PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

Research Agenda

ADVANCED RESIDENTIAL ROOF SYSTEMS

Prepared for:

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
Washington, D.C.

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Prepared by:

Newport Partners, LLC
Davidsonville, Maryland 21035

September 2005
Final Report

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ABOUT PATH

The Partnership for Advancing Technology in Housing (PATH), administered by HUD, is focused on accelerating the adoption of new technology by the housing industry to improve the value of new and existing homes. Through public and private efforts in technology research, information dissemination, and barrier analysis, PATH is adding value to seven of the nation's key housing attributes:

> ***affordability <> energy efficiency <> environmental impact <> quality***
> ***durability and maintenance <> hazard mitigation <> labor safety***

PATH is working to accomplish its goals by working with a variety of partners from industry, government, and the research community. PATH supports basic and applied research, as well as extensive marketing activities. Basic research includes cooperative efforts with laboratories, manufacturers, and universities. Applied activities are often carried out with the involvement of builders, remodelers, manufacturers and others up and down the supply chain who contribute to the construction of housing in the United States.

PATH research identification process

PATH has two processes to identify short-term and long-term research needs. First, PATH has ongoing work, referred to as roadmapping, that addresses the identification and prioritization of PATH research and related activities. Efforts of PATH have resulted in the following five PATH roadmaps that describe research needs and priorities in specific areas:

1. *Information Technology to Accelerate and Streamline Home Building*
2. *Whole-House and Building Process Redesign*
3. *Energy Efficiency in Existing Homes*
4. *Technology Roadmapping for Manufactured Housing, and*
5. *Advanced Panelized Construction*

These roadmap efforts address broad areas or sectors of the industry such as whole-house design, energy efficiency in existing homes, or manufactured housing. As such, the roadmaps are strategic planning tools. PATH is actively supporting research from the roadmaps and will periodically assess the need to update the documents as work is completed or as industry needs or issues change over time.

A second category of activity in the research identification process conducted by PATH is the development of research agendas related to more-narrow and specific systems or issues. PATH Research Agendas identify research topics and projects for both public and private entities to undertake. This report on advanced residential roof systems is the second research agenda prepared by PATH. The first research agenda, *Building Moisture and Durability: Past, Present and Future Work*, was completed in 2004.

The roadmaps and research agenda reports can be viewed or downloaded from the PATH website at www.pathnet.org.

Summary of research agenda activities

Five overall “strategies” that identify research activities related to residential roof systems are described in this report. These are as follows:

1. *Hazard mitigation.* This strategy has an objective of reducing damage to roofs during wind, seismic, and hail events.

2. *Improve the energy performance of roofs*. This strategy addresses methods to increase energy efficiency of existing roof systems. It also calls for research that will turn the roof from a source of energy losses to a system that can produce energy.

3. *Develop roof systems that are safer and more efficient to construct.* This strategy is further divided into two areas. The first area has an objective of improving safety and construction efficiency through the development of standard protocols, software and other aids for designers and contractors. The second area has an emphasis on tools, equipment, and process improvements.

4. *Expand or maximize the functions of roofs.* This strategy emphasizes the use of the attic and other parts of the roof to provide more useable space, increase the efficiency of mechanical equipment, and facilitate the introduction of renewable energy technologies into housing.

5. *Improve the environmental impact of roofs*. This strategy addresses the need to reduce the impact of storm-water runoff from roofs. However, it also addresses environmental issues from the standpoint of increasing the durability of roof systems.

The report recognizes an overarching need throughout the strategies to increase the industry’s understanding of how roof systems perform so we can improve on them in the future. This will require the development of standards and performance criteria to address current products and technologies and to set the stage for research into advanced roof systems.

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This report is the result of efforts of a wide range of participants from the residential construction industry and related fields of manufacturing, architecture, engineering, and research. The primary author is Mark Nowak of Newport Partners LLC. Other Newport Partners' staff contributed to this effort including Liza Bowles, James Lyons, and Christine Barbour.

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Advanced Residential Roof Systems

This report is one in a series of research agendas prepared by PATH to address needs relative to a specific system or issue affecting housing. Its focus is on residential roof systems. The objective is to identify the main areas for research and development (R&D) and related activities that can lead to improved performance, increased function, or decreased environmental impact. Through this process, new technologies and additional research will be generated as the strategies and activities in this report are implemented.

Industry Participation

This report draws on a broad base of expertise and experience to help identify potential advancements related to residential roofs. The approach included identifying and convening appropriate members of industry, academia, and government to develop a research agenda that will influence both private and public-sector R&D efforts.

Figure 1 – Roadmap participants identifying strategies and follow-on activities at spring 2005 session.

The effort began with a brainstorming session in January 2005 to identify the key issues surrounding residential roofs. A second working session was held in April 2005 to identify specific activities necessary to address the key issues. A follow-up web conference was held in May 2005 to further explore specific activities.

Deliberations throughout the meetings suggest that, although today's roof systems and materials can and usually do function as designed or expected, we don't fully understand the way roofs perform in many areas such as ventilation practices and moisture transport. How and when to apply some practices is often debated and somewhat controversial.

Generally, the strategies and activities identified in this report will result in improvement in one or more of the following:

- durability,
- maintenance,
- first or lifecycle cost,
- resistance to wind, seismic, hail, and other loads,
- energy or environmental performance,
- safety,

- labor efficiency,
- increased function of interior or exterior roof space

The list above goes beyond the performance expectations we generally have had for roof systems in the past – to keep water and other elements out while maintaining structural integrity. These basic expectations should always remain as new technology is developed that increases functionality or performance in other ways.

In the process of identifying and conducting research, it is also important to understand the needs, benefits, and limitations of participants up and down the supply chain, especially those individuals or companies who build homes and install and maintain products in them. Thus, the next section of this report describes the products typically used in residential roof systems and the people who work with them. This is followed by the description of specific strategies and activities that evolved from the sessions with participants who assisted in this project.

The Situation Today

Describing the current state of the roofing industry first requires a definition of the systems used in residential roofs. Most people would likely define the roof as the covering. They see the shingles, tile, metal, slate, wood shakes, or other material as the roof. However, defining the roof as just the covering would severely limit the opportunities to develop advanced roofing systems.

The tendency to focus only on the covering when discussing the roof may in fact be a significant part of one issue that this report is trying to address – installing systems in a home without regard to how they impact other parts of the home. The building science field continues to show that there is a need to look at all of the systems in homes and how they perform together, not only to avoid potential negative consequences but also to take advantage of positive interactions.

In today's home building process, few people ever communicate with the roofing contractor on the home's design, yet consider the roof as part of a whole-house or systems-based design approach. The result is the current fragmented situation where the carpenter builds the frame in isolation, the roofer puts on the shingles or other covering (in isolation), another contractor puts in the insulation (in isolation), and the HVAC contractor does whatever it takes to make the ducts fit.

This is not to say that the market has not made some moves toward a systems-based approach or to otherwise bring innovation to the roof design. For example, homes built in conjunction with the U.S. Department of Energy's Building America program often have ducts and mechanical equipment placed in conditioned attic spaces to help reduce energy losses. In addition, many manufacturers provide roof panels that contain the structure, sheathing, and insulation in a single product. A few companies have also begun to integrate photovoltaic material into shingles and metal roof coverings. Overall, however, the industry still relies on very traditional materials and processes.

For this overview, a broad definition of the roof is adopted so that all systems and subsystems above the top of the wall at the ceiling are considered. The main focus is thus on the components that make up a roof system and the companies who install them.

The following sections describe the size of the markets followed by a discussion of the characteristics and/or market share of the predominate types of materials or systems used in housing today. It concludes with a description of the installers of roof systems in today's homes.

