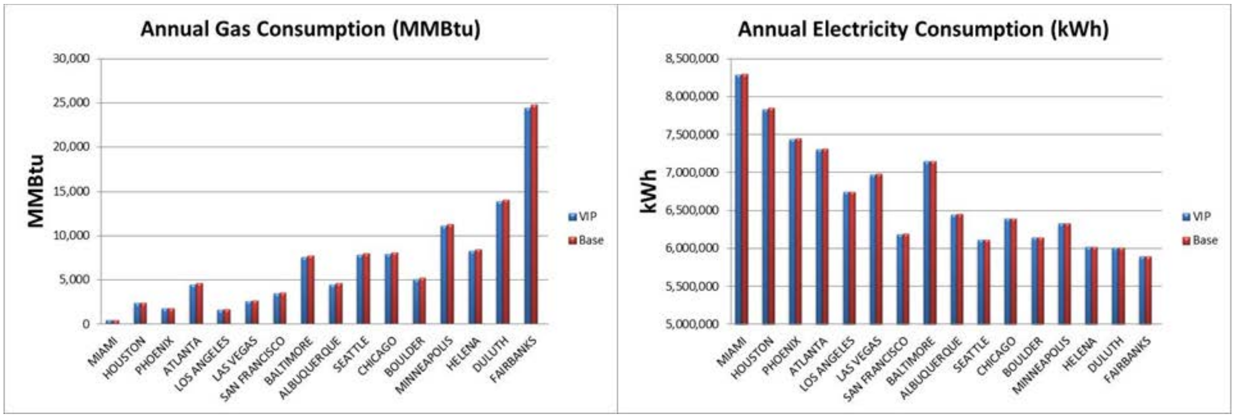

Figure 14. Annual Gas (left) and Electricity (right) Consumption in Large Office Buildings

The following are the key findings from this project’s energy modeling efforts.

- The marginal energy savings attained by going from code-compliant roof insulation to an R-50 insulation tend to be greater in climate zones that are more extreme, such as Fairbanks, Alaska, or the Southwest.

  - Even in the extreme climate zones, the marginal energy savings of an R-50 roof are less than what one might expect to find. This is due to the relationship of heat transfer rates and R-values, which leads to diminishing returns as one increases R-values.

- As in any energy economic analysis, site-specific utility rates and construction costs must be applied to a particular facility. The representative utility savings used in this study show that there is merit to using low-cost insulation to attain an R-50 insulation value on a new or retrofitted roof.

- If site conditions prohibit the use of conventional insulation to attain an R-50 rating, such as at the Camden facility, careful consideration must be given to other economic factors, such as the following, before going forward with a VIP installation.

  - The issues preventing the use of conventional insulation and the cost of overcoming these barriers.
  - The local cost of VIPs.
  - Availability of local contractors comfortable with VIPs in roofing applications so that costs will not be inflated to cover perceived risk in working with VIPs.

  - Whether the unit cost of energy is high enough that energy savings will cover the extra cost of using VIPs. The factors that go into this equation are unique to each site and must be carefully analyzed to ensure that any additional energy savings due to the higher marginal cost of insulation and VIPs will more than offset the higher cost of the insulation.

The building type (*i.e.,* whether the building is a low-, mid-, or high-rise) has a significant effect on heat loss through the roof and the payback on additional R-value.

Summary Findings and Conclusions

The VIP roofing project at the U.S. Post Office and Courthouse, Camden, New Jersey, was evaluated in terms of lessons learned under the GSA GPG program. For a variety of reasons, it was not possible to determine the exact effects that the VIP system had on overall building energy consumption. The main focus of the project was to capture the lessons learned at Camden in one document. This document is meant to be a useful guide for other facility managers who are considering using VIPs in a roofing installation.

Key lessons learned include the following.

- VIPs have a higher insulating material cost than conventional roof insulation systems. However, their higher insulating properties allow them to achieve higher R-values with much less thickness than the conventional system. If the thickness of a conventional insulation dictates that significant construction costs are needed to modify brickwork, windows, or flashing, the added material cost of the VIP panels might be offset. Careful consideration must be given to each situation to determine the viability and economics of each alternative at a particular site.

- VIPs are more robust than originally expected.

- Keeping the roof surface clean when installing the panels is important to ensure they are installed without puncturing the foil coating on the panels.

