

The Evolution of a Rating System

By Peter W. Turnbull

Editor's Note: This article was first published as part of the Proceedings of the Cool Roofing...Cutting Through the Glare symposium from May 12-13, 2005, in Atlanta, GA, sponsored by the RCI Foundation, Oak Ridge National Laboratory, and the National Research Council of Canada.

As a technology, cool roofing has rebounded from a false start or two in the early 1980s to become an important measure for mitigating peak air conditioning loads in buildings, thereby reducing air conditioning energy costs for building owners. Benefits extend well beyond energy savings. Cool roofing can reduce capital costs for air conditioning equipment, it can help roofs last longer, and it can help mitigate peak demand effects on the power grid. Likewise, widespread use of cool roofing together with other cool surfaces, has the potential to reduce heat island impacts, including photochemical smog formation in major urban areas and greenhouse gas production overall.

A major challenge faced by this industry has been integrating a large body of scientific knowledge into practical application for the roofing industry. In 1998, with the direct financial support of the California Energy Commission, EPA Energy Star, and Pacific Gas and Electric Company; and

strong technical support from Oak Ridge National Laboratory, Lawrence Berkeley National Laboratory, the Natural Resources Defense Council, and a number of roofing industry players; The Cool Roof Rating Council (CRRC) was formed. The CRRC charter provides that the organization establish, implement, and communicate a fair, accurate, and credible rating system with respect to the radiative properties of roof surfaces and the energy impacts associated with those properties. Using the CRRC's Product Rating Program as a foundation, cool roofing has become an important component in the state building code in California.

In this paper, we'll consider some of the early issues with the development of the CRRC Product Rating Program (PRP), how they were solved, and what issues are currently on the table for resolution.

Who Needs a Rating System?

An Early "False Start"

We'll start the story with a little personal history. Shortly after I joined Pacific Gas and Electric (PG&E), I was asked to administer commercial energy rebate programs for one of our 13 regional offices in northern California. These were handed down to us from our general office. Our job was to promote the programs, which consisted largely of getting our account representatives to

convince their customers to buy and install qualifying energy-saving widgets, fill out the paperwork, and send it in. And, yes, we were accountable for making goals, which largely amounted to getting a given amount of money "out the door" by way of encouraging rebate transactions.

There were several dozen items on the rebate menu when I started. I remember noticing a new one on the application circa 1983 called "reflective roof coating." What did that mean? More specifically, what qualified for the rebate – something I was to be asked over and over again). Well, it turned out that any roof coating that was white or "silvery" qualified. There were, literally, no further specifications in our program. Predictably, this led to a lot of inferior, inappropriate product – in some cases, product that was never intended to serve as roofing material – going on a lot of commercial roofs. In many cases, the installations probably didn't get the customer or the ratepayer much in the way of long-term energy benefits.

We at PG&E caught on to these problems quickly and ended the program as quickly as we could, but a lot of damage was done. To this day – almost 25 years later – there are people that believe cool roofing is of questionable value, largely due to memories of their experiences with cool roofing in this program in the early 1980s. (Lesson: Don't expect people to forget mis-

takes, even long after they are corrected and are no longer in play.) What was the net effect of rushing this technology to market? There can be no doubt that it slowed things down by a number of years.

The fundamental problem in the 1980s quickly became obvious, even at the time: there were no accepted, objective standards that could be used to define “reflective roof coating.” Although the fundamental science regarding radiative properties of materials had been understood for a long time, this science had not been “translated” across into roofing products or into a common understanding about roof performance. For this technology to gain a foothold in the marketplace, it became obvious that some fundamental definitions and objective performance criteria would have to be developed.