Housing and roofing markets

The potential impact of advanced roofing technologies depends on the size of the new construction and replacement markets. For the year 2004, U.S. Census data shows an estimated 1.6 million single family home starts (Census 2004). This is just over 1% of the 120 million homes that existed in 2003. Further, the Census estimates 345,000 multi-family units were started in 2004.

The Harvard Joint Center for Housing Studies recently issued a report showing remodeling expenditures totaled over $233 billion in 2003 (Harvard 2005). The same study shows consumers spent over $11 billion on roofing replacements in the same year. These numbers indicate a large opportunity for improving roof systems in both the new construction and home improvement markets.

Roof coverings

The $11 billion-plus roofing replacement market is dominated by asphalt-based shingles. The National Institute for Standards and Technology (NIST) released a report for PATH showing that asphalt-fiberglass shingles represented about 85% of the residential roofs that were replaced by consumers in 2000 (NIST 2001). Other roofing products and their share of the replacement market from the NIST study are shown in Table 1.

Table 1 - 2000 consumer replacements (for those reporting a specific material)

asphalt/fiberglass shingles	85.3%
wood shingles or shakes	5.9%
single ply/built-up	2.7%
metal	2.7%
tile	1.8%
other	1.8%

Although not part of the NIST report, the type of roof coverings in new construction generally follows the same trends as in the replacement market, with asphalt shingles the overwhelming choice for new homes. The National Association of Home Builders (NAHB) estimates that 80% of all roof coverings in new single family homes are asphalt shingles (NAHB 2004). Tile roofs make up 16.6% and cedar shakes about 1.6%.

The National Roofing Contractors Association (NRCA) also has published data that confirm the dominance of asphalt-fiberglass shingles in the single-family home roof-covering market. However, the NRCA data show that this dominance is not as great when all roofing is considered since low-slope roofs used in commercial and institutional buildings tend to be built with other materials (NRCA 2004).

Absent from the studies mentioned here are any data on the use of newer, more-advanced technologies. For example, PATH technology scanning reports, developed over the past few years to identify advanced technologies that may be applicable to housing, include newly developing composite materials, coatings, and similar advances that are a step beyond the traditional roofing materials. For the most part, the use rate of these advanced materials is just too small to be captured using the surveying techniques in the studies cited above.

Roof components

The new construction market provides an opportunity to modify much more of the roof than the existing building market. Trusses, rafters, sheathing, insulation, mechanical equipment, and attic space all represent potential areas of change for new construction. The information in Table 2 compiled from a study by the Wood Truss Council of America (WTCA) shows how some of these components are used in home construction.

Table 2 - Roof systems in homes for 2002

Type of structural frame	% of roofed area		Basic framing material	% of structural materials		Roof pitch	% of single family homes
rafters	31%		**dimensional lumber**	97%		**4/12 and less**	7%
trusses	67%		**engineered wood**	3%		**5/12 to 10/12**	86%
other	2%					**11/12 and greater**	7%

Source: *Building product trends: internal and external changes effect building materials usage in the home building industry*, Structural Building Components Magazine, December 2003

The WTCA study does not break down roof slope below 4:12. However other studies give a glimpse into how many residential roofs may be classified as low slope. Table 1 shows the percent of materials that were replaced in the year 2000. From this data, it may be inferred how many low-slope roofs exist in single-family homes by the number of replacements for materials that are used on these roofs. The types of materials replaced in 2000 suggest that overall, only a few percent of single-family homes have the types of low-slope roofs (e.g., single-ply or built-up) more typical of commercial buildings.

On the other hand, a review of the findings from the PATH technology scanning suggests that companies and organizations who serve the commercial roofing industry are conducting more and broader research on roof systems than those companies that focus on the higher-sloped roof market for homes. Thus, the commercial market offers perhaps some good opportunities to bring innovative technology into housing.

Other components in the home that could also be classified as part of the roof system include the attic, insulation, sheathing, and the mechanical systems. The conditioned attic is rare in new U.S. homes, mostly because of the heavy use of trusses and code requirements for roof ventilation. Insulation is almost always installed in the attic floor, or in the roof framing if a cathedral ceiling is used (i.e., no attic). Fiberglass batts and blown-in insulation are the most widely used insulating products in homes. NRCA's market survey indicates that polyisocyanurate is the predominate insulation material in low-slope roofs.

The roof sheathing in new homes is almost always oriented strand board (OSB) or plywood. Some older existing homes may have board sheathing. Finally, it is not uncommon to place ductwork and mechanical equipment in attics. In fact, the attic may be one of the areas where the most improvement over conventional practice could be achieved if it becomes possible to cost effectively turn the attic into a conditioned and/or useable area for storage, placement of mechanical systems, finished space, or other uses.

Advanced systems and research efforts

Although traditional subsystems (e.g. trusses or sheathing) offer opportunities to improve roof performance, there are other more advanced technologies that also need to be considered that can expand functions of the roof in homes. Structural insulated panels and photovoltaic materials integrated into a metal roof or shingle are two examples already mentioned. This last example illustrates that there are some advanced technologies that also apply to the roof replacement market.

In addition, this report is not the first time the roofing and/or building industry has come together to develop an agenda for advanced roof systems. In 1994, the Civil Engineering Research Foundation (CERF) published *Materials for tomorrow's infrastructure: a ten-year plan for deploying high-performance construction materials and systems, roofing materials section* (CERF 1994). Although the participants were mostly from the commercial sector of the construction industry, many of the topics discussed in the CERF report are applicable to residential roofs.

Among the attributes ascribed to a high performance roof in the CERF report are improved functional performance and construction efficiency. Perhaps most revealing in the CERF report is a statement that a central resource for roofing materials research does not exist in the United States. The report cites 11 different organizations that conduct roofing research.

Roof system installers

Adoption of new technologies or processes as described in this report will require the research and manufacturing communities to get information into the hands of decision makers in the industry. Thus, it is important to understand who the decision makers are as well as the people who install, repair, and otherwise maintain roof systems.

Perhaps the best way to sum up the industry is to quote the PATH *Technology Roadmap: Whole House and Building Process Redesign*, 2003 Progress Report:

> *The homebuilding industry is a fragmented industry with as many as 99,000 contractors building 1.2 million units each year. These builders rely for the most part on subcontracted labor and a wide range of suppliers, resulting in a complex management process. Furthermore, the structure works against the introduction of new technologies and processes.*

Although the number of homes built each year and the number of contractors have increased since the Whole House roadmap was compiled, the result is still a very fragmented industry. Furthermore, an NAHB analysis of the U.S. Census data shows that only about 25% of builders in 1997 constructed homes exclusively (NAHB 2000). The others are pure remodelers or do both new construction and remodeling. In either case, both the new construction and remodeling market consist of tens of thousands of contractors. These, in turn, rely on the same set of trade contractors, including roofing contractors who do the replacements and new installations for builders, remodelers, and consumers. Providing information to such a large and diverse group will remain a challenge to PATH and others who are committed to advancing the adoption of new technologies.

Performance Requirements

Throughout this report, there are frequent discussions about the need to develop standards and related performance requirements for various systems. Although this is an important issue because the lack of standards can be a barrier to widespread acceptance of technologies, it is not an easy task to define exactly what types of standards are needed far in advance of product or technology development.

The issue of standards development often arises after a technology has been in use for an undetermined period of time. These types of standards are often focused on narrow parts of the performance spectrum, such as a test method for roof coverings to resist hail as the materials age. Other examples include the development of metal-plate-connected wood trusses or other standards specific to a material or small subsystems in a home. Despite the fact that these types of standards may take years to develop, they may not be nearly as difficult to develop as those necessary for innovative products.