- Attention must be paid to remnants from the old roofing system, such as metal fasteners that protrude above the roof deck.

The VIP vendor is a critical partner in the project’s success. Vendor selection should be based upon the vendor’s willingness and ability to meet the material specification not only for R-value but also for life of product.

Installation will go more smoothly if the panel arrangement is preplanned and custom-sized panels are ordered.

IR images taken after the installation showed that when the above steps are taken during installation, the panels are quite durable and show no signs of having their thermal properties compromised.

Energy modeling showed that, for typical GSA buildings, there is likely merit to using conventional roof insulation to attain an R-50 value. However, the building type and site-specific utility and construction data must be used when evaluating each individual case.

If site situations dictate that conventional insulation is not feasible to reach the R-50 value, then VIPs can provide an alternative. However, the added cost of the panels dictates that a very careful analysis of all factors be conducted to ensure that the project will still be economically feasible.

V. Appendices

A. Building Energy Simulation Results

The annual energy consumption and savings due to VIP roofs in typical small, medium, and large office buildings for several selected locations covering all 16 U.S. Department of Energy climatic zones are given in Tables A1–A6.

Table A1. Electricity Consumption and Savings for Small Office Buildings

Location	Electricity consumption (kWh)	Electricity consumption (kWh)	Savings	Savings
	Base	VIP	kWh	%
MIAMI	118,930	112,543	6,386	5.4
HOUSTON	112,742	106,279	6,463	5.7
PHOENIX	123,067	113,703	9,364	7.6
ATLANTA	105,395	99,908	5,488	5.2
LOS ANGELES	94,489	90,693	3,796	4.0
LAS VEGAS	114,894	107,195	7,700	6.7
SAN FRANCISCO	88,239	85,711	2,529	2.9
BALTIMORE	100,549	97,116	3,433	3.4
ALBUQUERQUE	102,071	97,464	4,607	4.5
SEATTLE	90,970	88,713	2,257	2.5
CHICAGO	98,201	95,769	2,433	2.5
BOULDER	97,769	94,398	3,371	3.4
MINNEAPOLIS	99,693	98,159	1,534	1.5
HELENA	98,716	96,666	2,049	2.1
DULUTH	98,861	96,842	2,019	2.0
FAIRBANKS	106,560	103,967	2,594	2.4

Table A2. Gas Consumption and Savings for Small Office Buildings

Location	Gas consumption (MMBtu)	Gas consumption (MMBtu)	Savings	Savings
	Base	VIP	MMBtu	%
MIAMI	11.0	10.5	0.5	4.2
HOUSTON	48.2	39.8	8.4	17.5
PHOENIX	35.1	28.2	6.9	19.6
ATLANTA	93.7	76.2	17.4	18.6
LOS ANGELES	24.9	20.1	4.8	19.4
LAS VEGAS	61.0	48.7	12.3	20.2
SAN FRANCISCO	62.8	47.2	15.6	24.9
BALTIMORE	164.5	137.7	26.8	16.3
ALBUQUERQUE	119.5	97.4	22.1	18.5
SEATTLE	131.5	106.1	25.4	19.3
CHICAGO	213.9	186.4	27.5	12.9
BOULDER	163.9	139.5	24.3	14.8
MINNEAPOLIS	285.3	257.3	28.0	9.8
HELENA	224.9	201.2	23.8	10.6
DULUTH	359.9	325.0	34.9	9.7
FAIRBANKS	637.9	578.3	59.6	9.3

Table A3. Electricity Consumption and Savings for Medium Office Buildings

Location	Electricity consumption (kWh)	Electricity consumption (kWh)	Savings	Savings
	Base	VIP	kWh	%
MIAMI	1,134,209	1,119,744	14,465	1.3
HOUSTON	1,061,918	1,046,763	15,155	1.4
PHOENIX	1,170,623	1,148,766	21,857	1.9
ATLANTA	1,013,242	999,414	13,827	1.4
LOS ANGELES	859,405	852,653	6,752	0.8
LAS VEGAS	1,088,362	1,071,123	17,239	1.6
SAN FRANCISCO	793,522	790,837	2,685	0.3
BALTIMORE	955,854	946,521	9,334	1.0
ALBUQUERQUE	967,069	956,065	11,004	1.1
SEATTLE	830,941	825,903	5,038	0.6
CHICAGO	886,413	881,369	5,044	0.6
BOULDER	896,977	890,704	6,273	0.7
MINNEAPOLIS	869,415	867,947	1,468	0.2
HELENA	876,362	872,886	3,476	0.4
DULUTH	826,139	823,927	2,212	0.3
FAIRBANKS	864,430	859,662	4,768	0.6