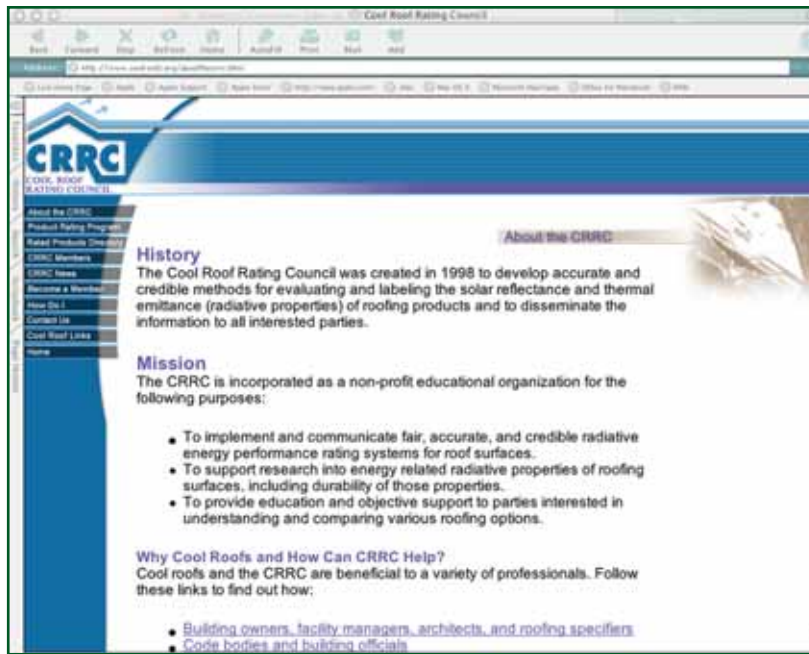
So how should the question, “Who needs a rating system?” be answered? Any party (such as a utility) that wants to encourage adoption of the technology is the answer.

As we shall see, having a robust, credible system becomes especially important if that system is to be used in building design or code applications.

Early Decisions on CRRC Scope and Organizational Structure

A Balanced Organization

From the outset, the CRRC gave careful consideration to its organizational structure with the intent of assuring a balanced approach to cool roofing issues. In many respects, the structure of the National Fenestration Rating Council – an organization that developed a performance rating system for windows – served as an organizational model for the CRRC. The CRRC board of directors was structured to achieve balance among a wide diversity of interests and to minimize the potential for the organization to be dominated by any single



CRRC's history and mission are detailed on its Web site. Its mission is: to implement and communicate fair, accurate, and credible radiative energy performance rating systems for roof surfaces; to support research into energy-related radiative properties of roofing surfaces, including durability of those properties; and to provide education and objective support to parties interested in understanding and comparing various roofing options.

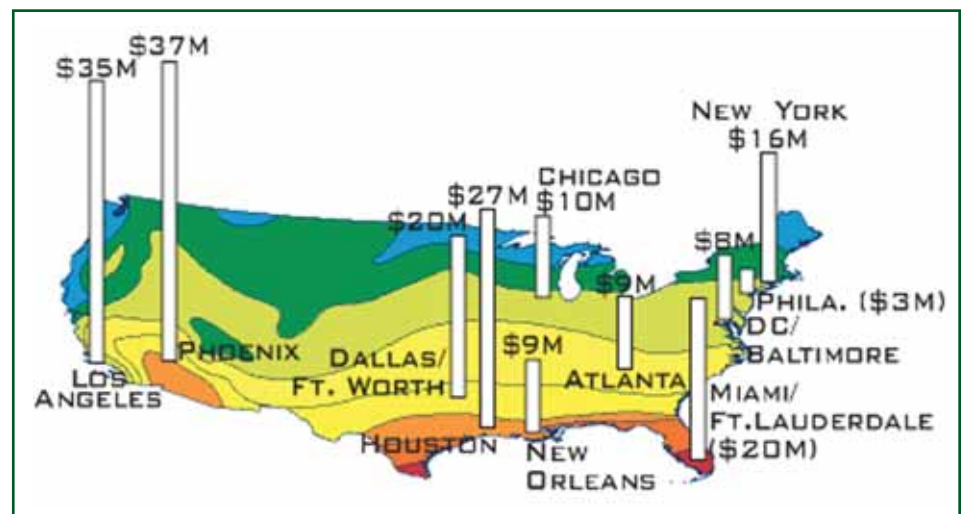
interest within the industry. Indeed, of the eleven board seats, six were assigned to members from the manufacturing segment (including their trade associations), characterized as the “A” category members. The other five seats were assigned to “B” category members representing other interested market players, including roof consultants, governmental agencies, energy suppliers

(including utilities), code bodies, non-profit organizations, and other trade associations. In the “B” category, no more than two board members could be from any single member sub-category.

Surface Properties Only

Early on, the CRRC deliberately chose to limit its scope to only the surface of the roof system. The organization deliberately made this choice in order to maintain a sharp focus on radiative properties – properties not well understood in the roofing industry (at least from the perspective of the physics involved). These properties are distinct from and largely independent of the insulative properties of roofing materials (which, depending on the product, may or may not be incorporated

directly into those materials). Further, the insulative properties of roofing systems – including the basic materials as well as ancillary insulation – are comparatively well known and understood, at least relative to radiative properties. As such, the CRRC perceived a need in the marketplace for a rating system to delineate radiative properties of roof surfaces.