The functions and performances of innovative technologies and products are, by nature, difficult to anticipate. Performance requirements that are based on what we currently know about the functions of roofs may not be applicable to an innovative system that is radically different from our expectations or that encompasses multiple functions. Research cited in this document indicates that standards focusing on systems interactions, or that otherwise cut across multiple subsystems, are rare (Nowak 2004). Those that do address multiple systems or functions were typically developed in response to problems that arose over time.

In conclusion, the development of a generic standard that covers all future innovative systems may not be realistic. PATH and other participants can, however, initiate the basic work to support moving toward expanding standards, test methods, or guidelines to include, at a minimum, the types of multi-function and innovative systems that are envisioned in this report. It is important for the industry to recognize that this activity would not result in a one-size-fits-all standard, but that the process would continually need to be expanded as new innovations arise or are anticipated. On the other hand, there are also specific standards and test methods discussed in this report for which PATH can take an immediate lead role in facilitating their development.

Strategies and R&D Activities

The strategies that follow for advanced residential roof systems were identified with the following vision in mind:

> *Development of residential roof systems that serve multiple functions and improve performance over today's systems.*

The vision should be viewed through the lens of the PATH goals of improved safety, durability/maintenance, energy efficiency, environmental impact, affordability, hazard mitigation, and quality.

Although quite simple at first glance, the vision can be interpreted to be very broad. The scope is thus intended to place some boundaries around the vision.

Scope

One of the challenges of this report is to determine what falls under the definition of an advanced residential roofing system. The most obvious part of the roof to address is the covering. On the other hand, a scope that focuses on the covering would tend to rule out revolutionary advances that may be based on a completely different way of thinking than with current practice. Given these concerns and the PATH program's emphasis, the scope of this report addresses:

- Primarily residential single-family type buildings (this is a loose definition that includes low-rise multi-family and recognizes that some technologies from commercial construction could also be useful for residential buildings).
- Roofs of all ranges of pitch (low through steep slope).
- All regions of the United States.
- Roof systems, where the "system" encompasses all components and subsystems from the top of the wall at the ceiling to the roof covering.

> HUD Assistant Secretary for Policy Development and Research Dennis Shea emphasized the importance of the roofing roadmap while speaking at a tour of housing in hurricane-ravaged Florida during late 2004, "Over the next few years, we will be conducting research with the goal of making roofing systems more disaster resistant, more durable, and more energy efficient."

Specific Strategies

Five specific strategies are identified in this report. The strategies were developed by small working groups having a broad range of expertise and then reviewed by the larger group of project participants. Just as building science shows us that a change in one system in a home can have an impact in other areas of the building, modifications to different parts of the roof often have impacts elsewhere. Thus, there is some unavoidable overlap between the strategies addressed by the different work groups.

Almost all of the strategies defined in this report require improvements in our basic understanding of the performance associated with roof systems used today. This is necessary if we are to make improvements and measure their effectiveness. At the same time, it will be necessary to identify the incentives and barriers associated with new or innovative approaches. PATH or other agency programs can take an active role in removing regulatory barriers. PATH should also facilitate the formation of strategic alliances with industry to remove market, cost, and similar barriers. Finally, the results of the activities in each strategy should be used to develop best practices and to disseminate them to the industry.

The five strategies are described in the following pages.

Strategy 1: Hazard Mitigation

Background/Rationale

The U.S. National Oceanic and Atmospheric Administration (NOAA) estimates that the United States has experienced 62 weather-related disasters from 1980 to 2004 in which damages exceeded $1 billion (NOAA 2005). Hurricanes, tornadoes and other extreme wind events are well-represented on the list. In fact, the top events include the 2004 trio of Hurricanes Frances, Ivan, and Jeanne that struck Florida and resulted in over $27 billion in combined damages.

A strong case can be made that the design and construction of the roof system is one of the most important factors influencing the degree of damage to homes during wind events. In a study following Hurricane Andrew in South Florida, the authors conclude that water damage to the interior of homes had the greatest impact on overall building damage, and that water damage can be attributed to widespread envelope failures, particularly to roof coverings and openings (Crandell 1993). Roofing system failures contributed to significant water damage in over 77% of the homes surveyed.

Figure 2 - Roof covering damage on Maryland home from Hurricane Isabel in 2003 (provided by Jay Crandell of ARES).

The research necessary to improve roof system performance during natural hazards covers a wide range. This includes activities ranging from basic research on the structural performance of roof systems to compiling and disseminating guidance on methods for designing, installing, and inspecting homes.

Just as the needs are broad in this area, related research completed or underway has been conducted by a broad range of organizations and individuals. Much of the work in the structural area has focused on component performance. Some specific components continue to need attention, including sheathing attachment and gable end bracing for wind resistance. However, a systems approach is necessary if larger strides are to be made toward optimizing the performance of roofs.

Perhaps the most comprehensive research program with a focus on residential buildings was the Program for Research and Optimum Value Engineering (PROVE). This program was a partnership in the late 1990s and early 2000s between HUD, the National Association of Home Builders, and other industry groups and Federal agencies. The PROVE 2003 Summary Report (PROVE 2003) describes over 33 projects either complete or in progress. Examples that relate to the roof include:

- Development of an improved hurricane wind map.
- Structural reliability and performance evaluation of housing based on performance in the Northridge Earthquake and Hurricane Andrew.
- Whole house structural testing and modeling leading to a "system-based" design methodology for lateral resisting systems of homes in wind and seismic events.
- Roof framing connections in conventional residential construction to develop a benchmark of system performance.

Other related research that may be applicable to a better understanding of residential roof systems is ongoing through the National Research Council of Canada. The SIGDERS (www.sigders.ca) project is a cooperative program with industry that has focused to date on performance of low-slope roofs under dynamic (wind) loads. They have recently produced a testing protocol that could be applied to roofs with a variety of slopes.

Although extreme wind events that cause extensive damage tend to receive the most attention, there are many other more typical hazards that contribute to extensive damage to homes, other buildings, agriculture, and infrastructure. Hail and thunderstorms are regular contributors to the damage that occurs to homes and which are particularly destructive toward roof systems. The Institute for Business and Home Safety (IBHS) recently published a study on an April 2003 storm that resulted in extensive damage in Texas (Smart 2005). The IBHS study called this "...one of the costliest storms ever to hit Texas, with an estimated total statewide insurance payment of $885 million, predominantly stemming from hail damage."

In today's market, many manufacturers offer hail-resistant roof coverings. However, performance testing on these products has not generally been conducted on materials that have been subjected to years of use under natural conditions. Over time, as the products are exposed to the elements, the performance would be expected to change. Research into the performance of roof coverings as they age is needed to fully understand the impact of selecting one product over another.

The structure and covering are two parts of the roof system that are particularly susceptible to hail or wind damage. However, the roof system also must perform well in other areas during both extreme and typical conditions. Prevention of water entry is one of the top areas of concern. Representatives of IBHS and the Florida Building Commission indicate that the advances made in strengthening homes are just one initial step, but that further work is necessary to prevent extensive damage due to wind-driven rain through soffits, ridge vents, and other penetrations (Johnson 2005).

Moisture and mold also continue to be hot topics in the housing industry, with a major focus on envelope water intrusion and HVAC related issues. Moisture is a particularly relevant issue for roofs in terms of wind-driven rain and other water intrusion during natural hazards. Although research in this area has been limited, some work is underway including a test facility about to open at Florida International University.

A final important point is that there is a wealth of experience from the past several decades on mitigation practices that have been adopted in response to natural disasters. For example, the study supported by HUD following Hurricane Andrew in 1992 showed that inadequate sheathing attachment and improper gable end bracing were not uncommon problems (Crandell 1993). Subsequently, much greater attention has been paid to nailing patterns for roof sheathing in South Florida and other high wind areas to keep the sheathing intact and help brace gable-end walls. Likewise, codes in these areas have been modified to better address waterproof membranes, tie downs, wind-borne projectiles, and other related issues.

