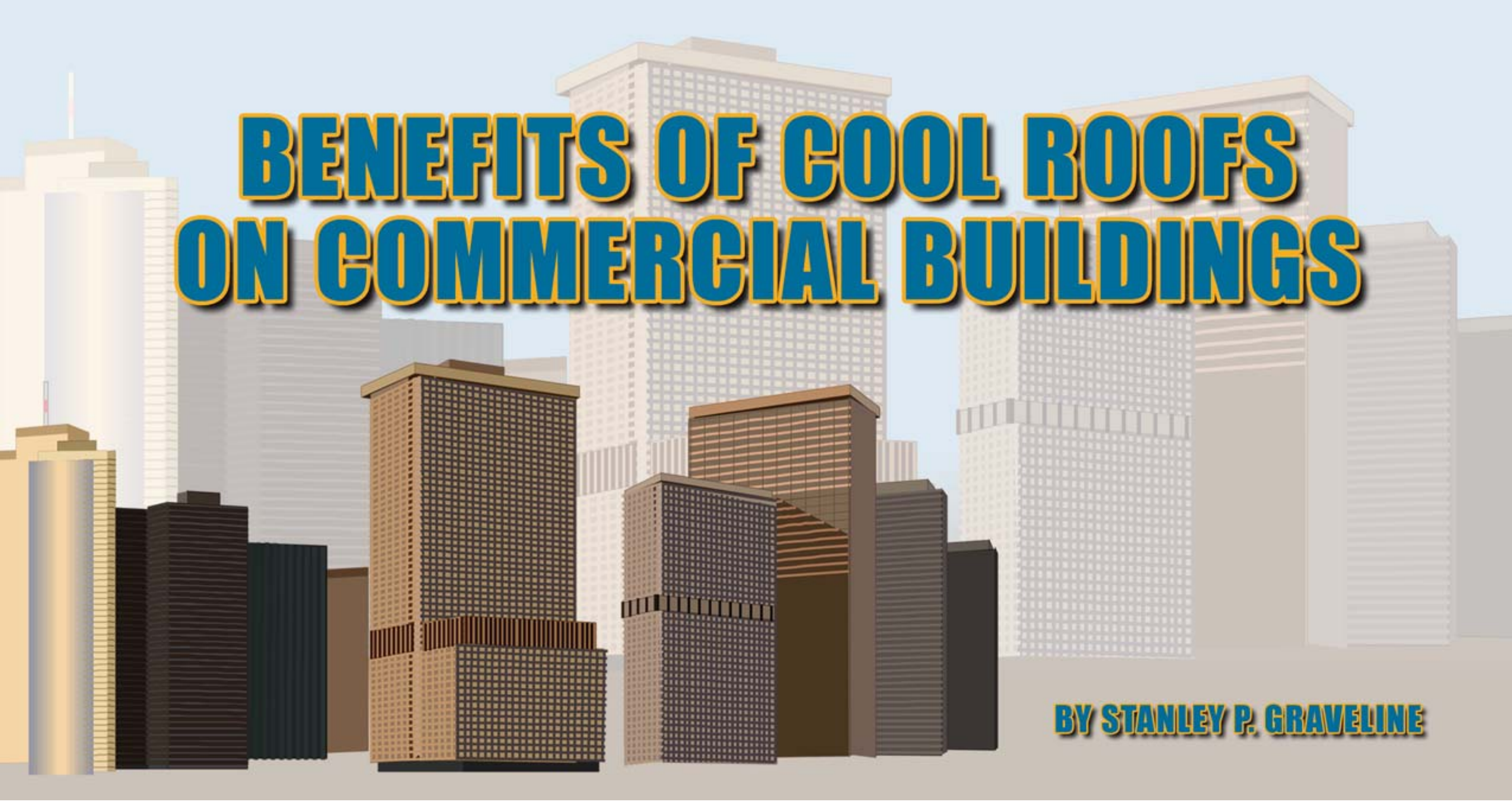

Benefits of Cool Roofs on Commercial Buildings

By Stanley P. Graveline

Introduction

Cool roofing is "hot." It is a frequent topic in trade magazines and at roofing symposia. Sales of various cool roofing products outpace the overall market year after year. Manufacturers expend significant development resources working on the radiative properties of their materials, looking to improve their market positioning and share. With all the talk surrounding the subject, one could be forgiven for thinking that the general concept is new and innovative. In fact, "cool" roofing has been around for quite some time now. Light-colored thermoplastic sheet materials and various types of coatings have been available for decades. Some have remained virtually unchanged over that time, and some of the earliest installations, dating back to the 1970s in North America and the 1960s in Europe, are still in service today.

