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Building a Prosperous Urban Future with Reflective Roofing

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Abstract

The great challenge of the next 100 years is to remake our rapidly growing cities into structures that can stand up to environmental changes with residents that are healthier, happier, and more prosperous than previous generations. We often do not think about the roofs above our heads, but making thoughtful materials choices on urban rooftops is a critical, readily-implementable strategy to help meet our new urban challenges. Roofs comprise over 25% of urban space and are readily accessible and easy to upgrade relative to other urban sustainability interventions. With roofing technologies that are currently available, cities can improve their biodiversity, reduce rising urban temperatures, improve health and quality of life, and defend against high energy costs and power blackouts.

One of the key sustainable roof technologies in the market today are reflective, "cool" roofs. Reflective roofing is an ancient concept achieved with modern technologies that have been growing in the market over the last 20 years. Reflective roofing is a cost-effective and easily deployable strategy to cut cooling energy demand by up to 20%, reduce temperatures in and around buildings, improve air quality and health, and cancel the warming effect of atmospheric greenhouse gases. This paper will provide building owners, government officials, and corporate decision-makers with:

1. the tools to quantify the benefits and costs of reflective roofing for buildings, communities, cities, and the planet;
2. an understanding of the available reflective technology options and a look forward at cutting-edge technologies that will be on the market in the next few years;
3. a roadmap for implementing reflective roofing in a variety of contexts via a detailed review of the most successful policies and programs worldwide that have helped spur local adoption of cool roofs including building and energy code requirements, construction specification requirements, green workforce development, and innovative public information campaigns.

Keywords: cool roofs, reflective roofs, urban heat islands, energy savings

1. Introduction

The parallel challenges of warming global temperatures and a mass migration from rural to urban spaces highlight the importance of improving the sustainability of cities. The benefits of sustainability to urban quality of life, economies, energy use and health are well understood, but even leading cities face difficulties in effecting real change quickly in their complicated and interconnected urban ecosystems. An effort to making smarter choices about roofs, such as using more solar reflective materials, can significantly and immediately benefit efforts to enhance the sustainability of the world's urban spaces. This paper will review the benefits, costs, and technologies available to implement cool roofs and describe a few examples of cities that have used reflective roofing to save energy, cut energy bills, improve grid reliability, cool urban heat islands, and improve the health and social welfare of its citizens.

2. Roofs are a platform for urban sustainability

2.1 Good roofs make sustainable cities

While the average person doesn't give it much thought on a regular basis, roof space is an important platform for urban sustainability efforts. Akbari (2008) found that roofs made up between 25% and 35% of the overall urban fabric in the studied cities. This is a significant amount of urban space that, if upgraded with reflective roofing, vegetation, solar power, or some combination, could drive benefits worth between \$0.40 per square meter and \$4.33 per square meter in the form of energy savings, reduced health care and storm water management costs, per Kats (2015).

Implementing sustainable roofs can rapidly change cities. Policy makers and building owners have more opportunities to upgrade the sustainability of roofs than other building components or pavements. Roofs are replaced every 15-20 years on average – a replacement rate of 5-7% per year. The benefits to energy use, air quality, health, urban economies, and global climate change mitigation of better roofing start the minute they are installed.

2.2 Urban heat is the defining sustainability challenge for the 21st century city

As Figure 1 from Zhang (2010) shows, cities tend to be an average of 4 to 6 degrees Celsius hotter than rural areas. This phenomenon, known as the urban heat island or UHI, is the result of several factors. Cities are less vegetated relative to rural areas. Buildings block or slow natural wind patterns that would help move heat. Cities are hubs of human activity that generate heat. The biggest contributor to urban heat islands, however, is the predominance of dark, impermeable roofs and pavements that absorb solar energy and radiate heat. UHI is both a day-time and night time phenomenon. Indeed, Climate Central (2014) found that night-time UHI can exceed 20 degrees.

The world is in the midst of a rapid urbanization. The United Nations reports that the percentage of the world's population living in cities will grow from 50% today to 80% in 2050 – all moving into urbanized space that makes up less than 2% of the earth's surface. Oke (1973) and Georgescu (2013) found that the increase in urban density and city size exacerbates all of the factors that cause UHI. Currently, excess urban heat is rising at twice the rate of global average climate change.