Visionary Approaches

It is important for industry to solve problems with roof systems that result in catastrophic or premature failure during hurricanes and other natural hazards. However, industry must move beyond solving problems and also identify opportunities that can take roof systems to a higher level of performance than found in today's homes.

Consistent with a general move away from designing homes as a series of unrelated components, the benefits of a systems approach to roof design and construction should be considered. There is much redundancy in roof systems when the design is based on performance of individual parts. This is particularly important when addressing the loads from different directions at the roof-wall connection. For example, multiple connectors are often used where one multi-function connector might suffice. Related work of this type was initiated previously under the PROVE program and can provide a starting point for future work.

Another area ripe for significant advancement is non-destructive testing of roof systems. Closed-panel systems are one area where a method to inspect the system could uncover water damage that would otherwise go undetected until the damage was severe. Inspection equipment that detects moisture in a closed panel would remove some of the uncertainty associated with using these types of systems.

Specific Strategy 1 Activities

This strategy will be implemented through the following seven activities:

1. <u>Improve our basic understanding of roof performance during typical and extreme hazards.</u> This is a broad category of activities necessary to improve the efficiency of the roof system, with an emphasis on the structural design.

The first activity under this task is to develop improved test methods for wind resistance that are specifically applicable to residential roofs. The test methods should address both conventional and innovative roof systems. This effort should be under the direction of ASTM or a similar organization with a consensus process in place. PATH could have a role in this effort by supporting development of a pre-standard that could be used as a starting point for consensus standard development.

A second activity would be to apply the test methods to improve our understanding of system behavior in handling loads at connections of the roof system to the wall below. The emphasis should be on better defining roof uplift and lateral loads in each direction and applying test results to the development of modeling or analysis methods to design these connections.

Cyclic loading impact on metal and similar roof covering systems is another important issue that will require testing. Results of this testing should be used to develop guidance for engineers and architects to follow when designing with these types of products.

2. Quantify benefits of past measures taken to mitigate wind, seismic, and hail damage to roof systems. This activity would include identifying specific measures and reviewing the performance of homes that have subsequently gone through an identifiable design event. The Federal Emergency Management Agency already conducts post-disaster assessments of homes and other buildings. Likewise, the roofing industry, HUD, and various building product groups have sent response teams into Florida, California, and other areas after natural disasters. These organizations may be able to expand their efforts to include data collection on the performance of improvements initiated in response to earlier events.

3. Develop methods to assess the impact of aging on roof system durability. In California, an approach to develop slab crack ratings to assess damage potential over time is being developed. A similar approach should be investigated for the impact of aging on wind resistance of different structural materials and coverings. In addition, PATH recently initiated development of a model to assess the remaining life expectancy of roofs and other building components (Dacquisto - 2003). These and similar approaches should be investigated as potential starting points under this activity.

4. Develop cost-effective approaches for bracing of roof systems. As mentioned earlier, gable-end truss bracing to resist high winds has been identified in numerous studies as an area where proper methods could provide significant benefits. This does not need to be limited to gable ends but could be extended to bracing of the entire roof system. It should include retrofit of older structures as well as developing more cost-effective and efficient methods for new homes. An important outcome of this task would be guidelines that should be disseminated to the industry.

   A related specific activity is the need to develop fastener standards for sheathing attachment. A standard and design guidance for deformed shank nails, screws and/or other fasteners should be developed so that cost-effective bracing systems can be developed and used.

5. Develop methods to analyze and prevent wind-driven rain intrusion. Details need to be developed to address rain entry under typical and severe wind events. Some best practices for retrofitting homes exist and should be gathered and disseminated as an interim step. However, in order to obtain basic performance data on conventional and innovative approaches, test methods will need to be developed to cover a variety of roof and opening configurations such as rain screens, soffits, off ridge and ridge vents. Construction of test facilities and follow-on testing to evaluate mock-ups under simulated conditions should be a priority and feed into the development of design guidance and/or modeling approaches.

6. Develop installation and inspection improvements for roof systems. Quality of installation related to roof structural elements and substrates is important to good performance in wind and seismic events. Basic R&D is needed to identify a current baseline of installation practices, identify critical issues such as overdriving of fasteners or torque settings, and develop solutions to critical issues. Tools and methods of installation that overcome the critical issues should be identified or developed with the manufacturing community. An accompanying document or training materials should be developed for contractors and installers to educate them on proper installation and responsibilities of each trade.

   Inspection strategies are a second part of this activity that is especially appropriate for non-conventional closed-panel systems. Since these systems have critical components that are concealed, water damage often goes undetected until it becomes severe. Non-destructive evaluation methods, sensors, or even maintenance/inspection programs should be investigated to address these systems.

7. Develop standard test methods for measuring performance of roofs in hail events. Existing test methods need to be improved to qualify brittle systems that could perform well in a real event but that often fail because of the test method. Methods should also address long-term performance of roofs in hail events due to aging effects.

Strategy 2: Improve the Energy Performance of Roofs

Background/Rationale

Energy efficiency continues to be a major objective in our national policies, and residential buildings are a significant part of the solution. According to the U.S Energy Information Administration's Residential Energy Consumption Survey (EIA 2001), heating and cooling are two of the largest end uses of energy in homes. The heating and cooling energy lost directly through roofs and indirectly through ducts and mechanical equipment in unconditioned roof spaces offers large potential for improving the energy performance of homes.

It should be noted that the systems and subsystems in a roof that influence energy use also interact with many other parts of the home, especially the HVAC system's efficiency and the moisture load in homes. For example, the presence or lack of a vapor barrier, the amount and type of insulation, and the use of vents to the exterior all play a role in moisture management. These related systems are important issues to the industry and consumers due to concerns over moisture, mold, and comfort.

It is also well documented that placement of ducts and HVAC equipment in unconditioned attics has a negative impact on energy efficiency, with some estimates of duct losses as much as 30% of the heating and cooling loads. Leaky ducts and equipment in unconditioned spaces also are sources of comfort problems and contaminants that can degrade indoor air quality.

As far back as the early 1970s, researchers observed the way in which the roof system interacts with the rest of the home in terms of moisture control. Much of these observations came as a result of programs with a goal of building more energy-efficient homes. The Energy Efficient Residence program supported by HUD in the 1970s and 1980s, for example, illustrated both positive and negative interactions based on how the roof/ceiling boundary is constructed. In fact, the debate over if and how much roof ventilation is necessary to control moisture and heat build-up in attics continues to this day because these interactions can be very complex and difficult to fully understand.

As with many of the other strategies in this report, it is first important to understand not only how roof systems of today perform but also our expectations for how they should perform so that we can develop newer materials and approaches. Thus, a major activity in this strategy is to develop a baseline of performance requirements and related criteria. A better understanding of performance requirements will help to address pressing current issues including the previously mentioned roof ventilation debate and enable us to develop measurement methods and protocols for energy-efficient roof systems. Some work related to this effort is already underway by ASTM International (formerly known as American Society for Testing and Materials) through their Committee E06.66. The ASTM and similar efforts should be a starting point for further work to develop performance criteria and other expectations.

Currently available technology can play a large role in this strategy. One of the more pressing roles that PATH can play is to work with industry and codes and standards developers and agencies to remove barriers to technologies that offer improvements over existing roof construction practices. SIPs (Structural Insulated Panels) and PV (photovoltaic) material integrated into roof coverings are technologies that can address many issues in this strategy if code barriers to their use were removed or minimized.