This map, by the Heat Island Group of the Lawrence Berkeley National Laboratory, shows potential net energy savings from changing roof reflectivities. Savings are measured in dollars. The net savings are the savings of cooling energy use less the penalties of heating energy use. Courtesy, LBNL.

This focus on radiative properties to the exclusion of other aspects has created some degree of confusion and churn regarding those properties, their application in building design and science, and the motivation behind their choice. The common generalization – useful at a high level, but dangerous if applied blindly – holds that cool roofing works well for reducing cooling load, but can work against a building in the heating season. Insulation, on the other hand, offers symmetrical benefits for buildings for both cooling and heating purposes. The corollary to the generalization is that policy-makers, building designers, and building owners ought not to prefer energy savings from one approach (more insulation) over another (cool roofs), and that the effects should simply be considered together.

The problem here is that radiative and insulative effects are not really the same. Yes, we can look at them together and add them up, but the physics of the two are entirely different, and the benefits – both to the building and to society at large – vary. The two effects perform very diversely under different conditions; a result that impacts (or should impact) building design. Cool roofs prevent solar heat gain from entering

a building envelope in the first place. Insulation retards heat flow into (or out of) the occupied space after it penetrates the building shell.

Radiative properties are discrete surface properties: some roofing materials have inherent insulative properties integral to the material; others do not (in which case insulation is added below the roof deck). Good building design takes advantage of the obvious opportunities to use these two properties in a complementary fashion appropriate for the specific location and climate for the building. But the two properties are different and must be analyzed separately. Further, the application, knowledge, and even code requirements around insulation applications are much better developed than for the radiative properties associated with cool roofs.

An overlay on the building science issue relates to peak power demands in North America. In most parts of the country (even the more northerly regions), the single largest driver behind the need for expensive new power plants and costly upgrades to

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transmission and distribution systems is air conditioning load. These costs drive customer bills. Further, grid stability is generally at highest risk during the warm summer months. As such, control of peak air conditioning load is an important consideration with respect to electricity supply, both

Not your garden variety green roof

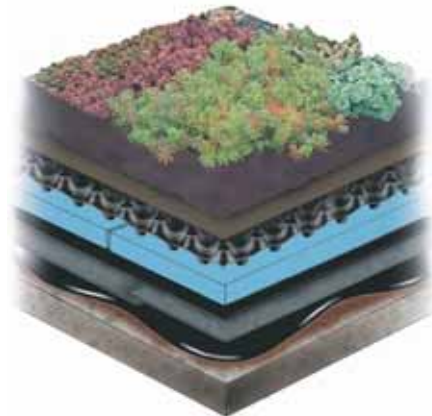


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in terms of price and grid stability. This is not to discount energy issues around the need for space heating, but simply to note that cooling load affects the power grid in a way that heating load does not. Since this article was first published in May, 2005, we have had the August 14, 2005 power failure in the eastern U.S. and southern Canada. Although this event did not occur during an extreme heat storm, it is not a coincidence that this problem occurred on a warm summer afternoon. Clearly, this event points to the need for improved transmission infrastructure and operations methods. Likewise, it highlights the problematic nature of peak summer loads that strain the system in the first place.

The CRRC Label and the Directory of Rated Products.

For the reasons outlined above, the CRRC decided to focus strictly on radiative properties in developing its Product Rating Program (PRP). In order to communicate the ratings obtained to any interested parties and to make the ratings readily available to building code officials, the CRRC decided to require both a directory listing and a product label under the PRP. As we shall see, the listing and the label both must include “initial” and “aged” values for solar reflectance and thermal emittance.

The Program Takes Shape

With the concept of a balanced structure in place, and with the scope determined to be confined to the “top layer” of the roof, the CRRC began developing the PRP. Key decisions were still to be made regarding the nature of how the program would operate, the properties to be reported, the test methods to be employed, and many other significant issues related to reporting the effects of aging, handling “custom” colors, non-uniform surfaces, and so on.