The developers of those products were broadly guided – directly or intuitively – by the principles of the Arrhenius equation, which states that for many common chemical reactions at room temperature, the reaction rate doubles for every 10°C increase in temperature. Applied to roofing materials, the thought process was generally that light colors would reduce the heat load on the surface, thereby slowing down the aging process of membranes and underlying materials. This concept is still valid today and remains a key reason for installing light-colored coatings on top of asphaltic and other dark-colored membranes.

What have changed are the identification, recognition, and quantification of other benefits of cool roofing materials. Reports on the potential for energy savings resulting from the use of these products began to appear in the late 1990s. The basic concept was that roofing materials that reflect substantial portions of the sun's incident radiation back into the atmosphere and quickly emit whatever heat is absorbed have lower surface temperatures and therefore require less energy to keep conditioned spaces below them cool.

ASHRAE first recognized this principle in 1999, in ASHRAE Standard 90.1-1999. A number of states and municipalities began to mandate the use of cool roofing materials, most notably the state of California, which included use of such materials as a prescriptive method to meet the requirements of its Title 24 energy code in 2005. Most recently, U.S. Energy Secretary Steven Chu, speaking at a climate change symposium in London, highlighted the broad implementation of cool roofs and paving as important measures in the current administration's "new revolution" regarding energy usage.

Assessing Cool Roof Impacts on Commercial Buildings

Since those first studies more than a decade ago, extensive research and analysis have been done on the various elements related to cool roofing. Much of that work has been carried out by the Lawrence Berkeley National Laboratory (LBNL). In its most recent study, which has just been released, LBNL simulated the potential impact of substituting cool roofs for conventional dark-colored roofs on commercial buildings in 236 U.S. cities.

The potential impact of a cool roof on any given building depends on numerous factors, including the building's local climate, its operating systems (HVAC types and efficiencies) and conditions (internal temperatures, occupancy, hours of operation, etc.), the roof surface area, and the roof assembly's construction, including its thermal resistance, mass, and emittance, as well as its solar reflectance.

The simulations modeled new (post-1980) and old (pre-1980) office and retail buildings. Two of the most important assumptions that have a significant impact on the results are the roof's insulation level and its solar reflectance. The roof insulations in each generation of structure were assigned thermal resistances of R-7 and R-19 for old and new respectively.

Many cool roof materials offer initial solar reflectances greater than 80%. However, roofs – like anything left exposed to the elements – will become soiled over time. For darker materials, this may actually increase reflectance ever so slightly, whereas for light-colored materials the effect is a decrease. Although a number of studies have shown that practically all of the initial reflectance of most materials can be restored through cleaning, few roofs are actually cleaned throughout their service life. Taking these factors into account, the authors assumed aged solar reflectances of 0.20 for weathered conventional materials (assumed to be gray), and 0.55 for weathered white cool roofs. The latter value is consistent with California Title 24's minimum requirement for low-slope, nonresidential roofs and is generally consistent with the findings of a number of studies.

Using the DOE-2.1E building energy model, LBNL simulated for each prototype building in each city the hourly heating and cooling energy uses during a typical meteorological year – first with a weathered conventional roof and then with a weathered cool roof. Savings and penalties were determined by comparing performance with a cool roof to performance with a conventional roof. State and national average rates of savings and penalties were then determined by weighting these results according to local building inventories (types, ages, and densities of construction). The following results are state or national averages per square meter of conditioned roof area (area of roof surface over a conditioned space, or CRA) for the stock of commercial buildings, and are not intended to be used to represent any given single building.

Although some standards may allow for them under certain circumstances, cooling energy savings should not be used as a basis for using less insulation below cool roofs in any climate.

Three key metrics in assessing the relative performance of cool roofs compared to conventional roofs are cooling energy savings, heating energy penalties, and overall energy cost savings.