Although this strategy has energy efficiency as a focus, researchers and product developers should realize that it overlaps with issues of durability and service life. Innovative materials should be addressed not just from their energy performance but also in regard to other performance characteristics.

Visionary Approaches

Not only is the roof system one of the remaining frontiers for reducing the amount of heating and cooling energy lost from homes, but roofs also offer many opportunities to turn the home from an energy user to an energy provider, or to otherwise develop more advanced roof systems to take us well beyond today's practices and materials. Innovations should be explored like smart roofs that can change characteristics depending on time of day, year, or local conditions. Great strides can also be made in using the roof to capture and reuse energy, or even to produce energy through PV systems or other solar technologies. Although much work needs to be conducted in these areas, there is related work underway or complete that should be examined, mined, and disseminated. Examples include:

- PV integrated into roof materials – Stand-alone solar panels often raise objections because of their appearance. UniSolar (www.uni-solar.com) has developed and markets PV systems that are designed to look much like conventional roof coverings. Their products include a shingle system that installs similar to and looks like traditional composition shingles and a laminate PV material that fits between the seams of a standing seam metal roof.
- PV Solar Energy has introduced PV roof tiles. The manufacturer claims that the tiles will produce electricity, can carry foot traffic, and can be pre-assembled to reduce the amount of work necessary on the roof. See http://www.members.optusnet.com.au/pvsoleng/ms/homepage.html.
- Cool roofs are built with materials or coatings that have a high solar reflectance and a high thermal emittance. These properties enable the roof to better reflect solar energy and to radiate it away once it is absorbed. Although factors such as location and roof construction play a role in cool roof performance, the U.S. Environmental Protection Agency (EPA) Heat Island Effect web site estimates

that building owners can save 20% or more on annual cooling energy costs using cool roofs. (See website information at http://www.epa.gov/heatisland/strategies/coolroofs.html).

The Cool Roof Rating Council maintains a rated products directory at www.coolroofs.org. Most applications target commercial buildings but cool roofs can be applicable to many homes, especially in cooling dominated climates.

Figure 3 – Cool roof. Photo courtesy of ATAS.

- Builder initiatives – Use of solar energy systems in homes is not new, although it has rarely been very cost-effective. However, several innovative builders from around the country have figured out ways to get the most out of these types of systems, to the benefit of their home buyers. Shea Homes of San Diego and John Wesley Miller of Tucson are two examples of builders who have used the roof as an energy producer by including PV and solar water heating in their homes. They rely on an approach that addresses whole-building needs, occupant issues, and is climate-specific. These types of homes offer insight into the potential for roof systems to move beyond current practice.

Figure 4 – Low profile solar pre-heat of domestic water (on left of roof) at PATH field evaluation in San Diego (source: Toolbase)

Specific Strategy 2 Activities

This strategy will be implemented through the following six activities:

1. Develop performance criteria for energy efficient and innovative roof systems. A recent comprehensive study of whole-house design approaches included a finding that standards exist or some criteria exist for almost all products in the building industry (Nowak 2004). However, many of these are not performance standards but are prescriptive in nature and specific to a single material or process. Most would not be applicable to an innovative technology or even one that slightly deviated from the norm. The study further claims that very few criteria or standards exist for cases where multiple systems interact.

   The main objectives under this activity are to develop the necessary performance criteria in a format that will allow manufacturers and others to develop new products or technologies and to facilitate their adoption through the regulatory, codes, standards, and other processes required to get a product to market. To meet these objectives, it will first be necessary to develop quantitative criteria for the systems involved in the roof and their relationship with the other systems in the home. Appropriate test methods and/or analysis methods are necessary to show conformance to the requirements. Finally, a commentary should be part of any standards or criteria-development process to explain the issues and approach to users who do not have the benefit of looking at all of the information that goes into the development of the criteria.

2. Encourage innovation on energy-efficient roofs (i.e., Solar-ready roofs). Once a roof is constructed, making changes to it by adding solar components and other features can be difficult or require extensive changes to the structure. Guidance should be developed for builders on roof designs that accommodate the later addition of solar and other emerging technologies.

3. Develop smart roof technology. Materials or roof systems that are dynamic in nature can be useful in improving energy performance of roofs. Of specific interest is a smart roof that changes characteristics based on time of day or season to optimize solar gains and losses.

4. Explore strategies for energy capture and reuse. The use or development of energy-efficient coverings should include capitalizing on the research and products that already exist for cool roofs, and helping to bring these materials and practices into the residential market.

   Another opportunity under this activity is to develop energy efficient materials or systems that combine products or functions traditionally carried out by separate materials, designers, or trade contractors. The list of opportunities can include incremental improvements such as structural, insulating foams that could provide both the roof structure and insulation in a single component and high R-value materials that could achieve maximum R-value in a reduced depth member.

   More complex improvements are also possible. Integration of PV material into a broad range of roof coverings or even roof panels is one activity that should be considered. Likewise, solar water-heating systems can be integrated into building materials to simplify the installation process. The ultimate objective would be for PATH and industry to work together to develop and demonstrate existing multi-function, advanced-panel systems that could include the structure, coverings, insulation, and even PV in a single panel product.

A previous PATH report on advanced panelized construction also identified the need to develop panel products that serve multiple functions including generating energy through solar or PV technologies. Thus, the activities under this strategy should be coordinated with the PATH panel roadmap.

5. Develop solutions to cost-effectively address ventilation and moisture transport through roof systems. The research community has developed reliable models to evaluate moisture transport. These include WUFI (see http://web.ornl.gov/sci/btc/apps/moisture/ at Oak Ridge National Laboratory web site) and MOIST (See http://www.bfrl.nist.gov/863/moist.html at NIST website). However, moisture transport through roofs is complex in itself. It is further complicated by regional practices and climate differences that are inputs into the models.

   Many resources are being spent on roof ventilation strategies that have evolved over the decades. However, some researchers question whether current roof ventilation practices are necessary in many climates, or even if they make the situation worse (Forest 1993 and Rose 1999). To further complicate the issue, many manufacturers of shingles require vented roofs as a condition to honor warranties. Prevention of ice dams is also tied into roof venting practices. Even the structural design in buildings is connected to the roof ventilation/insulation method in terms of how snow loads are analyzed.

   Given the debate over moisture, ventilation, and related issues, the industry needs to improve our understanding of venting of attics and related subsystems. This could be addressed by validating the moisture transport models, compiling appropriate weather and other input data, and using the results to develop protocols or guidance for designers and builders. It may also be useful to integrate existing models with CAD software to facilitate their use by designers. Research should consider regional differences and feed into the performance criteria tasks in Activity 1 of this strategy.

6. Accelerate acceptance of innovative energy systems. Removal of code barriers for SIPs, PV integrated systems, and other innovative products is necessary. These types of regulatory barrier removal activities are seen as a critical step in encouraging acceptance of innovations. In fact, other strategies in this report also cite removal of code barriers as an important activity (See Strategy 3, for example) for which government, under the direction of PATH, should take a lead role.

Strategy 3: Develop Roof Systems that are Safer and More Efficient to Construct

Background/Rationale

The typical practice followed in constructing roofs in the U.S. housing market offers many opportunities for building them in a safer and more efficient manner. In fact, the dual objectives of promoting safety and efficiency are closely inter-related. The methods and technologies frequently proposed to make safety improvements, such as using more prefabricated parts to reduce the need or time to be on a roof, often improve the efficiency of the construction. The opposite can also be true, where efficiency improvements create a safer environment for workers or even throughout the life of the building.