Participating Accredited Independent Testing Laboratories

Momentum Technologies, Inc.
Jeremy Elliott
 1507 Boettler Road
 Uniontown, OH 44685
 Tel: 330-896-5900
 jelliott@momentumtech.net

PRI Construction Materials Technologies, LLC
Don Portfolio
 6408 Badger Drive
 Tampa, FL 33610-2004
 dportfolio@priasphalt.com

R&D Services, Inc.
David W. Yarbrough
 102 Mill Drive
 Cookeville, TN 38501
 Tel: 931-526-3348
 rdserv1@frontiernet.net

Underwriters Laboratories, Inc. (UL)
Rick Titus
 333 Pflugsten Road
 Northbrook, IL 60062
 Tel: 847-664-3281
 rick.a.titus@us.ul.com

Participating Accredited Manufacturing Testing Laboratories

AKZO Nobel Coatings, Inc.
Lori Witherup
 1313 Windsor Avenue
 Columbus, OH 43211-2898
 Tel: 614-294-3361
 lori.witherup@akzonobel.com

BASF Corporation
David Story
 6125 Industrial Parkway
 Whitehouse, OH 43571
 Tel: 419-877-4313
 storyd@basf-corp.com

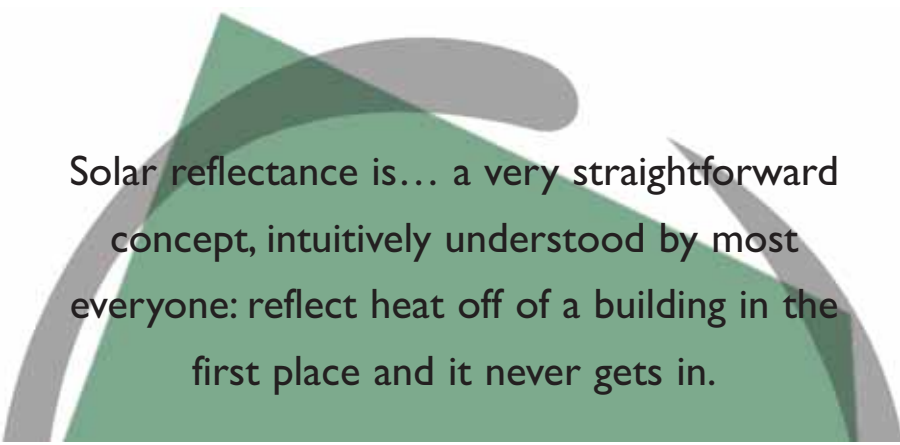
An Independent, “Third-Party” System

As one of the founders of the CRRC, the California Energy Commission (CEC) – the body with jurisdiction over the energy component of the state building code in California – was interested in making sure the organization produced a rating system appropriate for use in building codes. With such an application in mind, it quickly became apparent that the independence, objectivity, and transparency that could be provided by a “third party” testing system were of the highest importance.

In the abstract, it was an easy decision to go “third party” with the program; however, it created a large amount of organizational work that at first glance appeared to

be unnecessary, but in fact was essential. At the center of any independent, third-party system is the notion that material property values reported under that system be produced by some party independent of the material manufacturer. Although not fundamentally disputable, this was nonetheless a difficult decision for the CRRC since many large, well-established manufacturers already had extensive, highly credible, well-credentialed testing facilities and expertise. Further, there was no network of independent test laboratories in place and ready to implement the CRRC’s program. Understandably, the companies that already possessed extensive testing facilities were reluctant to be forced into a “reinvention of the wheel” at some new, incremental expense for their operations.

However, the core concept – that there cannot be a third-party system unless the data come from third parties – did prevail. The notion of an Accredited Independent Test Laboratory (AITL) was developed. This concept involved creating a program of training and quality assurance to guarantee that testing and reporting protocols were performed consistently and accurately. A licensing agreement governing the roles and responsibilities of the AITL in relation to the CRRC was developed.



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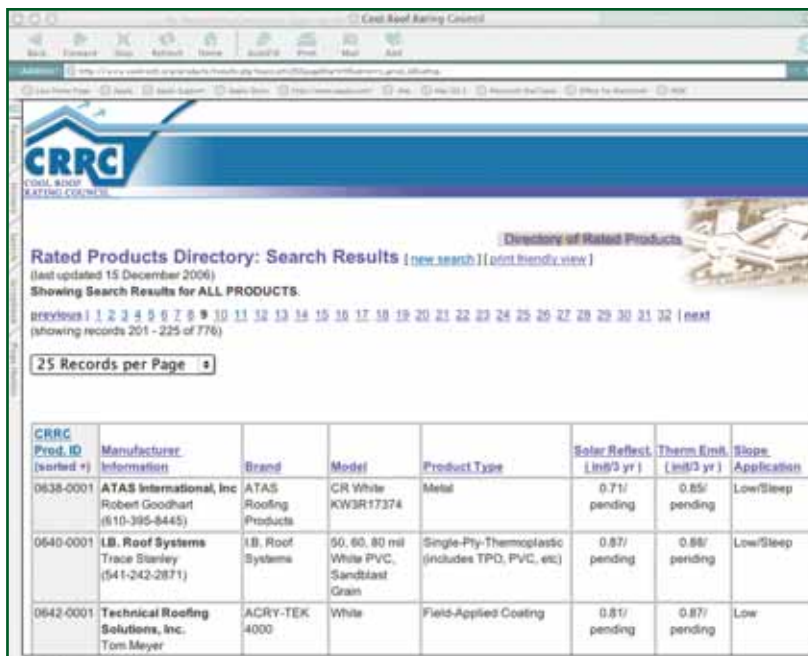
Materials Parameters and Test Methods