ENERGY AND COST IMPACTS

Not surprisingly, the greatest impact due to change from a conventional gray roof surface to a cool roof is achieved in hot states. Arizona, New Mexico, and Nevada benefit the most, with calculated average annual savings of 7.69, 6.92, and 6.86 kWh/m^2 of conditioned roof area. However, it is clear that even the

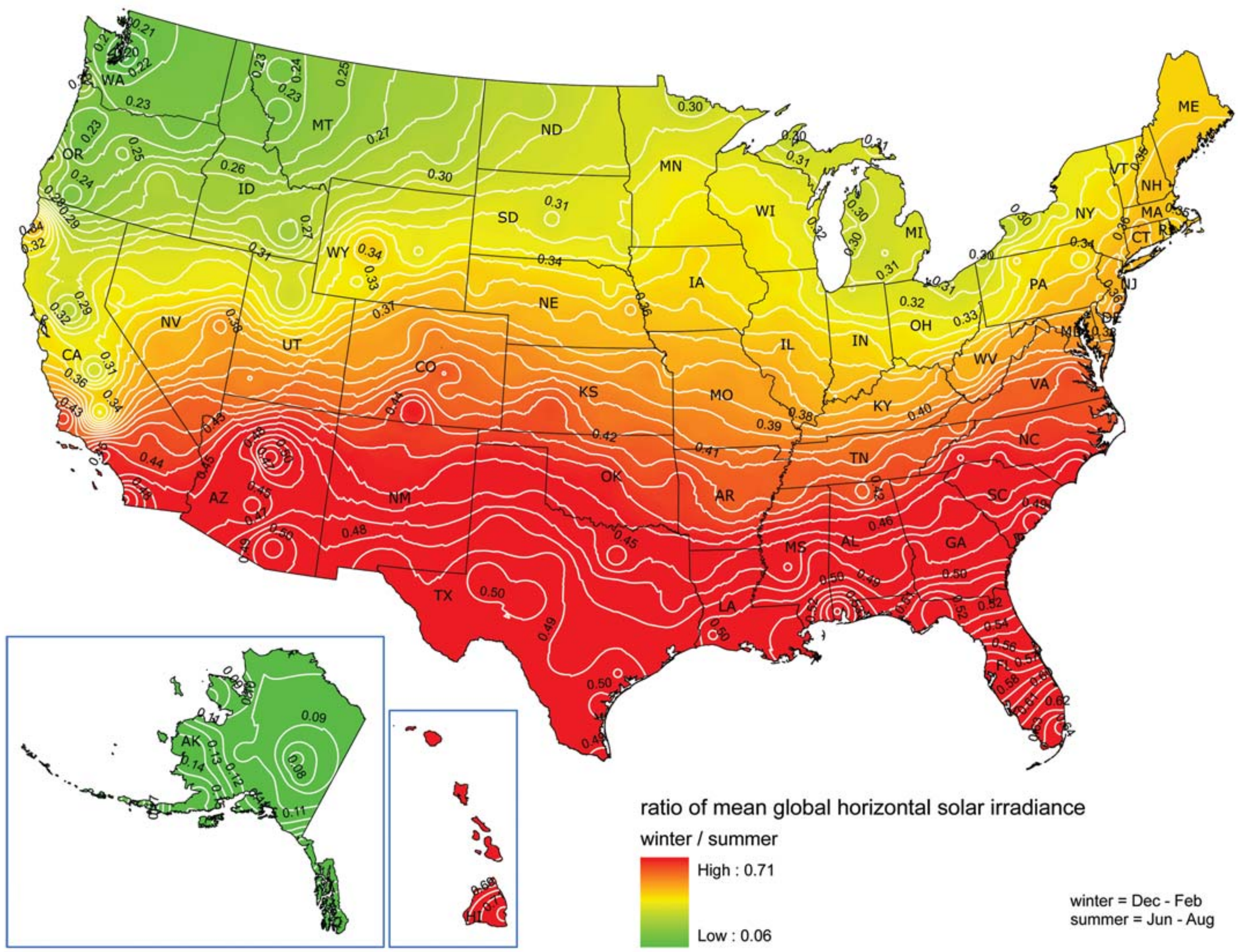

Figure 1

coldest states can benefit from significant reductions in cooling energy through the use of cool roofs. According to the paper, in Minnesota, for example, annual cooling energy reductions would average 4.17 kWh/m^2 of conditioned roof area.