Overheated cities experience a number of negative impacts that affect almost every aspect of urban life.

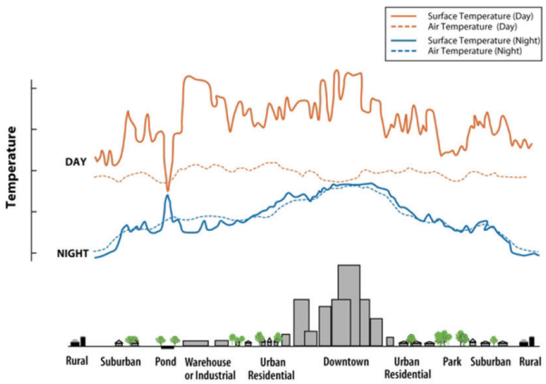

Figure 1: Temperature differences between different levels of urbanization. Source: NASAUrban heat leads to increased energy consumption

Solar energy absorbed by buildings converts into heat energy that is either transferred inside the building or blown off the roof to heat the surrounding air. For buildings with environmental controls, excess heat leads to an increase in cooling energy demand. In general, the relationship between temperature and city demand for electricity resembles a hockey stick. Below a threshold air temperature, typically between 24 to 27 degrees Celsius, daily energy demand is relatively constant. Demand for electricity spikes dramatically as temperatures rise above that threshold. Akbari (2001) indicated that peak electricity demand increases by 2 to 4 percent for every 0.5 degrees Celsius increase in temperature above a threshold of about 15 to 20 degrees Celsius. In New York City, for example, electricity consumption is 29 percent higher on a 32 degree Celsius day compared to a 26 degree Celsius day. The demand for cooling is generally highest during peak electricity consumption hours, the late afternoon and early evening. Akbari (2005) found that the UHI-related increase in air temperature is responsible for 5 to 10 percent of U.S. peak electric demand.

2.2.1 Urban heat reduces air quality

Decreased air quality is one of the most far-reaching effects of UHIs. Poor air quality, in which the ozone levels and levels of small, inhalable airborne particles (PM-2.5) from nearby coal plants are high, is detrimental to public health and the environment. The World Health Organization (WHO) estimated 21,000 premature deaths per year occur across 25 European countries because of high levels of ozone (Amann et al. 2008). WHO further estimates that 14,000 respiratory-related hospital admissions in Europe are directly due to high ozone levels.

Urban air quality influences and is influenced by a city's temperature. An increase in temperature corresponds to the rate at which ozone feed stocks cook into ozone. Akbari (2005) found that for every 1 degree Celsius the temperature in Los Angeles rises above 22 degrees Celsius, smog increases by 5%. Figure 2 from Piety (2007) showed how smog forms in a nonlinear fashion in accordance with the maximum surface temperature at Baltimore-Washington International Airport. Each point represents an 8-hour period. At 27 degrees Celsius, most of the points are below the minimum EPA compliance level of 60 parts per billion (noted with a red line in Figure 2). At and beyond 32 degrees Celsius, the majority of points lie above minimum compliance, meaning the amount of ozone is at dangerous levels.

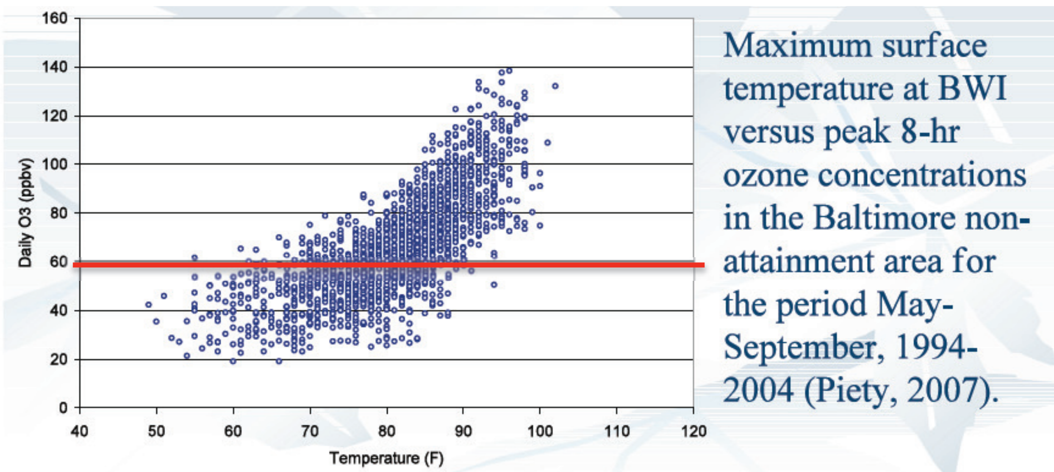

Figure 2: Ozone concentrations by maximum surface temperature. Piety (2007)