The building science developed at places such as Lawrence Berkeley and Oak Ridge National Laboratories has established that two important parameters are needed to define “cool roofing”: solar reflectance and thermal emittance. Of these two properties, solar reflectance is generally the more important one. It is also a very straightforward concept, intuitively understood by most everyone: reflect heat off of a building in the first place and it never gets in.

Thermal emittance, on the other hand, is difficult to understand in many respects, and works somewhat counter-intuitively. Since a significant amount of solar radiation is absorbed even by roofs with “high” solar reflectance, the thermal emittance parameter, which provides information on that portion of solar flux absorbed by the roof, is important in determining roof surface performance.

That absorbed radiant energy – even if it’s only 15 or 20 percent of the total – presents a problem because it takes the form of heat that has to go somewhere. With respect to cooling load, we prefer it to go away (to the atmosphere). If retained in the material, the energy causes it to get very hot. Materials with high thermal emittance “shed” or emit the absorbed energy quickly and easily compared to those with low thermal emittance. Since they emit heat easily, heat does not build up in the material and it remains relatively cool (within perhaps ten to twenty degrees F of the surrounding air, or in the range of 110-120 degrees F on a hot summer day). With poor emitters, surface temperatures can climb 70 or more degrees above the temperature of the air to 170-180 degrees F. From this point, the impact becomes obvious: the “hot” roof adds significantly to the building’s cooling load compared with the “cool” roof.

With one exception addressed shortly, almost all common roofing materials are good thermal emitters: generally, most show values of 0.80 and above, according to applicable test methods. If they reflect well in the first place, they stay cool since they



CRRC Prod. ID (sorted *)	Manufacturer Information	Brand	Model	Product Type	Solar Reflect. (10/3 yr)	Therm. Emitt. (10/3 yr)	Slope Application
0638-0001	ATAS International, Inc. Robert Goodhart (610-395-8445)	ATAS Roofing Products	CR White KW3R17374	Metal	0.71/ pending	0.85/ pending	Low/Sleep
0640-0001	IB Roof Systems Trace Stanley (541-242-2871)	IB Roof Systems	50, 60, 80 mil White PVC, Sandblast Gran	Single-Ply-Thermoplastic (includes TPO, PVC, etc)	0.87/ pending	0.86/ pending	Low/Sleep
0642-0001	Technical Roofing Solutions, Inc. Tom Meyer	ACRY-TEK 4000	White	Field-Applied Coating	0.87/ pending	0.87/ pending	Low

The CRRC's Web site (CoolRoofs.org) has a searchable directory of rated products that lists brands, models, product types, and tested solar reflectivity and thermal emittance, as well as slope application.

can easily shed the radiant energy they do absorb. To no one’s surprise, light-colored materials reflect well and stay cool; dark-colored materials absorb much energy and get hot. The exception here applies to “shiny” metallic surfaces. These surfaces – even if they do reflect quite well – still get very hot because shiny metallic surfaces are poor emitters (painted metal surfaces are not necessarily poor emitters). As such, thermal emittance is an important companion property to solar reflectance in defining cool roofs. If this were not the case, Tennessee Williams would have needed some title other than *Cat on a Hot Tin Roof* for his famous play.

The resolution of the applicable test methods to be used in determining solar reflectance and thermal emittance was, fortunately, relatively straightforward. Several existing ASTM test methods are available to measure these properties and the CRRC has adopted them for use within the Product Rating Program. Since the applicable test methods generally require specific pieces of test equipment, it has been necessary to focus on methods for which the test equipment is (1) available and (2) not prohibitively expensive for the AITL to obtain and maintain. In some cases, the CRRC has in force additional

prescriptions to the basic methods to make them useful for establishing measurements of roofing materials. (Much earlier work in this area came out of the space industry and involved materials and temperatures far different than found in roofing applications.) Originally, the CRRC methods emphasized field measurement; however, as the program has evolved, it has become clear that there is a greater need for laboratory-based methods in administering the program.