Despite the synergies that exist, the safety or efficiency objectives relative to roof systems could also be easily justified as important even if they were separate objectives. In recent years, the U.S. Occupational Health and Safety Administration (OSHA) has focused its attention on the four areas that create the most risk on a jobsite: trench and other excavation accidents, electrocutions, workers being struck or caught by equipment, and falls. These incidents account for 90% of accidents and fatalities in residential construction (NBN 2004). Falls from roofs are an important emphasis of OSHA's efforts.

As important as it is for the industry to protect people who work on roofs of homes, it is also important for the industry to find, train, and retain a skilled labor force. A focus on recruitment, training, and retention of skilled labor by itself, however, will not likely be an effective industry-wide strategy in the coming years. A shortage of skilled labor continues to plague all industry and relief does not appear to be in sight. Data from the U.S. Census and the U.S. Bureau of Labor Statistics show a widening gap between labor needed and labor available throughout the next 25 years and beyond (EPF 2001). Thus, the industry must look beyond the traditional approach of recruiting and training of labor not only to serve the market needs but to solve safety and efficiency problems.

A look at the construction process reveals that there are ample opportunities to improve the efficiency of roof system construction. In fact, one can make a case that the typical construction of a roof on a home is a piecemeal process at best. Often, the work one contractor performs has unintended impacts on another contractor's work. Rarely is an integrated or systems approach to design and construction followed. The result can lead to inefficiencies in terms of re-work, scheduling, quality, and costs.

Given the above issues, two areas are emphasized in order to achieve safety and efficiency improvements with residential roof systems:

1. Development of tools and protocols to facilitate better design and materials.
2. Improvement of methods and processes used to design and build residential roofs.

Development of tools and protocols to facilitate better design and materials.

This part of the strategy has several objectives including to encourage standardization or modularity; to facilitate later changes in the roof system without requiring extensive rebuilding; to extend the life or durability of materials used in roofs, thus minimizing the need for maintenance; and to consider safer ways of providing roof access during construction and for later maintenance, replacement, or repair of the roof.

Technologies and practices necessary to achieve a large part of these objectives already exist to a great extent. The main challenge the industry faces is getting the available solutions into design software, standards, or other protocols or tools such that the techniques are available to users in the proper context and can be implemented on a broad basis. This is not to say that all of the basic research has been completed, but enough solutions are available to make great strides in improving residential roof systems. In fact, ongoing and recent research and industry activities continue to add to the data. Examples include:

Whole-house research – PATH has supported a project over the past several years with VA Tech and Newport Partners, LLC to assess the performance of a home relative to different environmental and other factors. The research identified dozens of known interactions, many of which impact the design and construction of roof systems. These data can be molded with similar data from other studies into a set of best practices for roofs to illustrate how they can negatively or positively impact other systems in the home.

The MADE to Last Home -- HUD produced the *Builders Guide to Marketable, Affordable, Durable, Entry Level Homes* in the late 1990s to capture methods used by builders to address the project's objectives of marketability, affordability, and durability. A major emphasis of the manual, and four MADE homes built in the 2002 timeframe by NAHB Research Center, was to use as much of the roof area as possible to increase conditioned space and to serve as storage and for placement of utilities. Methods to increase the

Figure 5 - Roof panels at PATH field evaluation in Texas

durability of the roof were also stressed including minimizing roof penetrations through design and use of air admittance plumbing vents and related technologies.

ASTM Committee E06.66 – This subcommittee of the ASTM International has been working since the late 1990s to develop guidance for home design and construction with specific emphasis on durability and related issues. Much of the ASTM work could be used to develop guidance to improve the performance of roofs.

NRCA - The National Roofing Contractors Association publishes the *NRCA Roofing and Waterproofing Manual*. The fifth edition, published in 2001, is available at www.nrca.net. It covers a wide variety of roof systems and materials for new installations and replacements.

Improvement of methods and processes used to design and build residential roofs

This area has a heavy emphasis on tools and equipment to improve the materials handling and installation processes associated with roof construction. Offsite and onsite manufacturing processes such as prefabrication also fall into this area since they offer significant opportunity for improving safety and efficiency.

Much of the work under this area has not been completed and it will require extensive and long-term R&D. This is particularly true with respect to the development of new materials and equipment. However, some examples of related projects that demonstrate these approaches do exist and include:

Industrializing the Residential Construction Site – Virginia Tech researchers have been studying the residential industry over the past several years in an attempt to better understand current practices, particularly with regard to information flow and production processes (O'Brien 2000). The overall objective of the study is to help move industrialization methods to the job site. The project includes case studies of builders using varying production approaches and different levels of industrialization.

Optimum Value Engineering (OVE) Building System - OVE framing was developed as part of Operation Breakthrough, a HUD-sponsored R&D program in the late1960s to early 1970s. This project represented one of the first attempts to systematically integrate many of the major systems of a home. The main emphasis was on construction efficiency and cost reduction, mainly with the structural and envelope systems. The project team adopted a "systems" design approach. Basically they addressed the changes they planned to make in phases by first identifying innovations or changes, conducting analyses of alternative subsystems to optimize each one, and integrating the chosen innovations into the total building by considering impacts on other systems. The use of modularity in design was perhaps one of the outcomes of the OVE project that most impacted the construction of roof systems in homes.

Ryan Homes - This large-volume builder employs an approach for town homes that couples off-site wall panel production with an innovative site erection process for the floors and roof. The home is built conventionally up to the first-floor deck or slab. The first floor is then used as a staging area to construct the second-story floor and the roof assembly. The roof and floor assemblies are temporarily moved to the parking area. As the wall panels are erected, the second floor and roof assemblies are then lifted using a crane and placed on the walls. The process allows most of the roof work to be conducted closer to the ground, reducing potential for injury due to falls.

Figure 6 – Ryan Homes Project in Maryland

Visionary Approaches

PATH and the industry have an opportunity to accelerate the use of already existing tools, protocols, methods, and processes that have not yet made their way into widespread use. The best examples need to be identified and delivered to the industry as software or in other friendly and usable formats. However, more advanced or visionary improvements that could significantly impact the safety and efficiency of residential roof systems should also be explored. These improvements would require extensive research efforts, including product development efforts by the manufacturing sector. Examples include:

- Multi-function equipment. The goal would be to reduce the number of pieces of equipment required on the site by using a single piece of equipment throughout as many phases of construction as are possible.

- Advanced materials for roofs that are safer to install, more durable, and/or easier to install. This type of technology could include materials with better slip resistance or materials with little to no maintenance requirements to minimize the need for someone to be on the roof. Flexibility in terms of being able to modify the roof system could be greatly enhanced with advanced materials or connectors that make it easy to install or remove parts of the system.

- Robotics. The 2003 PATH *Whole-Building and Process Redesign Roadmap* addressed robotics from a whole-building perspective. While the 2003 roadmap acknowledged that development of robots for construction is progressing slowly because of the high investment requirements, the potential benefit for roofing applications may be one of the factors that encourages this type of investment. It's not far-fetched that dangerous roofing installation or demolition operations could be conducted by robots. Efforts by the U.S. Department of Defense for military uses are one potential source of technology transfer.

Figure 7 - U.S. Military robot. Source: http://www.redstone.army.mil/ugvsjpo/

Specific Strategy 3 Activities

This strategy will be implemented through eight specific activities as follows:

1. Develop design tools and protocols to encourage increased modularity and standardization of roof system components. This is an important aspect of the design that requires coordination with component and product manufacturers. The ultimate goal would be to allow the designer to develop a roof system that is consistent from building to building in terms of standard dimensions of components and corresponding overall layout and dimensions based on a uniform grid. Standardization and grid-based design lead to optimized use of materials and interchangeability of products and components independent of the manufacturer or supplier.

