Efficiency's Last Frontier: Building Reflective Surfaces

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ABSTRACT

This paper calls for discarding R-value as the means of measuring heat gain in hot climates and substituting the net effect of radiation, conductivity and convection to provide a level playing field for all heat abatement technologies. This is a first step toward synthesizing academic papers, manufacturer's claims and field tests into a proposed new energy code that specifically includes reflectivity, foams, radiant barriers, air gaps and other technologies. While national laboratories, notably the Lawrence Berkeley National Laboratory have conducted extensive studies on reflectivity for over 10 years [1], [2], some questions remain.

This paper looks first at the next steps needed to bring reflective surfaces to the mainstream, then merges with other insulating technologies and ends with outlining the requirements for a performance-based energy code and points to needed research in closely related areas. The exploratory nature of the research is reflected in many of the bibliography sources being primary sources rather than published papers.

Keywords: reflectivity, roofs, R-value, performance-based

1 BRINGING REFLECTIVE SURFACES INTO THE MAINSTREAM

1.1 Developing a Test Methodology for Product Life

Just two years ago LED lamps were "the wild west" of lighting technology, with no common tests for verifying manufacturers' claims. Now nationally-recognized tests known as LM-79 and LM-80 are in place and are helping the industry to grow. Reflectivity products still have "wild west" characteristics, in that some products crack and flake in less than one year [3], while other products have an apparent effective life of greater than 10 years, and there is no recognized labeling protocol. Independent testing methodologies modeled on LM-79 and LM-80 are needed.

1.1 Extended Reflectivity

This compares products' initial reflectivity to their reflectivity 3 years later. Reflective coatings are susceptible to organism growth, especially in the tropics. Many reflective surfaces in Guam and the Commonwealth of the Marianas Islands (CNMI), for instance, experience considerable organism growth within six months of application, and are virtually black within one year [4]. Some manufacturers cite extended reflectivity values and many do not. Again, standardized testing is needed.

Manufacturers' research is leading to breakthroughs. One company examined the surface of the lotus leaf and imitated its nanostructure in the laboratory. The result is its ability to avoid organism growth, just as the lotus leaf avoids the buildup of pollutants. Although the product is intended for exterior walls, an informal test on a roof receiving some 120 inches of rainfall a year shows an extended reflectivity of approximately 80% over a 16-month period [5].

A recent study indicates that TiO2, the most common element in reflective technologies, "doped" with nitrogen and palladium nanoparticles becomes a photocatalyst that disinfects water both in light and in the dark [6]. A Japanese company has developed "GAINA" a spinoff of Japan's rocket program, which claims extremely high reflectivity values and no microbial growth [7]. While these and other research papers describe promise in improving extended reflectivity performance, the chemistry of extended reflectivity is little understood.

1.2 Texture and Performance of Steep Roofs

The question of why smooth surfaces such as metal roofs offer much high reflectance values than rough surfaces such as asphalt shingles, has not been adequately addressed. The highest reflective rating of asphalt shingles is apparently 0.40, while the median rating for smooth surfaces usually exceed 0.75, which typically results in the underside of the metal sheathing being some 30 degrees cooler [8]. The possible reason is the "reef-like" effect of rough surfaces harboring organisms. Reefs, covering less than 1% of the ocean's surface, harbor 25% of all marine species. Closer to home, recent studies reveal that the most bacteria-intensive objects in homes are (reef-like) kitchen sponges. A leading scientist agrees: "Yes, roughness would tend to shelter microorganisms" [9]. Achieving higher reflectivity values on rough surfaces would constitute a major breakthrough.

2 ALTERNATIVE ABATEMENT TECHNOLOGIES & R-VALUES

A theory recently publicized is that technologies can be grouped in to "domains" and that some domains rise rapidly together, while others stagnate [10]. The domain of heat abatement techniques is indeed rising as a group, and is in need of standardized performance measurement as "R-Value equivalents" become prevalent within the domain.

Emerging insulation technologies claiming R-value equivalents include open foam, closed foam, structural integrated panels (SIP), reflective metal roofs, radiant barriers, attic ventilation, tiles with air-gap features, and even glass.

