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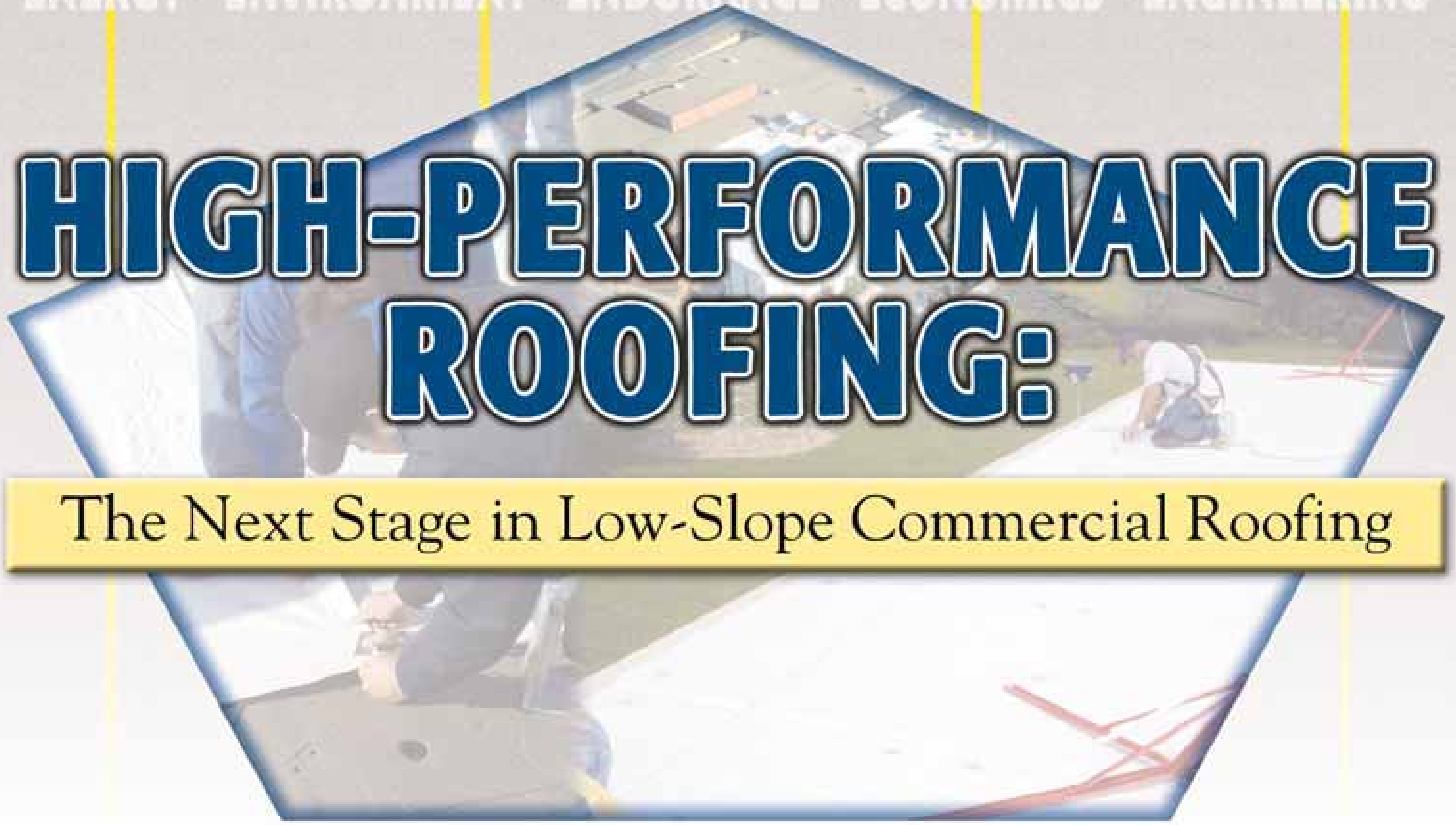

HIGH-PERFORMANCE ROOFING:

The Next Stage in Low-Slope Commercial Roofing

By Drew Ballensky

Cool and sustainable roofing emerged as separate, closely related commercial roofing trends about ten years ago. Today, both trends continue to gain momentum, and they are driving change in commercial roofing market dynamics, roof system design and manufacture, product innovation, industry initiatives, selection priorities, building codes, and legislation. They are also sparking controversy as specifiers, contractors, and building owners sort through their perceived benefits and potential shortcomings.

Cool and sustainable roofing have been embraced, discussed, and debated by a host of industry associations, including RCI. Meanwhile, government agencies at the federal, state, and local level are implementing more standards, regulations, and incentives to encourage or mandate the use of energy-efficient and/or sustainable roofing systems.