If reflective roofs are beneficial in cooling-dominated climates, one would intuitively assume that such roofs would be disadvantageous in heating-dominated climates. Presumably, in such climates, dark-colored, minimally reflective materials that absorb large amounts of the sun's energy should heat up, resulting in a reduction in the heating energy required to keep the occupied space below the roof's surface at the desired temperature. There should, in effect, be a "heating energy penalty" associated with the use of cool roofs in such climates. According to the paper, there *can* be, although the magnitude is surprisingly small, even in the coldest states. In Minnesota, for example, it would be 0.137 $therm/m^2$ per year on average. It would be similar in Alaska, at 0.128 $therm/m^2$ per year. There are a number of reasons for this. Snow may cover the roof for extended periods of time. Winter days are shorter and cloudier and the sun is lower. In fact, as can be seen in *Figure 1*, the wintertime horizontal solar irradiance is typically 20 to 35 percent of the summer irradiance in the mainland northern states. In other words, a horizontal surface in the northern states receives about three to five times more daily sun in the summer than in the winter.

The authors found that the reduction in annual cooling load exceeded the increase in annual heating load everywhere in the U.S. except the most remote areas of Alaska.

The most important metric from a building operations perspective is economic impact. Using 2005 commercial-sector energy prices obtained from the Energy Information Administration, the authors calculated the estimated average annual energy cost savings, taking into account both cooling energy savings and heating energy penalties for each state.

According to the LBNL simulations, Hawaii benefits the most from cool roofs ($1.14/$m^2$ of CRA per year on average), followed by California ($0.70/$m^2$ per year). At the low end, average annual savings on the order of $0.13/$m^2$ were calculated for northern mainland states such as Minnesota and North Dakota. Interestingly, Alaska, with calculated average annual savings of $0.319/$m^2$ per year, is only 10 percent below the overall U.S. average savings ($0.356/$m^2$ per year). This value is driven by the state's low cost of natural gas (heating) and its high cost of electricity (cooling).

State	Cooling Energy Saving kWh/m^2 CRA	Heating Energy Penalty $Therm/m^2$ CRA	Energy Cost Savings ($/$m^2$ CRA)
CA	6.13	0.0292	0.699
NV	6.86	0.0737	0.570
FL	5.72	0.0115	0.448
NH	5.35	0.1210	0.482
MN	4.17	0.1370	0.136
IL	4.22	0.0994	0.217
U.S.	5.02	0.0645	0.356

Table 1 – Calculated average annual results for selected states. (Source: LBNL)

Results for a cross section of states are shown in *Table 1*. With the plethora of cool roofing products now available on the market, there are technically sound solutions that are cost-competitive with noncool options for most, if not all, roofing situations. Therefore, even in locations where the energy cost savings are modest, they can be achieved without an installed cost premium. The installation of cool roofs can also result in additional benefits, which are outlined below.

The cost savings data represent a specific point in time. All major forms of energy are subject to pricing changes and to various degrees of volatility, all of which will affect the results. One thing is clear, however: Through all the noise of various market forces, the overall trend for energy costs is to increase with time. Despite the ups and downs that we experience, that trend is likely to carry on in the same direction for some time to come.

ECOLOGICAL BENEFITS

Although energy cost savings are a key driver (particularly in warmer climates), one could argue that the ecological benefits of cool roofs are of even greater importance. Much of the initiative behind the cool roof movement came as a result of the Environmental Protection Agency's (EPA) Heat Island Reduction Initiative (HIRI), which started in 1998. Urban heat islands occur as pavement and buildings replace vegetation in cities. These surfaces absorb significant amounts of the sun's energy, with the cumulative effect being an overall increase in the city's surface- and air-temperatures. Increased urban air temperatures are associated with increases in smog. Under the HIRI, the EPA, the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and LBNL developed a number of heat island mitigation strategies, including cool roofs. This ultimately led to the creation of the Energy Star® program for roofs.

Much like the economic impacts, the projected environmental benefits of cool roofs can also be quantified. Significant amounts of greenhouse gases and other pollutants in our environment are the by-products of energy generation and usage. In its paper, LBNL estimated the reduction in a variety of emissions associated with the energy savings described above.

