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A review of challenges, barriers, and opportunities for large-scale deployment of cool surfaces

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Abstract

Major urban centers are warming due to a combination of global and local phenomena. City governments are increasingly adopting strategies to mitigate the causes and impacts of extreme heat on their populations. Among these strategies are high solar-reflectance (cool) surfaces installed on building roofs and walls. Use of cool surfaces is a cost-effective and simple strategy that replaces conventional darker surfaces with surfaces that have a high reflectance to shortwave (solar) energy.

This report reviews the recent history of cool-surface deployment efforts. This includes peer-reviewed literature, conference proceedings, and grey literature to identify challenges and barriers to wide-scale deployment of cool surfaces. We have also researched heat action plans and programs from cities and different codes and standards, as well as available incentive and rebate programs.

The review identifies challenges, barriers, and opportunities associated with large-scale deployment of cool surfaces and categorizes them broadly as being related to product development & performance or policies & mandates. It provides a foundation upon which we intend to build a roadmap for rapidly accelerating future deployments of cool surfaces. This roadmap will address identified challenges and incorporate lessons learned from historical efforts to generate a practical and actionable plan.

1. Introduction

Cool surfaces have been considered a viable strategy for improving building thermal performance and cooling cities for decades, if not centuries. In fact, evidence of cool roofs in vernacular design dates back to ancient Rome and Greece. Such designs were commonplace before the widespread adoption of central air-conditioning in the mid-20th century [1].

Cool surfaces are materials that reflect a large fraction of incoming solar radiation, reducing the absorbed solar radiation and hence, surface temperatures and near-surface air temperatures. They can mitigate the urban heat island and reduce building cooling loads [2].

Cities are warming at an alarming rate due to the combination of large-scale global warming and local scale warming associated with urbanization [3–5]. The local warming, or urban heat island effect, is due in large part to rapid urbanization and the associated use of building materials that are highly absorptive to solar radiation, storing the sun's energy during the day, and releasing it slowly throughout the night. The result is an increase in the urban surface and air temperatures above those found in the unbuilt surroundings [6].

As a result of this heat island effect, cities around the world have experienced a sharp increase in the number of summer days with elevated air temperatures. For example in Boston, the historical average of 10 days per year over 32 °C (90 °F) has increased to 46 days per year [7].

Buildings emit heat to the surroundings through three mechanisms: convection and radiation from building envelopes due to surface temperature elevation above ambient temperature, exfiltration through buildings leakage and exhaust, and heat rejected from air conditioning systems [8]. However, more than 50% of the sensible heat emitted by the building is from the envelope (roof, wall, and window) [6], suggesting that envelope modifications have the potential to greatly impact the adverse urban warming effects of buildings.

Advances in building materials and coatings offer a direct solution to the growing urban heat problem. Installing highly reflective materials on building envelopes (roofs and walls) to reflect incident solar radiation can lower surface temperatures, and as result will reduce the heat flow into the building, and decrease cooling demand. Using highly reflective façade materials also benefits the surrounding urban area by reducing the near-ground air temperature [9].

Recent activities, including rebates, incentives, codes, action plans, and legislation, have helped to reinvigorate and expand the deployment of cool surfaces on a wide scale. These developments have influenced the deployment of cool surfaces on a large scale and have served as models for ongoing efforts that will be described in subsequent sections of this review.

2. Methods and data

2.1. Peer-reviewed literature

Scopus—a curated abstract and citation database of scholarly literature managed by Elsevier—was used to search for peer-reviewed literature relevant to this review. Scopus indexes articles from more than 34,000 peer-reviewed journals and includes more than 82 million records in 40 languages. The search query used in the Scopus search was (Title= "cool surface" OR "cool roof" OR "white roof" OR "roofs") AND (title/abstract/keywords= "urban" AND "mitigation" OR "policy" OR "code") AND NOT (title/abstract/ keywords= "green roof"). This search resulted in 65 sources. Additional sources were identified through a combination of searching within the reference lists of these 65 sources and other Google Scholar searches using similar search terms. The resulting list was further filtered based on reviews of abstracts, resulting in a total of 26 highly relevant and impactful articles (shown in Table S1 in Supplementary Material for detailed analysis and inclusion in this review.

2.2. Conference proceedings

Over the past several decades there have been several periodic conferences that include sessions focused on some areas related to urban heat mitigation, cool surfaces, and similar technologies. Many of these conferences focus on scientific and technical aspects of urban climate and heat mitigation. Among these are the International Conferences on Urban Climate organized by the International Association for Urban Climate (e.g., ICUC-10, 2018 in New York; ICUC-9, 2015 in Toulouse; ICUC-8, 2012 in Dublin, conferences organized by the American Geophysical Union (AGU), and the American Meteorological Society's (AMS) Urban Symposia, hosted by their Board on the Urban Environment.