These actions, combined with powerful economic drivers, are creating increased demand for a new class of High-Performance Roofing (HPR) systems that can satisfy traditional performance criteria – installed cost, performance, and longevity; as well as relatively newer criteria – life-cycle costs, energy efficiency, and preservation of the environment.

The High-performance Trend

High-performance roofing is part of a larger trend toward high-performance buildings, especially in schools and government facilities. The Department of Energy (DOE) defines the benefits and objectives of high-performance buildings and "whole-building design" as:

- Energy consumption reductions of 50 percent or more.
- Reduced maintenance and capital costs.
- Reduced environmental impact.
- Increased occupant comfort and health.
- Increased employee productivity.

High-performance roofing systems can contribute significantly toward all of these objectives. As part of a high-performance building, an HPR system acts as a vital, effectiveness-enhancing umbrella that protects the facility from the elements, enhances the function of other building components, accommodates ongoing operations, and contributes to the health and activities of occupants. Contrary to popular myth, HPR systems that are cool and sustainable do not necessarily involve additional costs. In fact, one essential definition of an HPR system is that it reduces life-cycle costs (LCC) significantly without substantial tradeoffs in performance or longevity.

The Five E's of HPR

While definitions of high-performance roofing are still evolving, all HPR protective umbrellas have five important, closely related attributes that make them relatively cost-effective, water-resistant, reliable, long-lasting, energy-efficient, and environmentally friendly. Think of them as the "Five E's":

- Energy
- Environment
- Endurance
- Economics
- Engineering.

HPR E-1: ENERGY

While there is nothing new about energy conservation in building design, it is increasingly important for many reasons. Rising costs led nearly 75 percent of building owners to agree that energy efficiency was an "extremely important" factor in selecting a replacement roof in a 2003 sur-