State	CO_2 Reduction kg/m² CRA	NO_x Reduction g/m² CRA	SO_2 Reduction g/m² CRA	Hg Reduction µg/m² CRA
CA	2.58	2.31	1.79	61.20
NV	3.64	6.37	4.74	71.80
FL	3.77	6.45	11.10	29.70
NH	1.82	2.14	6.36	21.60
MN	3.09	7.45	12.40	89.50
IL	2.97	5.48	19.60	89.90
US	3.02	4.81	12.40	61.20

Table 2 – Calculated annual average emission reductions for selected states. (Source: LBNL)

LBNL considered emission factors published by the EPA with the various forms of energy generation in each region and applied them to the calculated cooling cost savings and heating energy penalties per square meter of CRA for each state. It estimated the reductions in CO_2 (carbon dioxide), NO_x (nitrogen oxides), SO_2 (sulfur dioxide) and Hg (mercury) emissions that could be achieved by substituting (weathered) cool roofs for (weathered) conventional grey roofs. Results for the same selection of states considered previously are shown in *Table 2*.

Climate is a key driver in the magnitude of the energy savings. However, the types of energy generation in a given location have a significant impact on the emission reductions for a given level of energy savings. For example, the impact per unit of energy is less in areas with "cleaner" sources of power, such as hydro generation, than in areas with "dirtier" sources of power, such as coal generation.

LBNL estimates that converting 80% of all commercial buildings in the U.S. to cool roofs could result in a reduction of 6.23 metric tons of CO_2 emissions, which equals the annual CO_2 emissions of 1.2 million typical cars.

CO_2 "PAY-BACK" PERIOD

The numbers are impressive at a macro level. However, we deal with buildings one at a time, and it is helpful to bring the discussion to that level. Additionally, to date, we have only considered the "savings" side of the equation. Clearly, every action we take on this planet comes at a "cost." In order to get a complete picture, we must consider the "cost" of the cool roof. Building on LBNL's work, one company commissioned a study to determine the cost, in terms of CO_2 generation, of its cool roof membranes.

The company that manufactures reflective thermoplastic PVC roof membranes commissioned Carbotech AG, Swiss environmental consultants, to establish the amount of CO_2 emissions generated in the production of its roof membranes. Carbotech considered the various cool membrane types and thicknesses sold. The assessment was made on a "cradle-to-gate" basis: from raw material extraction to chemical precursor production to membrane manufacturing.

Using the manufacturer's sales data for 2007, Carbotech calculated the amount of CO_2 generated from "cradle to gate" from the production of the material sold into each state, taking into account the product mix (type and thickness). The average CO_2 generated per m² of membrane produced varied from about 4.0 kg/m² of membrane to less than 5.0 kg/m² by state. Comparing these values to the data in *Table 2*, it is clear that the CO_2 generated on a unit-of-production basis exceeds the energy-saving CO_2 reduction calculated by LBNL for cool roofs.

However, the CO_2 generated in the production of the materials as calculated by Carbotech is a one-time cost. The energy savings evaluated by LNBL are incurred annually, throughout the service life of the membrane. It is helpful to consider an environmental payback period for CO_2. Analogous to any financial model, the CO_2 payback period is the time it takes to recover our "environmental investment" (CO_2-generated producing membrane), through our "annual environmental return" (CO_2 reductions associated with energy savings). Payback periods ranged from a low of 0.9

State	CO_2 Payback Period in Years	CO_2 Payback Multiple Over 20-Yr Service Life
CA	1.8	11.1
NV	1.2	16.7
FL	1.2	16.7
NH	2.4	8.3
MN	1.3	15.4
IL	1.6	12.5
U.S.	1.7	11.8

Table 3 – Average CO_2 payback periods and payback multiples for selected states. (Source: Carbotech)

years, in Hawaii, to a high of 4.3 years, in Alaska. Results for the states previously highlighted are shown in *Table 3*. The national average is 1.7 years.

Looking at it another way, assuming a life expectancy of 20 years for the membrane, the CO_2 investment would pay for itself almost 12 times over during the roof's service life on average across the U.S. Similar results for the selected states are shown in *Table 3*.

ROOF PERFORMANCE

One cannot forget that the primary purpose of any roof is to protect the structure from the elements. Roofing materials, whether "cool" or not, should be chosen based on their proven track record of durability. There are numerous cool products on the market in various product types that have provided decades of exemplary service.