2.2.2 Urban heat compromises health

Increased daytime temperature, reduced nighttime cooling, and high air-pollution levels increase health problems and mortality, especially among low-income and elderly populations. In fact, Wong (2012) found that between 1989 and 2000, studies of 50 U.S. cities recorded a rise of 5.7% in mortality during heat waves. The Centers for Disease Control and Prevention (2012) reported that over a 12-year period (1999-2010), excessive heat caused 7,415 premature deaths in the United States. Heat waves in Europe claimed over 52,000 lives in 2003 alone – one of the greatest natural disasters in history.

In addition to causing higher daytime temperatures, urban heat islands keep cities and their residents from cooling off at night. Hotter nighttime temperatures are especially dangerous during extreme heat events. Urban populations are often unable to recover from the daytime heat and become more vulnerable to heat-related health problems in subsequent days.

2.3 Reflective roofing mitigates urban heat

Replacing dark urban surfaces with more reflective and lighter-colored surfaces on roadways, walkways, and roofs is a primary UHI mitigation strategy. The darker a surface, the more potential it has to store heat. A light-colored or reflective surface has a very small potential to store heat because of its high albedo, or reflective ability. Surfaces that reflect solar energy stay cooler, release less heat into the surrounding air, and allow for nighttime cooling in a city.

Cool surfaces are measured by how much light they reflect and how efficiently they radiate heat (thermal emittance or TE). Solar reflectance is the most important factor in determining whether a surface is cool. A cool roofing surface is both highly reflective and highly emissive to minimize the amount of light converted into heat and to maximize the amount of heat that is radiated away.

Most roofs are dark and reflect no more than 20 percent of incoming sunlight (i.e., these surfaces have a reflectance of 0.2 or less); while a new white roof reflects about 70 to 80 percent of sunlight (i.e., these surfaces have a reflectance of 0.7 to 0.8). New white roofs are typically 28 to 36 degrees Celsius cooler than dark roofs in afternoon sunshine while aged white roofs are typically 20 to 28 degrees Celsius cooler.

2.3.1 Benefits of cool roofs to individual buildings

Energy savings potential: Increasing the reflectance of a roof from 0.1-0.2 to 0.6 can cut net annual cooling energy use by 10 to 20 percent on the floor of the building immediately beneath the roof by reducing the need for air conditioning. Levinson 2010 presented an analysis of energy savings in new and old office and retail buildings by U.S. zip code. The analysis found that there are net energy savings in every part of the U.S. (warm and cold climates) except in northern Alaska. Target Corporation, one of the largest American retailers, has experienced net overall energy savings (based on all energy consumed for heating, cooling, lighting and equipment) between 0.5% and 1.0%, depending on location, in their facilities across the USA by specifying white reflective thermoplastic membranes. These energy savings collectively result in several millions of dollars in energy cost savings annually for the company.

Cost savings potential: Levinson 2010 found the average annual net energy cost saving (cooling energy saving minus heating energy penalty) for a white roof on a commercial building in the U.S. is $0.36 per square meter ($0.40 in 2015 dollars). Retrofitting 80 percent of the 2.6 billion square meters of commercial building roof area in the U.S. would yield net annual energy cost savings of $735 million. Globally, cool roofs could save billions of dollars. Kats 2015 evaluated the economic benefits from the installation of cool roofs on municipal buildings in Washington DC and found that cool roofs installed on 2.6 million square meters of municipal roof space would generate net savings to the city of $46.5 million ($17.88 per square meter) in energy cost reductions and avoided health costs.

Improved thermal comfort: In a building that is not air conditioned, replacing a dark roof with a white roof can cool the top floor of the building by 1 to 2 degrees Celsius. Programs to install cool roofs and train proper fan use in Philadelphia led to 3 degree Celsius reductions in indoor air temperature during hot days. These temperature reductions are enough to save lives in extreme heat waves and make non-conditioned work environments like barns and warehouses more usable and comfortable for employees.