2. Facilitate designs that accommodate safe and efficient expansion or changes at a later date, especially in regard to energy efficiency, deconstruction and other environmental features. This is both a structural issue and a space-planning issue. Roof trusses and other structural components could be designed to support loads from solar or other equipment that may be added later. Openings could be roughed-in to roofs for easy access or modification. More revolutionary changes could include roof systems that can be detached from the structure and raised to add another story. These types of changes would require coordination during the design and layout of the original building to account for stairs or other future access to expanded areas.

3. Evaluate the impact of advanced materials on the roof system and subsystems. Protocols are needed to help designers determine how advanced materials impact the safety and installation efficiency of roof systems. The protocols could include methods for identifying slip resistance, ease or speed of installation, and other aspects of performance and matching them against characteristics of an advanced material.

4. Improve long-term safety through increased roof durability and safer roof access. This activity will require integrating safety into the design process at the earliest stages. One goal would be to develop a design tool or best practices that would educate designers on steps they can take to make roofs last longer and thus reduce the need to access them for maintenance or repair. A second goal would be a tool that addresses the need for access when it is necessary. For example, built-in access from the inside of the building may be one way to reach equipment without exposing workers to roof heights. Alternately, it may be possible to build in anchors or other features on the outside that allow workers to tie off or otherwise provide protection against falls.

5. Improve material handling. As more and more factory components are introduced into construction, the need for more specialized equipment will also increase. Cost effectiveness and maneuverability could be significantly improved through the development of equipment that is sized specifically for residential applications. Further, there are opportunities to develop equipment that serves multiple purposes on the site. Finally, automation or robotics may be an area where safety could be greatly improved by using machines to do risky work.

6. Facilitate use of manufacturing methods such as pre-fabrication to improve on-site and off-site activities. Falls from roofs can be reduced by performing more work at ground level or in a factory. Advanced manufacturing methods can also reduce cycle time and ease installation. Successful methods should be compiled, evaluated and disseminated to the industry.

7. Improve safety-related performance through equipment improvements. Safety equipment can always be improved to make it lighter, stronger, and easier to use. Lower-cost scaffold systems; simple-to-use equipment to remove snow, ice, or moisture; or even back-up systems to catch objects or people who may fall from a roof could be designed under this activity.

8. Encourage tools and fasteners that increase the efficiency in making connections and/or that are safer to use. Methods such as adhesives or fastener systems that are applied from the inside of the building instead of from the roof side for attaching roof sheathing could be developed and tested under this activity. These methods could be combined with pre-fabrication methods to further reduce worker risk.

Strategy 4: Expand or Maximize the Functions of Roofs

Background/Rationale

Roof systems used in homes have traditionally been designed and built to protect the building from the elements. In today's building industry, however, a number of trends are driving the concept of designing roof systems for multiple functions. Key issues include:

1. More Space. Homeowners today want more storage and living space in their houses. In fact, based on NAHB's analysis of American Housing Survey data, houses have increased in size by 37% over the last 30 years. Further, today's homeowners want a home that is 33% larger than their current home.

Figure 8 - Cape cod house from U.S. Library of Congress survey of historic houses

Roof systems can be designed to provide for additional living or storage space or they can provide an attic area that is suitable for subsequent conversion to a living space. This is certainly not a new concept in home design. The traditional cape cod design that was a common home design prior to the 1970s is a good example of a home often built to allow the space to be expanded into the roof area. Changing preferences and the move toward trusses instead of rafters resulted in a move away from this type of design over the past several decades.

Recent research has also revived interest in the use of attic space for living area. The PATH-sponsored MADE homes were based on a modernized cape cod design as a way to provide expandable space.

At least two significant issues need to be overcome in using attic space for living space - access to the space and ventilation of the roof system. In the case of access, there is not always room to insert a set of stairs into the existing home plan. Some emphasis is needed on innovative designs and/or technologies for access. For example, builders involved in the PATH Concept Home development project, which is looking at ways to provide expandable space in the home, cite the use of areas over the garage as a more affordable means to expand the living space.

Ventilation of the roof and the related placement of insulation are controversial issues in the building science community. The U.S. Department of Energy's Building America program is supporting research in this area. Likewise, ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.) continues to debate how residential roof ventilation should be approached in its publications.

2. Location of Mechanical Equipment. In the past two decades the building science community has gained a greater understanding of the efficiency impacts of locating mechanical equipment in unconditioned spaces like traditional attics. At the same time, larger homes have increased the use of dual-zone HVAC systems where one system is located within the attic.

Placing HVAC equipment and ducts outside of the thermal envelope (i.e., the insulation) and air-pressure envelope (i.e., the air barrier boundary) of the building can result in significant heat loss/gain, entrainment of unconditioned air into ducts, and air pressure imbalances within the house. This realization has led to research on innovative roof and attic systems that can still host HVAC equipment, but within a more tempered environment. The Building America program is one of the research efforts taking the lead in this area.

3. Integration of Renewable Energy. As renewable energy technologies like solar photovoltaics (PV) continue to improve in terms of performance and cost-effectiveness, there is increased interest in residential rooftop applications. This includes the installation of PV arrays in new and retrofit construction, as well as longer-term issues like designing today's roof systems such that they could easily incorporate renewable technologies in the future. In this way, as the economics and technologies continue to evolve, today's homes can easily adapt and integrate renewable energy in the future.

Rooftop-mounted PV systems are one example of integrating energy production within the roof. Solar water-heating systems are another example of adding an energy collecting component to the roof system. However, in both of these examples, an energy generating system is *added* on to the core roof structure. Opportunities for advancements can also be realized when a home's roof is being replaced. In this case, a single new product could be designed to serve two functions, such as shedding moisture and also collecting solar energy.

This topic is closely related to Strategy 2 activities to encourage innovation on energy efficient roofs.

4. Storm Water Runoff Impacts. In many areas of the country the extent of development has significantly altered storm water runoff behavior and associated environmental impacts such as erosion, sedimentation, and pollutant transport. The impervious area created by residential rooftops is a significant factor in this issue, leading to interest in roof systems that can mitigate storm water impacts.

This issue of storm water runoff was viewed as an important enough topic that a separate strategy was developed to address it along with related methods to reduce the environmental impact of roofs. Thus, the storm water issues with roofs are covered as specific items under Strategy 5.

Visionary Approaches

Incremental changes to parts of the home are necessary to address this strategy, as is the need to develop guidelines and approaches for improving our use of existing technologies. However, more innovative approaches that require more risk on the part of research supporters are also necessary. These include:

1. Developing a trombe wall system that could work on roofs. Typically, the heavy mass material necessary for these types of systems to efficiently store heat from the sun is not used in residential roof construction. If successful, this could open up roof systems to pre-fabricated concrete or masonry panel products or other systems like Insulating Concrete Forms (ICFs).
2. Wind generation of electricity. The potential for this technology in housing has not been well explored. Wind generation is a technology with great potential in the area of renewable energy.
3. Partial use of the attic space for utility placement. The typical approach to moving ducts and equipment into the conditioned space is to condition the entire attic. However, there are alternatives that may prove as beneficial but not require as much cost or effort. These include modified truss configurations that have utility cores or spaces built into them inside the thermal envelope.