“Aged” Performance and “To Wash or Not to Wash”

Everyone knows that materials placed outside and exposed to the weather degrade and get dirty. If the material is going on a roof and affects a building’s air conditioning load, the designer needs information in this area to make correct decisions about system sizing. If state building code developers are to include cool roof requirements, they, too, need information about how these systems will perform over time if they are to make good decisions. For these reasons, the CRRC decided that

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the PRP needed a component to address the effects of aging by way of an “aged test protocol.”

After a lengthy deliberative process involving significant debate over all available information, the CRRC settled on a three-year protocol using exposure “test farms” to determine “aged” radiative values. Three years was chosen since all available data indicated that most of the performance drop-off that did occur happened prior to the third year. There was a serious attempt to develop an accelerated protocol to determine the effects of aging, but this effort did not produce satisfactory results. Within this discussion, it is worth pointing out that dirt pick-up and biological growth (not material failure) were the main causes of performance drop-off for solar reflectance.

Also, after much debate, the CRRC opted for a “test farm” procedure in lieu of other possibilities, including the measurement of existing roofs. The main driver in this decision was the notion that all products be exposed under identical conditions in a manner such that the CRRC could easily monitor those conditions and time-frames. To account for variable conditions across the country, the CRRC system

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or toll-free 800-255-3738
Fax: 623-465-9409
jwonders@atlas-mts.com

employs a protocol requiring sample exposure at three different test farm locations: one in south Florida, one in Arizona, and one in the Midwest. After three years of exposure, the “aged” value is determined by measuring and averaging results from the three test-farm locations.

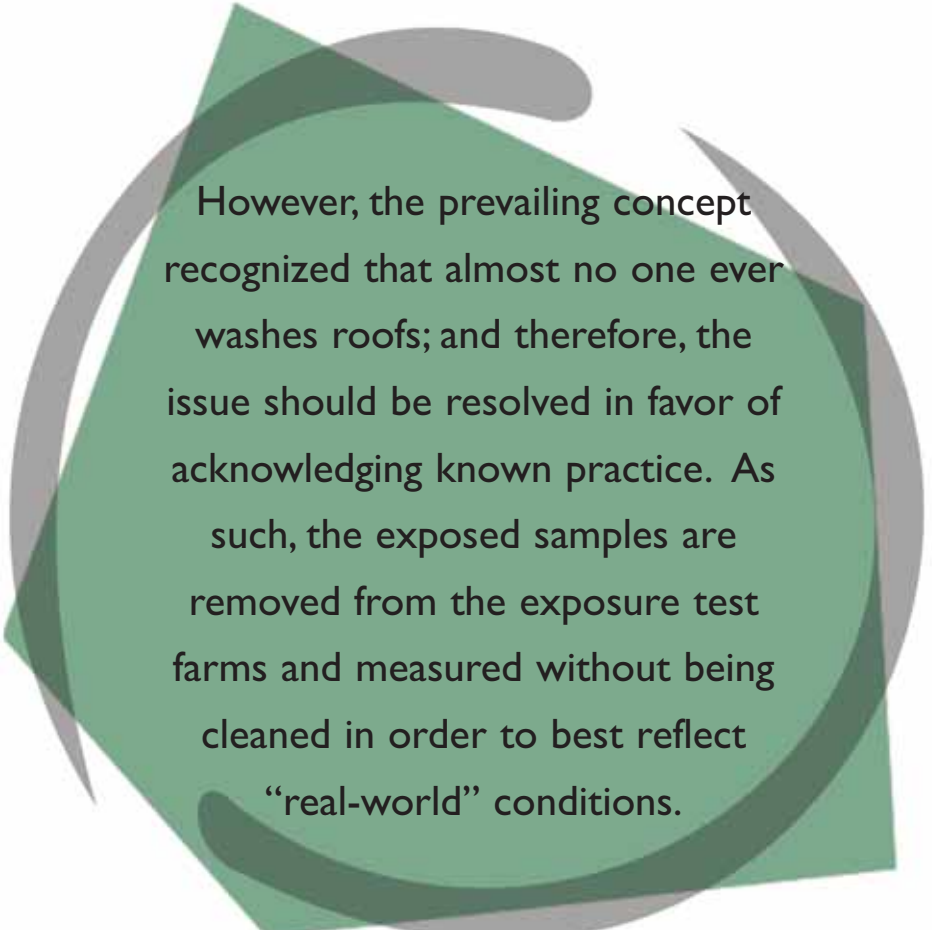
A third issue that received much attention in development of the CRRC’s “aged test protocol” was the issue of whether or not to permit (or require) “washing” of the