2.3.2 Benefits of cool roofs to cities

Reduced summer heat island effect Simulations run for several cities in the U.S. in Akbari (2001) have shown that city-wide installations of highly reflective roofs and pavements, along with planting shade trees will, on average, reduce a city's ambient air temperature by 2 to 4 degrees Celsius in summer months. Reducing urban temperatures makes cities more comfortable and enjoyable to live in and promotes healthier populations.

More resistance to heat related deaths Cool roofs can cool the areas in a building where the risk of death during heat waves is high. For example, there were 739 deaths in the Chicago heat wave of 1995. Virtually all of the deaths occurred in the top floors of buildings with dark roofs. Subsequent heat waves have claimed thousands of lives in the U.S., France, Russia, and elsewhere. Kalkstein 2014 found that 10 percent increases in urban vegetation and reflectivity can reduce mortality during heat waves by 6-10 percent.

Reduced peak electricity demand Cool roofs can improve utility capacity utilization and therefore profitability, reduce transmission line congestion, avoid congestion pricing, and forego the need for additional investments in peaking generation capacity. Rosenfeld et al. (1996) estimated that eliminating the urban heat island effect in Los Angeles a reduction of 3 degrees Celsius could reduce peak power demand by 1.6 gigawatts and save about $175 million per year ($268 million in 2015). Approximately $15 million of that amount was due to more reflective pavements. A 2004 analysis of New York City by the Mayor's Office of Long Term Planning and Sustainability, when electricity averaged $0.165 per kWh, found that a one degree reduction in temperature would cut energy costs by $82 million per year. Electricity prices have subsequently increased by over 20 percent. Hoff (2014) found that peak energy cost savings can be double the base energy savings in many cooler climate zones. Most cost benefit analyses have not quantified this important aspect of energy savings until recently.

Air quality benefits City-wide temperature reduction not only makes cities more comfortable, but also improves air quality because smog (ozone) forms more readily on hot days. Simulations of Los Angeles in Akbari (2001) indicate that lighter surfaces and shade trees could cool temperatures and thus reduce exposure to unhealthy levels of smog by 10 percent to 20 percent. Across the U.S., the potential energy and air quality savings resulting from increasing the solar reflectance of urban surfaces is estimated to be as high as $10 billion per year.

2.3.3 Benefits of cool roofs to the planet

Global cooling potential Akbari 2008 found that replacing the world's roofs and pavements with highly reflective materials could have a one-time cooling effect equivalent to removing 44 billion tonnes of CO_2 from the atmosphere, an amount roughly equal to one year of global man-made emissions. Every 10 square meters of white roofing will offset the climate warming effect of one tonne of CO_2. Assuming the average car emits 4 tonnes of CO_2 per year, the combined "offset" potential of replacing the world's roofs and pavements with highly reflective materials is equivalent to taking all of the world's approximately 600 million cars off the road for 20 years. Put another way, the cooling offset of global reflectivity from cool roofs would cancel the warming effect atmospheric GHG generated by 500 medium-sized coal power plants over the life of the roof.

3. Reflective technology options

3.1 Reflective Roof Technology Options

3.1.1 Roof Types and Cool Roof Options

Cool roofing materials can be divided in to two categories, based on their intended use. Although some technologies are suitable for both applications, generally they are intended for use in either low (≤9.5°, 2/12) or steep (>9.5°) slope installations. The requirements for being considered a cool roofing material vary by category and program. Table 1 summarizes the requirements of the two most prominent programs in the USA, California's Title 24 Energy Code and the Environmental Protection Agency's Energy Star Program.

Table 1. Cool Roof requirements

	Reflectivity		Thermal Emissivity		SRI
	Initial	Aged	Initial	Aged	
California Title 24					
Low Slope	n/a	0.63	n/a	0.75	75
Steep Slope	n/a	0.20	n/a	0.75	16
Energy Star					
Low Slope	0.65	0.5	n/a	n/a	n/a
Steep Slope	0.2	0.15	n/a	n/a	n/a

In the United States, the reflectivity and emissivity (together, their surface properties) of roofing materials are tested according to protocols defined by the Cool Roof Rating Council (CRRC).