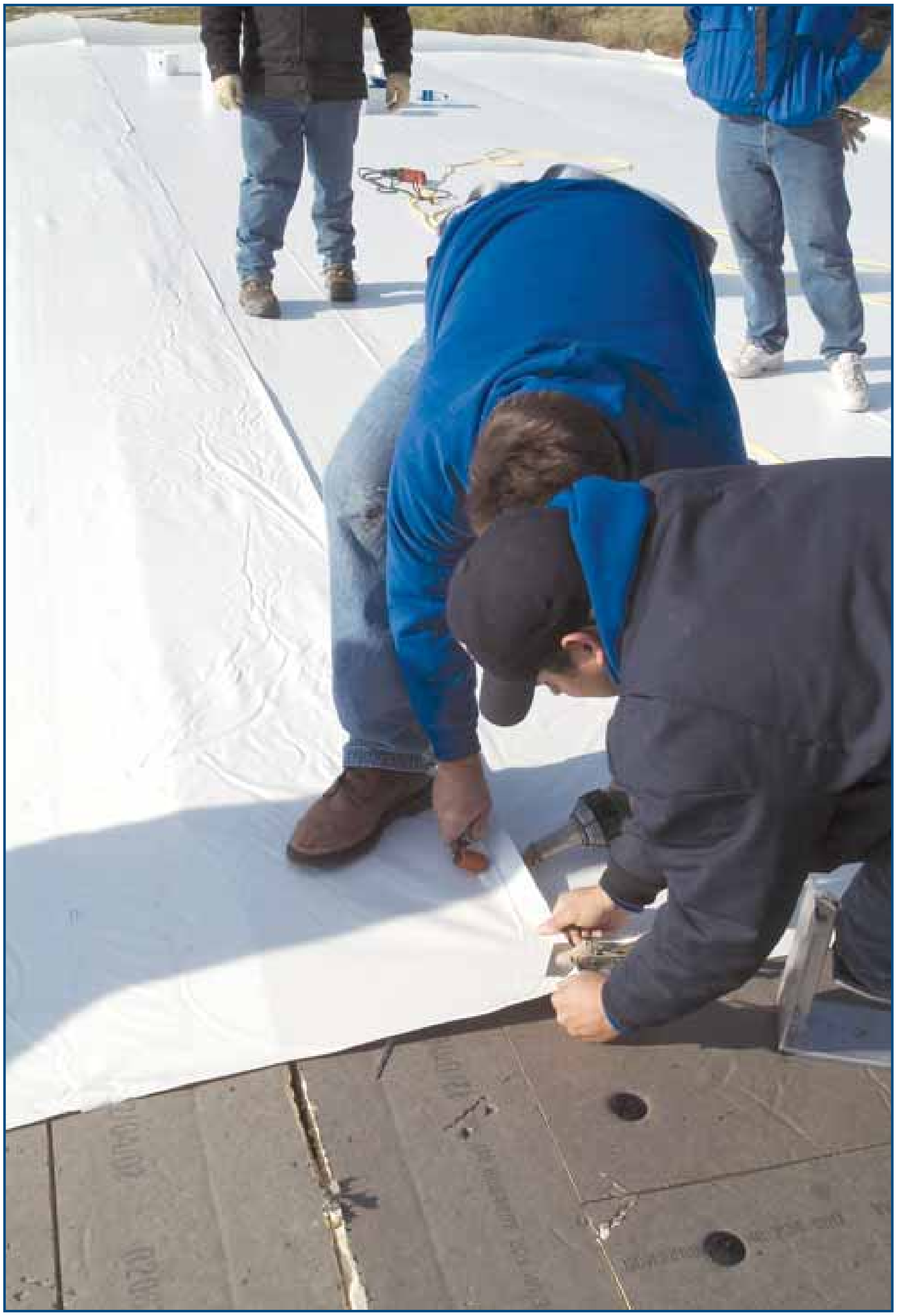

Photo 1 – Thermal insulation is a crucial part of HPR systems, reducing heat loss through convection in winter and controlling heat gain through conduction in the summer. Since cool roofing surfaces are significantly cooler than black surfaces on hot days, the underlying insulation can be 25 to 50 percent more effective at resisting thermal conductivity under summer heat loads. (Photo courtesy of Duro-Last Roofing, Inc.)

vey funded by the Roofing Industry Alliance for Progress (RIAP). A recent study by Godfried Augenbroe and Annie R. Pearce of the Georgia Institute of Technology estimated that 54 percent of the energy consumption in the U.S. is directly or indirectly related to buildings or building construction.

Equally important, a series of studies by Lawrence Berkeley National Laboratory (LBNL) and Oak Ridge National Laboratory (ORNL) have established the cause and effect between energy consumption and global warming, air pollution, and the Urban Heat Island (UHI) effect.

Roofing can contribute to energy efficiency through insulation and reflective (cool) surfaces.

Insulation

Roofing insulation reduces heat loss by convection in winter months and controls heat gain through conduction in the summer. Local building codes typically require minimum thermal resistance properties for specific types of buildings, expressed as an "R-value." The higher the R-value, the higher the thermal resistance. One study by LBNL found that increasing the R-value on a "typical" roof system in Los Angeles from R-9 to R-15 would reduce average annual energy costs by $2,500 while lowering carbon dioxide emissions by thousands of pounds. (See *Photo 1*.)

The dominant type of roof insulation in the U.S. is polyisocyanurate foam, or ISO board. Others include wood fiberboard, perlite, and expanded/extruded polystyrene (EPS). According to technical authority Carl G. Cash in his book, *Roofing Failures*, thermal insulation performs several other important functions in a roofing system, acting as:

- A structural bridge across deck corrugations or discontinuities.
- An attenuating layer between the deck and the membrane.
- A reservoir to handle seasonal moisture variation within the system.
- Structural support for the roofing membrane and any static or dynamic loads applied to the system.

Cool Roofing

The popularity of cool roofing systems stems from the significant energy savings they can deliver nationwide. Demand is also fueled by utility company rebates in every part of the country, as well as federal, state, and local legislation and incentives, such as California's Title 24 "green" construction standards and the Chicago Energy Code.

The May 2005 symposium sponsored in part by the RCI Foundation – "Cool Roofing…Cutting Through the Glare" – demonstrated the great interest in cool roofing and the ongoing debate over its definition, applications, and effectiveness. Cool roofing is generally understood to involve a white roof that reflects sunlight. This keeps building interiors cooler, with less energy needed for air conditioning. Related but different categories that contribute to energy efficiency and sustainability include garden roof systems (sometimes called "green" roofs), and solar-integrated roofs. (See *Photo 2*.)

While there is legitimate concern that cool roofing has been over-promoted at the expense of insulation, there is little doubt among government and technical communities that reflective surfaces are a powerful tool for reducing energy consumption and improving air quality nationwide. Numerous private and government studies, as well as real-world experience, have proven that high-performance cool roofs can help reduce annual energy consumption in buildings by 15 to 45 percent, depending on building design, climate, and other factors. But the benefits of cool roofing go far beyond energy savings:

- Research by LBNL has shown that cool roofing helps reduce the heating/polluting effects of urban heat islands (see *Figure 1*).
- Reflective roof surfaces improve the performance of the underlying insulation. High surface temperatures lower the effective R-value of most types of insulation in use today. Because cool roofing surfaces are up to 80 degrees cooler than black surfaces on hot days, studies[1] have shown that insulation underneath can be 25 to 50 percent more effective at resisting thermal conductivity under summer heat loads.
- Cool roofs can extend the useful life of the roof. Deterioration of roof substrates is accelerated by ultraviolet (UV) radiation, infrared (IR) radiation, and moisture penetration. Studies[2] have found that the rate of deterioration of substrate materials can be slowed by as much as 75 percent when a cool roofing system is used. Cool roofing systems slow the rate of degradation by reflecting UV radiation, by reflecting heat-generating IR radiation, and by preventing moisture penetration.
- Cool roofs can reduce the capacity requirements for a building's HVAC system.[3] Most HVAC units have efficiency ratings performed at 95˚F. As rooftop temperatures rise above 95˚F, rooftop air conditioning efficiency drops. On hot days, black roof surface temperatures can reach 180 degrees or more. Cool roof surface temperatures under the same conditions are up to 80 degrees cooler. With traditional black roofs, the HVAC inlet air temperature at 30 inches above the roof surface can be up to 15 degrees hotter than reflective cool roofs. This is why cool roofing systems enable rooftop cooling equipment to run more efficiently and may reduce the cooling equipment capacity requirements. (See *Photo 3*.)
- Indoor comfort can be improved dramatically by cool roofing systems in buildings that are not climate-controlled. Inside temperatures typically run 15 to 20 degrees cooler under a reflective roof membrane, improving occupant comfort and productivity while keeping building contents cooler.
- LBNL studies have shown that most American cities, including those in northern climates, can benefit significantly from reflective roofing systems. According to LBNL, if every building in Los Angeles today had light-colored, reflective roof systems, total energy- and smog-related savings would be more than $500 million a year.

Photo 2 – By the late 1990s, cool roofing was the "hottest" trend in commercial roofing, and white thermoplastic single-plies began a sustained run as the fastest-growing category of commercial roofing systems. (Photo courtesy of Duro-Last Roofing, Inc.)

Cool Roofing Questions

Two frequent criticisms of cool roofing are the loss of reflectivity over time and the potential "heating penalty" during winter months. A number of independent studies[4] have shown that most reflective roof systems maintain 75 to 90% of their reflective properties after several years in service. Most of the loss in reflectivity tends to occur during the first year in service, and reflectivity properties generally remain steady after three years of service without cleaning. One white polyvinyl chloride (PVC) single-ply roofing system tested by ORNL went from an initial reflectivity of 88% to 86% after three years of service.

Photo 3 – According to roofing contractor Rod Heitfield, owner and president of Heritage Roofing Systems in Enid, Oklahoma, energy savings from the cool roofs installed in several other district schools were so great that they virtually paid for the entire 81,803-square-foot PVC cool roofing system protecting Enid High School. (Photo courtesy of Duro-Last Roofing, Inc.)

Other studies[5] have shown that while there may be a small "heating penalty" from using cool roofing systems during winter months, it is negligible. During summer months, surface temperatures of black roofing systems are typically 50 to 80 degrees higher than white roofing systems. In winter, white roofing systems are just 10 to 15 degrees cooler than black roof surfaces. In addition, the cost per BTU of energy to achieve a comfort level with air conditioning is higher than the cost per BTU to achieve the same comfort level with heating. Other factors that reduce the heating penalty include:

- The *Stack Effect* – Hot air is lighter, pushing upward on the roof to exit the building.
- The *Fan Effect* – HVAC system pressure is usually positive to reduce the infiltration of dirty air.
- The *Wind Effect* – Wind usually creates a net positive pressure at the side of the building opposite the wind direction and through the roof.
- The potential for solar heating is reduced by the low angle of the winter sun and by shorter, cloudier days.
- Northern areas typically have more white snow covering the roof, which makes all roofing surfaces reflective.

Cool Roofing Options

Although many categories of commercial roofing are now available with reflective surfaces, there are two primary types of widely accepted cool roofing products on the market today: protective paints/coat-

ings and single-ply roofing systems. A variety of reflective paints/coatings have become very popular as effective, inexpensive solutions for reducing energy costs on a wide range of roofing systems, from metal to EPDM.

Reflective single-ply roofing systems are popular, longer-term alternatives to energy efficiency. White PVC systems date back to the early 1960s in Germany. Introduced to the U.S. in the 1970s, PVCs became the first single-plies, in 1985, to obtain a standard designation from the American Society for Testing and Materials (now ASTM International): ASTM D4434 – Standard Specification for Poly(vinyl chloride) Sheet Roofing.

More recent cool roofing single-ply developments include co-polymer alloys (CPAs) in the 1980s and thermoplastic polyolefins (TPOs) during the 1990s. An ASTM International standard for TPO single-ply roofing was established in 2003. Today, many single-ply roofing systems are available in white or light colors, including EPDM and modified bitumen. PVC and TPO thermoplastic single-ply systems are the most popular and best-performing in terms of long-term reflectance. The coolest among them range from 70 percent to 88 percent solar reflectance.