Specific Strategy 4 Activities

Specific activities under this strategy are focused on providing additional living or storage space, locating mechanical equipment in a tempered environment, and incorporating energy production and storage devices now and during future modifications. In carrying out these activities, PATH and others should keep in mind that additional functionality of the roof system must be viewed as secondary to the fundamental objective of keeping a building dry and protected from the elements. Specific activities under this strategy are as follows:

1. Develop innovative systems that provide for usable space in the roof/attic area. One part of this requires the identification and dissemination of design alternatives that would allow the traditional attic to be converted to useable space. A second part is the development of alternative materials. Examples of advanced materials already mentioned include structural insulating foams that could provide both the roof structure and insulation in a single component and high R-value materials that could achieve maximum R-value in a reduced depth member. These types of advances would not necessarily result in additional living space by themselves. However, they would make it easier to build conditioned attic space. Alternative materials for roofs are also part of Strategy 2 and are covered there as specific activities rather than in this strategy.
2. Develop roof systems that create useful space above the traditional roof surface. The roof above a home rarely is used for purposes other than to support the roof covering. Yet this area could serve other functions. Roof-top decks, storage, mechanical rooms and similar uses should be identified and guidance on their use developed and disseminated to the industry.

3. Develop roof systems that provide a tempered environment for mechanical equipment. The most often cited example of this is the conditioned attic space described in item 1. However, there is an opportunity to also conduct research on other innovative approaches that may not include the entire attic but only a part of it or its components. Modified truss designs or similar approaches that provide built-in utility chases or areas inside the thermal envelope should be identified, evaluated, and demonstrated to the industry.

4. Explore the development of trombe wall designs suitable for roof applications. These systems are used on walls to collect heat from the sun and store it in a masonry or other mass assembly. They could be applicable to roofs, especially on steeper pitched assemblies. At a minimum, the industry should evaluate the feasibility of this approach for roofs.

5. Explore the development of roof systems that would allow for the addition of components for wind generation of electricity. Wind generation is a viable renewable energy resource in some parts of the country. A study is necessary to determine if wind generation could be feasible as part of a residential roof system.

Strategy 5: Improve the Environmental Impact of Roofs

Background/Rationale

Roof systems impact many areas of our environment. Perhaps at the top of the list are the impacts on the quality of water that leaves a site and eventually makes its way to a waterway or infiltrates into the ground. This issue has a strong regulatory side to it.

Beginning in March of 2003, the National Pollutant Discharge Elimination System (NPDES – see http://cfpub.epa.gov/npdes/stormwater/swphases.cfm) under the U.S. EPA's direction, moved into an expanded phase. Under Phase II of the program, construction projects that result in more than one acre being cleared fall under the program. The impact of this on construction can be summed up as follows: Prior to the NPDES, the main objective of stormwater management was typically to get the water off the site without causing downstream flooding. Water quality was only addressed in terms of sediment control except in critical areas or exceptional circumstances. The NPDES expanded the objectives to include a stronger focus on maintaining water quality.

Other regulatory requirements have similar impacts on construction as the NPDES including the Coastal Zone Reauthorization Act of 1990 (www.epa.gov/owow/nps/czmact.html) and many local or state ordinances. However, the regulatory issues are not the only drivers in this area. Environmental values are changing, especially around critical areas like Puget Sound or the Chesapeake Bay. Concerns over the environment are displayed by the media, citizens groups, environmental advocacy groups, and by the general population, bringing pressure on everyone to reduce our impact on the environment.

One approach to improving stormwater management is to reduce the amount of runoff leaving a site by minimizing impervious areas. Roof systems can be a major contributor to impervious area on a building site. In fact, many jurisdictions have set maximum limits on the amount of impervious area, and thus the size of the home, as a condition for a building permit.

Methods to minimize the impact of roof runoff is an important area on which to focus research. Activities could include development of methods that capture runoff, retain it, or reduce it from the start through best management practices; development of innovative materials, green or vegetative roofs; and other approaches.

Although runoff from roofs is a major theme under this strategy, other areas should be addressed because of their impact on the environment. Some of these cross over with the topics in other strategies in this report. For example, the contribution that roofs make to the heat island effect was identified as part of this strategy, but it is also closely related to the cool roof topic in Strategy 2.

Increasing the durability of roof systems through improved materials and practices was another major theme. This overlaps with other strategies in this document including the need to create longer-lasting materials and better construction details to keep moisture away from susceptible components. The lack of good data on current materials and their life expectancies is also a barrier to improving the durability of roof systems.

Visionary Approaches

Like the other strategies, many of the activities under this strategy do not require basic R&D but rather a mix of some applied research and proper packaging and dissemination of current information. However, if we are to move beyond problem solving with existing roof systems and into exploiting opportunities to raise the performance bar, then some more revolutionary changes will need to occur.

Perhaps the most dramatic changes are in the development of new materials. This will require extensive research between PATH and the manufacturing and academic communities.

One goal for industry to pursue is to develop a 100-year, low-maintenance, affordable roof. This could be produced from material in use today, but will more likely require development of a composite material that combines the long life of materials like metal or slate with the low maintenance and affordable characteristics of composite shingles and similar products.

Specific Strategy 5 Activities

This strategy will be implemented through the following four activities:

1. <u>Develop options for reducing the negative impacts of impervious surfaces.</u> As buildable and desirable land becomes more scarce, communities encourage infill in response to environmental concerns over green fields development, and building puts more pressure on the environment in critical or sensitive areas (e.g. estuaries), the roof area will become a larger relative part of the impact of runoff from impervious areas.

   Methods that can reduce the roof system's impact include decreasing the roof footprint size without necessarily reducing square footage of the home. This could include identifying design approaches such as taller structures with the square footage spread out over more stories, but requiring a smaller roof area.

   A related approach would be to find ways to handle rainwater that falls on the roof so that it has less impact than if it were simply allowed to run off through gutters or otherwise drain off the roof.

Approaches under this option could include collecting and reusing rainwater before it drains from the roof or developing technologies that slow runoff time and reduce peak runoff volume. The development of absorbent roof materials is a technology which could provide multiple additional functions. This may even lead to the development of methods to pre-soak roof structures that are in the path of a wildfire. Green or vegetative roofs that retain some or all of the water are another area where R&D could bring this concept to reality for residential roof systems.

An important item with all of these approaches is to measure the impact of solutions so that performance information is available to the industry. Measurement of impacts could be accomplished through field evaluations, case studies, laboratory testing, or a combination of these approaches.

2. Reduce the heat island effect. The heat island effect is related to an increase in temperatures in and around urban areas. EPA estimates that air temperatures can be as much as 10˚F higher over urban areas compared to surrounding countryside (EPA 2005). These higher temperatures translate into higher air conditioning costs. In addition to planting trees and using cool pavement materials, the roofs of buildings can be changed to help mitigate the heat island effect.

   Approaches to mitigate the roof impact on the heat island effect include the use of "green" or vegetative roofs and cool roofs. The cool roof topic was raised in multiple strategies under this report and is addressed as a specific activity under Strategy 2. Thus, the efforts in this strategy should be focused on the development of vegetative roofs for residential buildings.

3. Create innovative or improved environmentally friendly products. Before new products can be developed, we first need to understand how current materials perform. Thus, the first step in this area is to develop real measures of life expectancy for the different material types used in roof coverings and related components. This will provide product manufacturers and researchers with a baseline on which to improve.

   After the measures of life expectancy are provided, a number of improvements can be made through the development of materials or products that result in an affordable, low-maintenance roof covering. The goal of a 100-year life expectancy was established. Likewise, the establishment of life expectancy measures will enable the development of roof products that can be reused, recycled, or otherwise designed to reduce waste.

4. Develop better methods for addressing roof penetrations. Water damage is one of the largest threats to roof durability. There is a need to prevent entry through self-sealing flashing systems for use around vents, skylights, and other openings in the roof. Emphasis should also be placed on compiling design techniques to reduce or eliminate the need for penetrations in the first place.

The work group for this strategy also discussed the need to address the growing controversy over attic or roof ventilation requirements. Scientific analysis is needed to resolve the debate over the need to ventilate roofs in various regions for each house type and for different roof materials and systems. This topic was also raised in Strategy 2 and is addressed as a specific action item in that part of this report.

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