The CRRC includes representatives from roofing manufacturers and other experts. The CRRC's standards are recognized in major building energy codes and list both initial/ as received and 3 year aged values.

Cool roofing materials are available in a wide variety of technologies. The most common low slope roofing materials include coatings, single ply membranes and mutli-ply bituminous systems. Coatings are applied over waterproof membrane systems such as dark colored elastomeric single ply sheets or bituminous systems, to provide the desired reflective properties and/or to extend the underlying membrane's service life. Acrylic coatings are most commonly used in these applications. A significant advantage of coatings is that they can be applied to in-place membranes, thereby salvaging the existing materials and negating the need to remove, dispose and replace them, most significantly, the existing thermal insulation. Acrylic coatings have some of the highest initial reflectivity values, with a few products in the low 90 percent range.

Liquid membranes are also available which typically consist of multiple layers of field applied acrylic, polyurethane or other fluid chemistries, incorporating reinforcements. These types of products are particularly beneficial for roofs with difficult access and extensive amounts of roof top equipment and other penetrations concentrated in small, congested areas where roll goods are impractical, such as on high rise buildings.

Combined, thermoplastic single ply membranes, which include both polyvinyl chloride (PVC) and thermoplastic olefin (TPO) materials, represent more than 40% of the low slope roofing market in the United States. The ever increasing demand for energy saving cool roofing materials has been a key driver in their growth over the past years. These materials have initial reflectivity values within the low to the high 0.80 range. They can be applied in a variety of configurations including mechanically attached, induction welded, and adhered. The use of hot air welding to seal the seams of the sheets in roll widths of 8' or 10' allows for high application productivity and low installed costs. Although much less common, some suppliers also offer elastomeric membranes with a white, reflective weathering surface.

Modified bituminous membranes have benefited from the development of reflective granules, and products are now available that achieve reflectivity levels above 0.70. Some metallic surfaced materials achieve values in the same range as thermoplastic membranes and acrylic coatings. Modified bitumen sheets which are typically installed in two or more layers, provide redundancy and a high level of resistance to mechanical damage. A variety of sheets are available depending on the application technique to be used: torched on, adhered with hot asphalt or cold adhesives, or mechanically attached. They are often selected in re-roof situations where their compatibility with existing bituminous materials is advantageous.

Table 2 provides a summary of the initial and three year aged solar reflective properties of the various types of materials available (NOTE: All of these materials have high thermal emittance values, therefore for clarity, only the reflectance values are included)

There are a myriad of cool roofing material options available to choose from. Ryan (2015) noted that there are more than 4,600 products listed in the Energy Star database, and about 2,600 products listed in the Cool Roof Rating Council's database (2015). With products available across the entire spectrum of technologies, performance levels and price there is a cool roof solution for every need and situation.

Table 2: Reflectivity performance ranges for common roofing products.

Type	Number of CRRC Rated Products	Initial Reflectance			Aged (3-year) Reflectance		
		Average	Max	Min	Average	Max	Min
Asphalt Shingles	58	0.26	0.41	0.13	0.26	0.37	0.16
Build-Up and Modified Bitumen Sheet Roofing	84	0.49	0.88	0.25	0.45	0.8	0.23
Concrete/Clay Tile and Slates	429	0.31	0.82	0.08	0.30	0.74	0.1
Field-Applied Coatings	484	0.80	0.94	0.04	0.68	0.87	0.03
Metal Products	1008	0.36	0.77	0.25	0.36	0.74	0.24
Metal Shakes/Shingles (including Granular Coated Metal)	17	0.31	0.46	0.22	0.30	0.44	0.23
Other Roof Products: Fluid Applied Membrane Roofing	10	0.80	0.9	0.42	0.68	0.78	0.43
Single Ply Thermoplastic and Thermoset Roofing	123	0.71	0.91	0.06	0.60	0.81	0.07

There are alternative approaches to achieve similar effects to high surface reflectivity. Some jurisdictions recognize ballasted roofs as alternatives to reflective membranes or coatings in their regulations. Large stone ballast acts as a heat sink, moderating heat transfer into the building. Vegetated or "green" roofs consist of waterproofing membranes covered with growing medium and vegetation. These roofs provide cooling energy savings and help mitigate the urban heat island effect through a combination of shading by the plant media and evapotranspiration. Some major metropolitan areas are incentivizing the use of green roofs as a means to provide some relief to aged, deteriorated storm water sewage systems which often are tasked with handling water volumes far greater than anticipated when they were installed. Although costs continue to decrease over time, they generally have installed costs that are upwards of 50% more expensive than conventional roofing systems.