HPR E-2a: ENVIRONMENT/EXTERNAL

The definition for sustainable roofing most U.S. experts cite today is from the *Proceedings of the Sustainable Low-slope Roofing Workshop* sponsored by ORNL in October 1996:

— A roof system that is designed, constructed, maintained, rehabilitated, and demolished with an emphasis throughout its life cycle on using natural resources efficiently and preserving the global environment.

In its *Primer on Sustainable Building Design*, the Rocky Mountain Institute maintains that sustainable roofing can be accomplished in five ways:

- Recycled content in the roofing product.
- Use of recyclable materials.
- Extended service life.
- Efficient use of energy and other natural resources.
- Actual renewal of natural resources.

A more exhaustive guide to sustainable roofing, published in 2000 by the International Council for Research and Innovation in Building Construction (CIB), is called *The Tenets of Sustainability*. It includes 21 specific guidelines under three categories:

1. Minimize the burden on the environment;
2. Conserve energy; and
3. Extend roof system lifespan.

Life Cycle Assessments

Life Cycle Assessments (LCAs) are science-based studies designed to measure the environmental impact of a product through its life cycle – a "cradle-to-grave" analysis that yields an ecoprofile. For roofing products, important LCA criteria include: material extraction costs, manufacturing waste, hazardous waste generation, recycling/reuse, and embedded energy – the amount of energy required to extract, transport, manufacture, deliver, install, maintain, and discard a roofing product during its life cycle.

LCAs are complex, and results can vary depending on methodology, underlying assumptions, and (unfortunately) the source of funding. Although the U.S. Green Building Council has a task group studying the practicality of applying LCAs in construction, they are used primarily as guidelines for establishing or defining standards and in the design phase of product development.

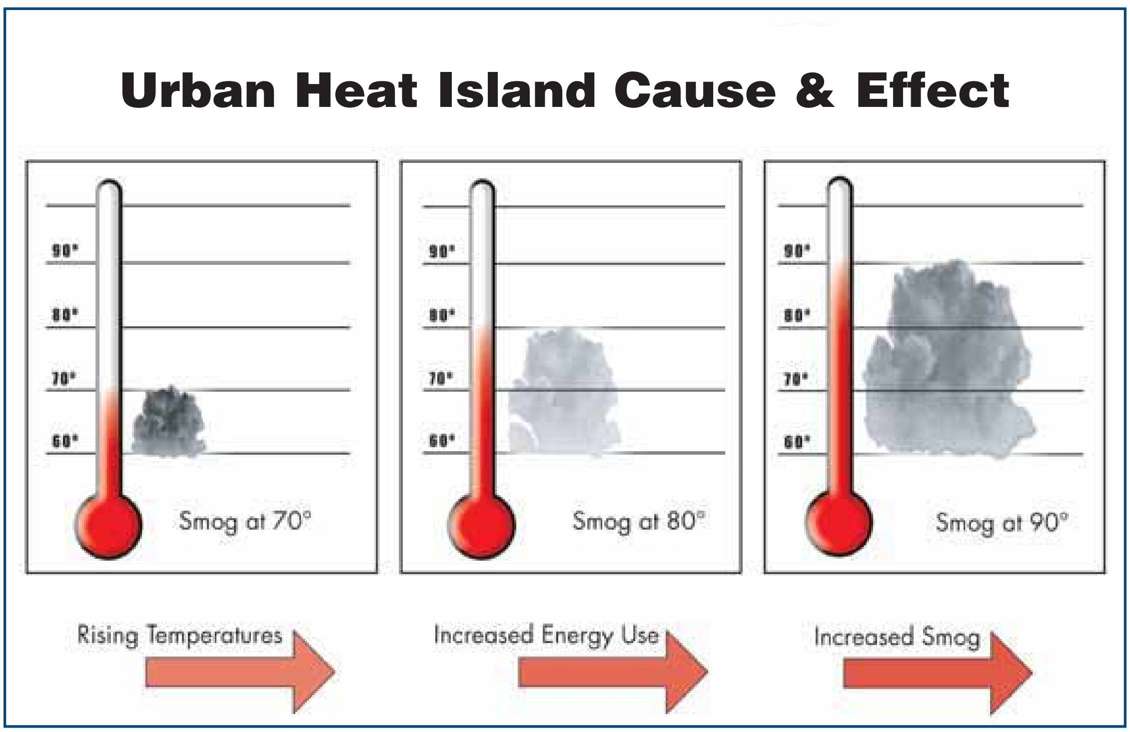

Figure 1 – LBNL identified the UHI chain of cause and effect: As temperatures increase, more electric power is needed for air conditioning and more fossil fuel is consumed, which leads to higher levels of air pollution. The probability of smog generation rises five percent for each one-half degree temperature increase above 70 degrees F. At this rate, the level of smog doubles with every temperature increase of 10 degrees during summer months.