Table A4. Gas Consumption and Savings for Medium Office Buildings

Location	Gas consumption (MMBtu)	Gas consumption (MMBtu)	Savings	Savings
	Base	VIP	MMBtu	%
MIAMI	23.5	23.3	0.2	1.0
HOUSTON	126.0	117.5	8.5	6.8
PHOENIX	62.3	57.9	4.4	7.0
ATLANTA	281.8	261.7	20.2	7.2
LOS ANGELES	45.3	42.9	2.4	5.3
LAS VEGAS	108.6	98.9	9.8	9.0
SAN FRANCISCO	130.7	116.0	14.8	11.3
BALTIMORE	578.9	540.9	38.0	6.6
ALBUQUERQUE	298.1	271.5	26.6	8.9
SEATTLE	445.8	408.4	37.3	8.4
CHICAGO	819.3	771.1	48.3	5.9
BOULDER	496.4	457.7	38.7	7.8
MINNEAPOLIS	1,275.3	1,217.5	57.7	4.5
HELENA	863.9	817.3	46.7	5.4
DULUTH	1,654.0	1,582.1	70.9	4.3
FAIRBANKS	3,110.2	3,000.0	110.2	3.5

Table A5. Electricity Consumption and Savings for Large Office Buildings

Location	Electricity consumption (kWh)	Electricity consumption (kWh)	Savings	Savings
	Base	VIP	kWh	%
MIAMI	8,303,335	8,288,514	14,821	0.2
HOUSTON	7,848,912	7,832,839	16,073	0.2
PHOENIX	7,452,134	7,435,168	16,966	0.2
ATLANTA	7,317,053	7,309,486	7,568	0.1
LOS ANGELES	6,744,052	6,741,724	2,328	0.0
LAS VEGAS	6,986,847	6,971,581	15,266	0.2
SAN FRANCISCO	6,191,372	6,189,621	1,751	0.0
BALTIMORE	7,152,789	7,151,689	1,100	0.0
ALBUQUERQUE	6,450,337	6,443,306	7,031	0.1
SEATTLE	6,116,436	6,115,107	1,329	0.0
CHICAGO	6,398,075	6,396,415	1,660	0.0
BOULDER	6,147,055	6,143,531	3,524	0.1
MINNEAPOLIS	6,334,386	6,333,843	543	0.0
HELENA	6,021,637	6,020,879	759	0.0
DULUTH	6,007,905	6,007,536	369	0.0
FAIRBANKS	5,891,865	5,891,363	502	0.0

Table A6. Gas Consumption and Savings for Large Office Buildings

Location	Gas consumption (MMBtu)	Gas consumption (MMBtu)	Savings	Savings
	Base	VIP	MMBtu	%
MIAMI	499.5	490.6	8.9	1.8
HOUSTON	2,455.6	2,382.5	73.1	3.0
PHOENIX	1,821.3	1,766.0	55.3	3.0
ATLANTA	4,624.3	4,495.1	129.2	2.8
LOS ANGELES	1,673.6	1,632.5	41.1	2.5
LAS VEGAS	2,641.1	2,557.3	83.7	3.2
SAN FRANCISCO	3,531.6	3,445.2	86.5	2.4
BALTIMORE	7,712.7	7,541.5	171.1	2.2
ALBUQUERQUE	4,643.3	4,488.0	155.3	3.3
SEATTLE	7,983.9	7,834.9	149.0	1.9
CHICAGO	8,132.2	7,952.9	179.2	2.2
BOULDER	5,253.7	5,083.4	170.3	3.2
MINNEAPOLIS	11,322.3	11,143.4	178.9	1.6
HELENA	8,450.4	8,288.7	161.7	1.9
DULUTH	14,079.8	13,856.8	223.1	1.6
FAIRBANKS	24,772.1	24,428.3	343.8	1.4

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