3.1.2 Design Considerations for Low Slope Cool Roofs

As with all roofing materials and other outdoor surfaces, cool roofs are subjected to various forms of soiling. Research has shown that the degree of soiling tends to level off or plateau after approximately three years of exposure, which is the basis for reporting aged reflectance and emittance values in the most prominent cool roof rating programs. When accounting for the effects of cool roofs in HVAC and other building physics calculations and assessments, only aged values should be considered.

Akbari (2005) has shown that cleaning of some types of cool roof materials such as thermoplastic membranes can restore practically all of a product's initial reflectivity it is rarely practical or cost effective to do so. The benefits of cool roofs are clearly reduced by surface soiling. However, an analysis of all products in the CRRC database with an initial reflectivity of 0.70 or greater (average: 0.82), and an initial emissivity of 0.75 or greater, showed the average 3 year aged reflectivity of these products to be 0.70, with over 90% of the products having an aged reflectivity greater than 0.60. Most modeling on the energy and UHI mitigation impacts of cool roofs is based on an assumed value of 0.55 for aged reflectivity.

Some have postulated that in cold climates cool roof surfaces do not heat up as much as darker materials in the winter months, thereby making them more prone to condensation, and less capable of drying out any condensate that may form. Fenner (2014) reported on a survey of twenty four retail stores in northern US states. All the roofs had mechanically fastened reflective thermoplastic membranes and had been in place more than 10 years. None of the roofs had a vapor retarder. No evidence of condensation was found in any of the roofs. As the Department of Energy (2010) has noted with regards to the potential for condensation in cold climates, "…while this issue has been observed in both cool and dark roofs in cold climates, the authors are not aware of any data that clearly demonstrates a higher occurrence in cool roofs.."

Energy codes are calling for ever greater amounts of thermal insulation in buildings, which some believe negate the energy savings benefits of cool roofs Desjarlais (2012) ran simulations using the "Simplified Thermal Analysis of Roofs" (STAR) model to attempt to answer this question. They modeled a cool white roof, incorporating code mandated insulation levels, for a representative city in each of the USA climate zones to establish the base lines. They then repeated the analysis with a black roof, and found that additional insulation was required in all cases for the black roof to achieve the equivalent energy performance as the white roof (Table 3). Ramamurthy (2015) conducted a field study of 5 roofs with various combinations of albedo and insulation values (up to R48). They found that the most energy efficient roof construction consists of a high albedo membrane over high amounts of insulation at their location in the North Eastern USA, where the number of heating degree days is approximately five times greater than the number of cooling degree days.

Table 3: Additional insulation required for a black roof to achieve the equivalent energy performance as a cool roof

Climate Zone	Representative City	Default R-Value, White Roof,	Additional R Value required for Black roof
1	Miami, FL	20	17
2	Austin, TX	25	16
3	Atlanta, GA	25	11
4	Baltimore, MD	30	10
5	Chicago, IL	30	6
6	Minneapolis, MN	30	5
7	Fargo, ND	35	5
8	Fairbanks, AK	35	3

3.1.3 Cool options for steep-slope roofs

The most commonly used steep slope materials in the USA include asphalt shingles, various types of tiles, wood shakes and metals (which can also be used in some low slope applications). Traditionally, with the exception of white colored products, these materials had modest levels of reflectivity, typically 20 percent or less. There has been, particularly in the residential sector, resistance to the use of white products for aesthetic reasons. However, there have been significant developments in most technologies such as reflective granules in shingles, and advances in cool pigments for use on metal, concrete and clay tiles, to name but a few. A variety of "cool colors" is now available in most technologies, which removes a significant obstacle to broad implementation of the concept in sloped, particularly residential, market segments. Some steep sloped materials are approaching reflectivity levels of some of the more common low slope products.