A company specializing in ultra-high performance glazing cites values as high as R-20 at the center of glass they manufacture [11]. A reflective coating manufacturer claims that their product on metal roofs "surpasses R-19 heat gain testing" [12]. (The same company supplied the reflective coating for the Anaheim Convention Center.)

A heated debate is going on regarding the performance of foam technologies in hot, humid climates. Tests indicate that fully-encapsulated homes perform far better than the rated R-value would indicate. One theory is that foam seals a home against air leakage far better than other technologies, and substantially reduces the work the AC must do to dehumidify [13]. A side-by-side comparison of a fiberglass-insulated home with an open-cell foam insulated home showed the foam-insulated home saved $109 a month in utility costs [14].

A Hawaii-based roofing professional summarizes, "In my opinion, R-value should not be the gauge in tropical environments..." [15].

In dry climates, spray foam technologies have dropped energy consumption in forward-base housing in Iraq and Afghanistan by 40-60%, while appreciably improving the comfort and productivity of troops [16].

The Oak Ridge national Laboratory (ORNL) is developing a "Roof Savings Calculator" which will model "white roofs, radiant barriers, above-sheathing ventilation and other such modern technologies" [17].

3 A PERFORMANCE-BASED CODE FOR BUILDING ENVELOPES

An entirely new testing methodology such as the Roof Savings Calculator must be standardized to discard the traditional R-value and create a net-effect, or whole-house performance energy code.

The new methodology may compare the exterior ambient temperature with the temperature 2' beneath the ceiling in habitable spaces, or measure the energy use index (w/sq/yr) of the air conditioning system. The testing procedures developed for the Light-Emitting Diode (LED) industry may serve as a model.

Substantial progress is being made in the energy codes arena. Reflectivity is either credited or required in California's Title 24 and Cool Roof Rebate program, the Chicago Energy Conservation Code, Hawaii's Model Energy Code, ASHRAE/IESNA 90.1.-2007, the EPA Energy Star Code, LEED ratings, the Green Globes code, the Guam code, Florida's and Georgia's energy codes, and even the Canadian Energy Code.

Codes are expanding beyond the building boundaries. The IECC 2009 calls for lighting zones extending to wilderness areas, which opened the way for the ICC's 700 draft Green Construction code to include a "Heat Island Effect" section which includes credits for reflective hardscapes and landscaping that provides shade to urban areas [18]. The way is paved for entirely new energy codes.

4 ADDITIONAL PROMISING AREAS OF REFLECTIVITY RESEARCH

Cradle-to-Cradle: Not examined in this paper is the cradle-to-cradle environmental impact of each abatement technology. Manufacturers of reflective coatings, for instance, claim that reflective technologies "rescue" deteriorating roofs by first applying restorative coatings and then applying reflective coatings. This, they say, keeps the embodied energy of the original roof intact, rather than landfilling it and using new resources for a new roof.

Walls: Seminal work on the savings to be gained from reflective exterior walls has been done by ORNL. The results of testing in Oak Ridge TN were marginal. Work is needed in Hawaii and the American Territories with 9,000+ cooling degree days [19].

TiO2: A great deal of exciting research is being done into the physics of reflectivity. Why titanium dioxide, the most commonly used reflective element, performs so effectively is not yet known. (A recently discovered use is in clothing, where Ti02 nanocrystals protocatalyze and decompose dirt and stains when exposed to light [20]).

Other elements: The reflective properties of hematite, bismuth antimony telluride, low thermal conductivity caused by increased scattering, and even Heisenberg's theory of atoms coherently radiating in phase with one another, are the subjects of intense research.

How Far North?: While this paper refers to reflective surfaces in hot climates, a LEED builder in St. Paul, MN, prefers white roof surfaces to dark, vastly expanding the possible geographic range.

Pavements: Finally, not included in this paper is the potential of reflective paved surfaces. Permeable concrete has a high reflectance value and absorbs water (feeding the water table below) and oils and other pollutants, thus retaining reflective values [21].

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