Urban Heat Islands (UHI) and Sustainable Roofing

LBNL studies have confirmed that most large American cities experience an urban heat island effect – higher temperatures than the surrounding countryside. This results in higher electric consumption for air conditioning and higher air pollution levels. (See *Figure 1*.)

LBNL identified three primary causes of UHIs:

1. Reduced vegetation – 56%.
2. A concentration of dark, energy-absorbing roof surfaces – 38%.
3. Dark, energy-absorbing surfaces for roads and parking lots – 6%.

Clearly, the most practical, economical means of reducing the UHI effect is a reduction of dark roofing surfaces.

Waste, Recycling, and Recycled Content

Another way of making roofs more sustainable is recycling and waste reduction of roofing materials. ORNL estimates between nine and ten million tons of asphalt roofing waste are sent to U.S. landfills annually, which costs more than $400 million in disposal fees. Not included in this estimate is the waste generated by other types of roofing. (See *Photo 4*.)

While roofing waste cannot be completely eliminated, there are ways of reducing the amount of waste significantly. Building owners can consider installing roofing systems directly over existing asphalt, metal, and/or single-ply systems, depending on the level of saturation and certain other conditions. In many cases, thermoplastic single-ply systems can be installed with full warranties directly over existing roofs.

Building owners can also specify single-plies that are custom pre-fabricated to fit each building. This reduces installation waste significantly, with fewer trips to the landfill. Finally, building owners can select roofs that can be recycled and re-used in other applications, such as flooring, park benches, or new roofing components. Metal, PVC, and TPO are easily recyclable in the plant, after installation, and after the roof's useful service. New technology now makes EPDM recycling possible, and the use of recycled content in certain modified bitumen roofing systems can also contribute to waste reduction. (See *Photo 5*.)

The LEED Rating System for Sustainability

Perhaps the most practical way of determining if a roof system is sustainable is whether it qualifies for points under the U.S. Green Building Council's LEED Green Building Rating System. Buildings can be credited one point toward current LEED 2.2 certification if their roofing system meets the standards for specific sub-categories, including Heat Island Effect, Stormwater Management, Minimum Energy Performance, Renewable Energy, Building Re-use, Construction Waste Management, Resource Re-use, Recycled Content, and Innovative Design Process.

HPR E-2b: ENVIRONMENT/INTERNAL

An HPR system can contribute to a better indoor environment in two ways: ventilation and moderation of indoor air temperatures. Increased circulation of indoor air is one method for preventing "sick building" syndrome – the accumulation of unhealthy, toxic particles in the air. Vented roofing systems help reduce moisture and mold. A study by the Army Corps of Engineers at the Cold Regions Research Laboratory concluded that two-way roofing vents were more effective than one-way vents for moisture evaporation. Vented roofing systems also relieve positive air pressure, allowing

Photo 4 – Cool roofing systems are especially effective on low-rise buildings with large roof areas. Potential energy savings during the hot Mississippi summer months helped convince the Grenada Medical Complex in Grenada, Mississippi to install a recyclable, high-performance thermoplastic cool roofing system covering 69,474 square feet. (Photo courtesy of Duro-Last Roofing, Inc.)

buildings to "breathe."

HPR systems moderate indoor temperatures, even in buildings that are not fully air conditioned. In 1999, the Chartered Institution of Building Services Engineers published a report – "Environmental Factors Affecting Office Worker Performance: A Review of Evidence." The report indicated that improvement of physical working conditions, including thermal comfort, could improve worker productivity by as much as 15 percent. Other studies dating back as far as the 1960s (e.g., W. Schweisheimer, "Does Air Conditioning Increase Productivity?" *Heating and Ventilating Engineering*, 1962, p. 419) have also shown a direct relationship between thermal comfort, overall mental concentration, and manual work rates. (See *Photo 6*.)

Even cows are more productive when they're comfortable. Artique Farms, Ltd., Chilliwack, British Columbia, recently discovered that a reflective PVC single-ply roof installed over its 31,000-square-foot milk production barn lowered temperatures dramatically during summer months. This resulted in much healthier, happier, cows and significantly higher milk production, even with a smaller herd.