3.1.4 Advances in Cool Roofing Technology

Developmental work is being carried out in most roofing material technologies to further improve upon the reflective properties of materials. Although still in the early stages, the use of fluorescent cool dark pigments is expected to provide metal roof coatings with unprecedented levels of reflectivity. Similarly, the use of synthetic granules will improve the reflective properties of shingles and modified bitumen membranes. One area of great interest is reducing the degree of soiling so as to maintain higher levels of reflectivity over time. Some suppliers are adopting photocatalytic technologies which trap and remove ground level ozone precursors from the air. In the longer term, shingle type products incorporating "directional reflectivity", will have a dark, traditional appearance from the ground, while the portion of the product's surface facing the sky will be reflective. Promising research is also being carried on thermochromic and electrochromic materials, that will shift color as temperatures change, potentially eliminating any winter heating penalty.

4. Reflective Surfaces in Policy

Cities and other jurisdictions have enacted a variety of programs and policies to encourage the deployment of cool roofs. Voluntary programs include awareness programs, volunteer cool coating initiatives, and incentive programs to reduce first costs. The most effective measures to drive a transition to reflective roofing have been cool roof requirements. In nearly all cases, the requirements apply to new roofs and when a roof is undergoing a substantial repair or replacement and include alternative compliance options such as solar PV installations or vegetated roofing. Chicago was the first U.S. city to require cool or vegetated roofs, in 2001. Since then, about half of the 30 largest cities in the U.S. have some sort of reflectivity requirement for roofs. Figure 3 details the evolution of cool roof requirements in the U.S.

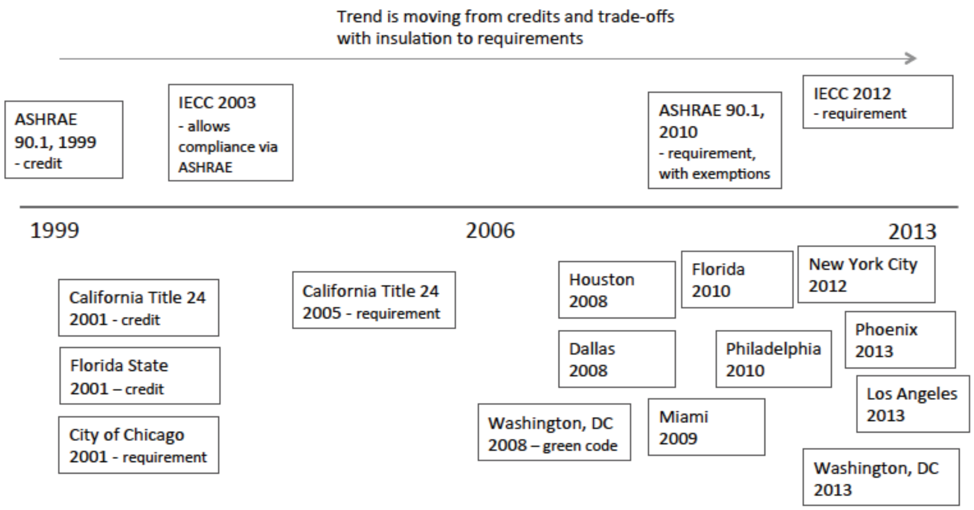

Figure 3: Evolution of cool roof requirements in the U.S.

5. Conclusions

The high concentration of dark heat absorbing roofs and paved surfaces covering significant portions of cities creates Urban Heat Islands (UHI), where localized ambient temperatures are significantly higher than in adjacent rural areas. These elevated temperatures contribute to reductions in air quality and decreased cooling energy demand in conditioned facilities. The additional GHG emissions resulting from the additional power generation compound the air quality issues. The confluence of climate change and the rapid urbanization projected over the coming decades will only exacerbate the problem globally. Broad adoption of cool roofing can play a significant role in mitigating these effects. By reflecting incident solar energy away from roof surfaces, they can moderate the UHI effect and decrease cooling energy consumption, resulting in a significant reduction in GHGs. Cool roofing can also reduce the impact of extreme heat events on occupants of non-conditioned spaces. Cool roofs provide the greatest benefit during peak power demand periods, which can delay or even negate the need to construct the additional power plants in many locations. All of these benefits can be achieved without appreciably changing the way we construct our buildings, and generally without a cost premium over traditional darker materials in all types of low and steep slope roofing technologies. Although a rapid transition to broad implementation of cool roofing strategies would be preferable, requirements mandating the use of cool roof materials in all new construction and during the re-roofing of existing structures will achieve the desired effect over time without additional cost to any stakeholder.

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