samples after the three-year exposure period. The “pro-wash” argument held that (1) many materials can be restored to values approaching their initial solar reflectance if they are washed and that, therefore (2) washing should be encouraged by adopting it as a requirement. (Before the final decision was made to assure exposure consistency by way of exposure test farms, there was also an argument that suggested that test results would be more fair, uniform, and repeatable if all were washed according to a consistent protocol prior to obtaining the three-year values. This argument was rendered moot by adoption of the test farm protocol.) However, the prevailing concept recognized that almost no one ever washes roofs; and therefore, the issue should be resolved in favor of acknowledging known practice. As such, the exposed samples are removed from the exposure test farms and measured without being cleaned in order to best reflect “real-world” conditions.

The CRRC Today

As mentioned, the CRRC was formed in 1998. It took until September 2003 to officially “launch” the PRP such that a manufacturer could actually obtain a product rating. While this represents a slow start in some respects, interest in the program has accelerated rapidly since the launch date. At the original press time for this article in early 2005, the CRRC Rated Products Directory listed 239 products; as of December 2006, there were 776 products. All of these products have obtained initial product ratings from an AITL and have been shipped to the exposure farm sites and placed on exposure racks such that their three-year “aged” performance values can be established.

Each Directory listing contains initial values for solar reflectance and thermal emittance. Beginning in early 2007, the CRRC will begin to list three-year (or “aged”) values as well. The first group of products (from early 2004) that entered the program will have completed the prescribed three years of exposure such that their three-year reflectance and emittance data can be obtained. Although the majority of the products now in the Directory are low-slope, non-residential products, the number of steep-slope products is increasing rapidly. The organization has about 150 members – up from 90 two years ago. Approximately 135 manufacturers maintain CRRC program licenses, up from 60 two years ago. Licensed manufacturers can choose among



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four AITLs to obtain the testing services required under the program.

The CRRC PRP continues to evolve as practical applications of it are established for classes of materials difficult to rate under the original offering (which was oriented toward low-slope materials). In the first edition of this article (2005), a streamlined methodology for handling variegated surfaces (such as those found with asphalt shingles) was pending. That procedure, worked out using "Monte Carlo" statistical sampling, has since been approved and the Directory now contains asphalt shingles rated accordingly. Likewise, the PRP now contains a procedure making it feasible to obtain ratings for coated metals using a "color family" approach, which greatly simplifies the rating process for that product class (which would otherwise require separate ratings for an extremely large number of colors which differ either not at all or only slightly within the 18 "family" groups established). By early 2007, the CRRC expects to have in place simplified procedures for handling "high profile" products such as curved tiles. As these various procedures become established, new products are added to the program and the Directory grows rapidly.

California's Title 24

In November of 2003, the CEC adopted the changes to California's Title 24 Building Code. Under California code, any job involving roofing and requiring a building permit (which includes most re-roofing jobs) falls within the scope of this change. This update, which became effective in October 2005, has had significant impact regarding cool roofing on low-slope nonresidential buildings (that by far the majority of the first several hundred products rated are for low-slope, non-residential applications reflects industry awareness of this code development).

Although Title 24 stops short of making cool roofs mandatory, the practical impact of the code change will most likely have the effect of requiring cool roofing for the majority of roofing jobs for low-slope, non-residential buildings, including not only "Greenfield" new construction, but re-roofing jobs as well. Under Title 24, the base definition for cool roofs for low-slope, non-residential buildings requires:

- a solar reflectance of 0.70 or greater,
- a thermal emittance of 0.75 or greater, and
- a CRRC label demonstrating that the ratings have been established

under the CRRC rating system.

We should point out that the underlying calculations behind the code assume performance degradation of about 20% (that is, California is assuming that the material performs at about 0.55, not 0.70).

Alternate code compliance methods are available for those situations where a cool roof is not feasible for some reason. Under one compliance method, it is possible to "trade off" other (improved) building efficiency measures against roofing materials that fall short of the 0.70/0.75 requirement for cool roofs. Under that method, materials not rated by CRRC default to low values for reflectance and emittance (that is, unrated materials are assumed not to be "cool" materials). As a practical matter, however, in the opinion of this author, the preferred compliance path for most users is likely to be one of choosing materials that meet the cool roof definition in the first place.

In the period prior to the effective date of the 2005 Title 24 update, utilities in California offered rebates of approximately \$0.10 per square foot for cool roof installations covering nonresidential, low-slope applications. These rebates have since

ended because the code update is now in effect.