HPR E-3: ENDURANCE

Most green building experts believe that longevity is critical to the sustainability of building products. Long-lasting roofs reduce the rate of landfill waste buildup and the pace of demand for re-roofing projects. Many factors affecting longevity are beyond our control – climate, catastrophic accidents, and violent storms. In terms of HPR, endurance is the ultimate reflection of the performance of every roofing component or element that can be controlled by intelligent design, manufacture, installation, and maintenance, including:

- Proper design for the location, climate, roof deck, and building type.
- A roof deck that is matched to the insulation/membrane systems.
- Proper drainage.
- Professional workmanship.
- Physical properties over time.
- Flashing details used around roof penetrations, walls, and curbs.
- Regular inspection and maintenance.
- A warranty for the entire roofing system, versus partial systems with several warranties.

Photo 5 – Custom, pre-fabricated, single-ply roofing systems are precisely measured in advance to fit each roofing job. This reduces material waste, labor requirements and installation time, and minimizes the risk of human error by performing most of the seaming in the factory under controlled conditions. (Photo courtesy of Duro-Last Roofing, Inc.)

Roof Longevity

According to the 2003 RIAP survey, the average life expectancy for low-slope roofs is 17 years. In January 2006, *RSI* magazine reported a "national average for roof service life" of 12 years. In *Roofing Failures*, Carl Cash estimated the average service life of specific types of roofing systems, ranging between 12.1 years for spray polyurethane foam to 16.7 years for a five-ply BUR system.

More importantly in terms of HPR, Cash suggested that building owners consider the durability range of various systems as a better indication of how long the best roofing systems in each category can be expected to last. By this measure, five types of

Photo 6 – High-performance roofing systems moderate indoor temperatures, even in buildings that are not fully air-conditioned at all times, such as the Textron manufacturing facility in Williamsport, Pennsylvania. Various studies have shown a direct relationship among thermal comfort, overall mental concentration, and manual work rates. (Photo courtesy of Duro-Last Roofing, Inc.)

roofing systems have a high-end range of service longer than 20 years: PVC and EPDM single-plies; asphalt-glass fiber and asphalt-organic felt BUR; and SBS modified bitumen.

Roofing Endurance and Failure

After analyzing more than 1,500 roofing failures, Cash concluded that there is no accurate means of predicting the longevity of specific roofs, but there are ways of maximizing the potential for a long-lasting roof. Anyone interested in a high-performance roof should consider Cash's four guidelines for roofing endurance:

- Peer review of the contract document before bidding by a specialist with no financial interest in the project can eliminate one-third of typical problems.
- Use roofing systems, manufacturers, designers, and contractors with long, successful track records.
- Use monitors hired by the owner to oversee the installation, and use suppliers who train their contractors and inspect every roofing job shortly after completion. Estimates for the percentage of roofing failures attributable to defective workmanship range from 30 (Cash) to 47 percent (NRCA).
- Buy competence, not price, and long-term value rather than installed costs.

HPR E-4: ECONOMICS

Life-cycle costs (LCCs) are the third most important consideration, behind installed cost and quality of installation, according to the 2003 RIAP survey of building owners. Clearly, economics is a very important criterion for building owners, and HPR systems must be economical to become viable, real-world options.

Unlike immediate installation costs, LCCs estimate future considerations, such as longevity, maintenance, and repair. LCC estimates are not as precise as installation cost estimates, and like LCAs, they often reflect the bias of the organization funding the estimate. Nevertheless, LCCs can serve as a useful guide, and building owners would be wise to ask for them as a means of relative comparison.

For instance, LCCs should reveal differences among roofing systems in the anticipated frequency and cost of maintenance and repair. They should also compare potential energy savings over time, which can make an enormous difference in the final long-term cost of a roof. In one hypothetical, 20-year LCC comparison of black and white roofing surfaces, a reflective roof saved the owner of a 50,000-square-foot Midwest re-roof project $84,000 over 20 years, making it much less costly in the long run than the black alternatives.[7] Although far from perfect, LCC comparisons can help building owners make informed choices.

HPR systems must be cost-effective based on both initial cost and, more importantly, the entire life cycle cost. No roofing system will gain wide acceptance if it does not make economic sense to building owners and managers. The bottom line on roofing economics is simple. If a roofing system is not cost-effective, it is not sustainable. If it is not sustainable, then it does not contribute to high performance.

HPR E-5: ENGINEERING

Many roofing experts believe that defective design and engineering account for half of all roofing failures. Smart, coordinated engineering/design is not only the essential enabler for the other four E's of High-Performance Roofing, it is key to what the DOE calls "whole-building design," which integrates all parts of the building to work more effectively together.

A high performance building is a complete, engineered system made up of subsystems, including electrical, flooring, HVAC, roofing, doors, windows, etc. Achieving high performance requires that all these elements work in harmony. Every sub-system must perform its own functions without negatively impacting the performance of any other sub-system. Ideally, at least some of the sub-systems should actually enhance the performance of other sub-systems.