Roof assemblies must be properly designed incorporating vapor retarders or air barriers where required, multiple layers of insulation to prevent thermal shorts, appropriate fastening technology, proper detailing, etc. They must be installed by qualified contractors, ideally in the presence of trained roof observers. Taking shortcuts or "value engineering" key elements of the roofing package will compromise roof performance, "cool" or not. One area in particular where specifiers should avoid the temptation to value engineer their design around cool roofs is with regard to insulation. Although some standards may allow for it under certain circumstances, cooling energy savings should not be used as a basis for using less insulation below cool roofs in any climate. Cool roofing should be used as an enhancement to the insulation rather than as a partial substitute or a reason to specify a lower R-value. The one exception may be a building in a hot climate that contains many internal heat sources (equipment, people, lighting), where increasing the thermal resistance of the shell may actually increase the cooling load.

Ultimately, our collective objective should be to improve roof performance and energy efficiency, wherever possible.

CONCLUSIONS

The latest LBNL report highlights the potential cooling energy savings possible on commercial buildings around the country. Its evaluation of "heating energy penalties" shows that, even in northern states, the magnitude is quite small in this building segment. Taking into account year-round energy impacts, net energy and corresponding cost savings are achievable on commercial buildings across the country.

These energy savings can translate into reductions in greenhouse gases and other pollutants. Although the production of cool roofing (and all other materials) results in the generation of CO_2 and other greenhouse gases, the environmental "cost" is quickly recouped through reductions in emissions associated with the energy savings. Most importantly, these benefits can be achieved without sacrificing performance or durability.

In an interview on the topic of cool roofs as a greenhouse gas mitigation strategy, Stephen Schneider, codirector of Stanford's Center for Environmental Science and Policy and the editor of *Climatic Change*, summed things up nicely when he said, "It's a clever idea that has no obvious side effects and gives us a good bang for our buck."

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Updated VOC Adhesive Rules for NE and Mid-Atlantic States

The Ozone Transport Commission (OTC) is a coalition of 13 Northeastern and Mid-Atlantic states that work cooperatively on regional solutions to ground-level ozone. The OTC created a model rule regarding the reduction of emissions from volatile organic compounds from adhesives and sealants. States have taken this model rule and used it as a foundation for drafting their own regulations. All states with final regulations have included a modified implementation schedule that indicates that low VOC products must be used during warm-weather months.

Following is an overview of passed, pending, and proposed regulations in these states concerning emissions of volatile organic compounds from adhesives and sealants, updated from a similar table published in the April 2009 *Interface*.

	IMPLEMENTATION DATES			
	2009	2010	2011	2012
Connecticut www.ct.gov/dep/lib/dep/regulations/22a/22a-174-1through200.pdf	6/1 - 8/31	5/1 - 9/30	5/1 - 9/30	01/01/12 and thereafter
Delaware www.regulations.delaware.gov/register/april2009/final/12%20DE%20Reg%201333%2004-01-09.htm	6/1 - 8/31	5/1 - 9/30	5/1 -9/30	01/01/12 and thereafter
District of Columbia	Under consideration			
Maine www.maine.gov/dep/air/regulations/proposed.htm	Regulation pending			
Maryland www.dsd.state.md.us/comar/subtitle_chapters/26_Chapters.htm. Select 26.11.35.01	5/15 -9/15	5/15 -9/15	5/1 -9/30	01/01/12 and thereafter
Massachusetts	Under consideration			
New Hampshire	Under consideration			
New Jersey www.state.nj.us/dep/aqm/Sub26.pdf	6/1 - 8/31	5/1 - 9/30	5/1 -9/30	01/01/12 and thereafter
New York www.dec.ny.gov/regulations/36816.html	Under consideration			
Pennsylvania www.depweb.state.pa.us/pubpartcenter/cwp/view.asp?a=3&q=523288	Regulation pending			
Rhode Island www.dem.ri.gov/programs/benviron/air/25313344.htm	7/1 - 8/31	5/1 - 9/30	5/1 -9/30	01/01/12 and thereafter
Vermont	No action planned at this time			
Virginia www.townhall.state.va.us	Regulation proposed			

Updated April 30, 2009 — ***Courtesy of EPDM Roofing Association (ERA)***