In future years, California is likely to consider cool roofing code requirements for residential, low-slope and steep-slope roofs, as well as for nonresidential, steep-slope roofs. It is likely that the cool roof definition in these cases will be significantly different than for the current nonresidential, low-slope case. With respect to the October 2005 low-slope rules, once three-year CRRC values become commonly available, it is likely that Title 24 will be amended in a manner such that three-year values can be used for code compliance purposes. It is likely that the first opportunity for such changes will occur in the first part of 2009.

Meanwhile, PG&E, with a residential customer count of nearly 5 million households and a service territory population of about 14 million, has begun (as of September 2006) offering rebates for steep-slope, residential cool roofing. Other California utilities may follow suit in early 2007.

Developments in Other Jurisdictions

Other jurisdictions – notably the states of Arizona, Florida, Georgia, and the city of Chicago – have either adopted or are con-

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sidering adoption of cool roofing into their building codes. The ASHRAE 90.1 (commercial) and 90.2 (residential) standards for building energy efficiency, in use by about 30 states as the energy component for their building codes, incorporate radiative roofing properties into their standards (such that cool roofing receives “credit” in the energy calculation). The U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED) rating program likewise recognizes and encourages cool roofing as an environmentally friendly building technology. Under LEED, cool roofing provides two benefits: it qualifies directly for a “heat island mitigation” benefit worth one rating point; additionally, a cool roof contributes to the energy efficiency of the building and can contribute to the building’s point total in that area as well.

Summary and Additional Information


Cool roofing, the CRRC, and its Product Rating Program are here to stay. The technology and the organization are rapidly becoming recognized for the benefits each provides. Work and research done by the U.S. Department of Energy’s (DOE) national laboratories, private industry, as well as other institutions such as the Florida Solar

Energy Center (FSEC) and EPA ENERGY STAR have been integrated into the body of knowledge from which the CRRC and its PRP emerged. New challenges will emerge as cool roof technology and the building industry evolves. The CRRC will be there to meet those challenges.

Additional information on cool roofing technology and applications is available at the following Web sites.

- Lawrence Berkeley National Laboratory Heat Island Group: www.eetd.lbl.gov/HeatIsland/CoolRoofs/
- DOE Cool Roof Calculator www.ornl.gov/roofs%2Bwalls/fact

s/CoolRoofCalc1_1.htm

- California Cool Roofs Information: www.consumerenergycenter.org/coolroof/
- The Cool Roof Rating Council: www.coolroofs.org
- The Energy Star Program: www.energystar.gov
- The California Energy Commission (Title 24 information: standards. Documentation for Title 24 cool roof standards prepared by PG&E: standards/documents/2002-08-27workshop/2002-08-14_COOLROOF_UPDATE.pdf. 

Peter W. Turnbull



Peter W. Turnbull is a senior program manager with 23 years of experience in Pacific Gas and Electric Company’s Customer Energy Efficiency Department. He has worked extensively in various technical areas involving energy efficiency, especially in building-related arenas. He currently oversees programs for food service technology, building operator certification, emerging technologies, and codes and standards at PG&E. Peter currently serves as the board chair of the Cool Roof Rating Council and maintains membership in AESP and ASHRAE.



GLASS CURTAIN WALL BENT ON SITE

Workers on a curtain wall for the 10-story headquarters of Interactive Corp., in the Chelsea section of Manhattan, purposefully bent each of the 1,437 flat-glass cladding panels manually, with gloved hands, as they installed them. It was the first time cold-bending on a curtain wall sector was done intentionally, claim architects Frank Gehry and Craig Webb, designers of the building.

Mike Budd, president and CEO of cladding supplier Permasteelisa Central-South of Miami suggested the cold-bending. The company determined how much stress the aluminum-framed, double-glass units could take before breaking and the concrete contractor had to set the curtain-wall bracket embeds in the building’s concrete frame slab edges perfectly.

The cladding units were almost all individually shaped trapezoids, triangles, and rectangles and no two floor plates were the same. The finished building looks like wavy sails of a sailing vessel undulating in the wind. No U.S. glass fabricator

would take the job or warranty it, so Permasteelisa found Zadra in Italy to produce the double-glass units and St. Gobain in Belgium to supply the low-iron, fritted glass. Some panels are warped in excess of 4 inches out of plane over their height. The typical panel is 8 inches thick and heights vary from 14.5 feet to 20 feet and from 3 to 12 feet wide. Not a single unit cracked during site-bending.



— ENR