High-performance buildings not only operate at optimal levels, but they do so with minimum negative effect on the local environment, and they optimize the health and comfort of occupants. Well-designed HPR is a critical part of any high-performance building. An HPR system is a protective, performance-enhancing umbrella that defends buildings from the elements, accommodates ongoing facility operations, and contributes to the health and productivity of the building occupants.

Summary: Toward a High-Performance Future

The demand for energy-efficient, environmentally friendly buildings is creating market demand and government regulations for high-performance buildings. Likewise, the demand for cool and sustainable roofing is creating market demand and government regulations for HPR systems that provide optimal functionality with respect to energy, environment, endurance, and economics. If they are well designed and engineered, HPR systems require no tradeoff between "green" and performance, or "green" and cost. High-performance roofing is not costly, it is cost-effective. The best HPR systems cost less over time because they reduce energy bills, minimize environmental impact, require less maintenance, and keep the weather outside, where it belongs.

FOOTNOTES

1. Leonard, J. and T. Leonard. "Beyond 'Cool' to 'Sustainable' Reflective Roof Coatings." *Cool Roofing...Cutting Through the Glare*. RCI Foundation. Atlanta, GA. 2005.
2. Kirn, W. *et al*. "The effects of Acrylic Maintenance Coatings on Reducing Weathering Deterioration of Asphaltic Roofing Materials." *Roofing Research and Standards Development*. Vol. 3. 1994.
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4. Miller, William, PhD, Susan Pfiffner, PhD, Nan Byars, PhD. "The Field Performance of High-Reflectance Single-ply Membranes Exposed to Three Years of Weathering in Various Climates," U.S. Department of Energy, Oak Ridge National Laboratory. 2002.

   Roodvoets, D., A. Desjarlais, W. Miller. "Long Term Reflective Performance of Roof Membranes." *Proceedings of the RCI 19th International Convention and Trade Show*, March 31 - April 6, 2004.
5. Snyder, R. A., and D.L. Roodvoets.

Test your knowledge of cool roofing with the following questions, developed by Donald E. Bush Sr., RRC, FRCI, PE, chairman of the RRC Examination Development Subcommittee.

1. **What are the four basic mechanisms by which solar cooling load is dissipated?**
2. **Which of the four mechanisms that dissipate solar heat loading is predominately a natural geographic property of the building's location?**
3. **How does surface material or color dissipate heat energy?**
4. **To qualify as a cool roof, what was the standard set by Lawrence Berkley National Laboratory for minimum solar reflectance and emittance?**
5. **When calculating cooling energy savings using the ASHRAE method, what is the assumed aged value of roof surfaces with initial reflectance of 0.70?**

Answers on page 30

??? ROOF KNOWLEDGE ASSESSMENT

Answers to questions from page 29:

1. **• Surface reflectance**
   • Surface emittance
   • Conductance
   • Convection
2. **Convection**
3. **By reflectance and emittance.**
4. **Minimum solar reflectance = 0.70 and minimal thermal emittance = 0.75, or for emittance less than 0.75, minimum reflectance shall be 0.955 - 0.34 emittance.**
5. **Reflectance of 0.55**

Reference: ***The Manual of Low Sloped Roof Systems* — 4th Edition**

"Economic Feasibility of Cleaning Roofs to Maintain their Solar Reflectance Ratings." *Cool Roofing... Cutting Through the Glare.* RCI Foundation. Atlanta, GA. 2005.

Bret, S. and H. Akbari. "Long-Term Performance of High-Albedo Roof Coatings." *Energy Build 25*: 159-167. 1997.

6. Leonard.
7. Duro-Last Roofing, in cooperation with two independent roofing contractors with extensive experience installing and estimating PVC, BUR, and EPDM roofing systems. LCC study compared hypothetical PVC single-ply with black EPDM single-ply and BUR systems, using the EPA EnergyStar® Reflective Roof Products Program cool roof energy savings calculator (available online at **www.roofcalc.cadmusdev.com**) to estimate energy savings. For more details, contact Drew Ballensky, Duro-Last Roofing by phone, 877-556-6700 or by e-mail at Dballens@duro-last.com.

Drew Ballensky

Drew Ballensky is general manager of Duro-Last Roofing, Inc.'s Sigourney, Iowa, plant and spokesman for the Duro-Last Cool Zone High-performance Roofing system. Currently serving as president of the Chemical Fabrics and Film Association, he earned his degree in industrial technology from the University of Northern Iowa and master's degree in business administration from Florida State University. Ballensky has ten years of experience in facilities engineering and maintenance management and 12 years in the roofing and construction industries. He can be reached at 877-556-6700 or via e-mail at Dballens@duro-last.com.