For this review, we are more interested in application-focused literature and conferences. Several conferences focus on applications and codes & standards: for example, the periodic International Conference on Countermeasures to Urban Heat Islands (IC2UHI-3, 2014, Venice; IC2UHI-4, 2016, Singapore; IC2UHI-5, 2019, Hyderabad). The American Society for Heating Refrigeration and Air Conditioning Engineers maintains a technology portal for journal articles, research reports, seminars, and papers presented through their various conferences and journals. Additionally, the American Council for an Energy-Efficient Economy (ACEEE) conducts a Summer Study conference on Energy Efficiency in Buildings, held biannually in Pacific Grove California.

We searched through available abstracts from these conferences using keywords that included “roof”, “reflective”, “albedo”, and “cool”. We also searched on “incentive”, “polic*”, “demonstration”, “green building”, and “code” to identify relevant presentations that might reveal example best practices for implementation of cool surfaces or other energy efficiency strategies. From among the matching records, we further refined our search to focus on relevant presentations that focused on deployment, policy, and incentive programs, arriving at 11 particularly important and relevant conference presentations (see Table S2 in Supplementary Materials).

2.3. Other resources

We searched websites from various industries and non-profit groups to identify additional sources of relevance to this review. This included a review of a database including 136 codes, and standards maintained by the Cool Roof Rating Council (CRRC).

Finally, we conducted multiple Google searches, focusing on the following search terms and phrases: “incentive”, “rebate”, “code”, "cool roof", “reflective”, "high albedo", “action plan”, and “programs”. This search only considers articles from 2006 to present, to focus on more recent efforts.

This resulted in a total of 58 highly relevant results, summarized in Table S3 in the Supplementary Materials.

Figure 1 shows the distribution over time and category of all highly relevant sources, including those from peer-reviewed literature, conference proceedings, and other resources. The Article Type “Deployment experience” includes lessons learned from deployment efforts with other technologies, while the article type “Other cooling strategies” includes technologies such as trees, green roofs, and cool pavement.

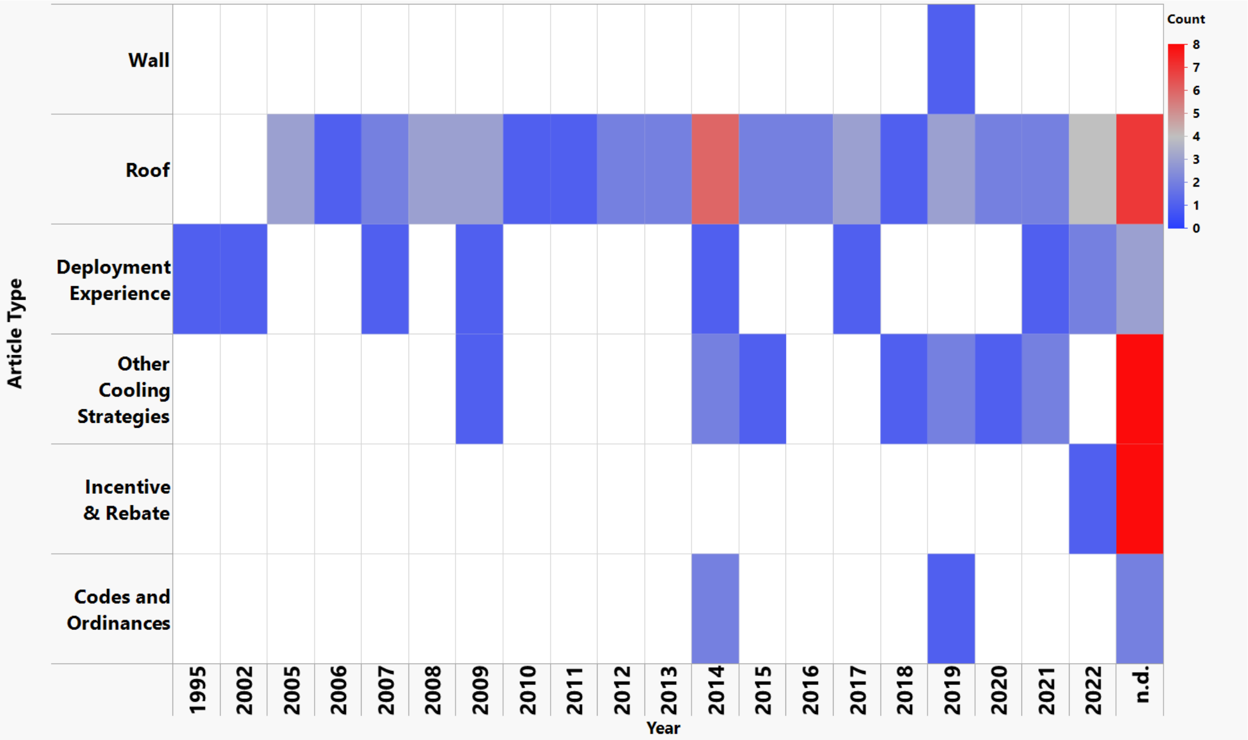

Figure 1. Distribution over time and category of all highly relevant sources. [n.d. refers to articles with no publication date]

3. Results and discussion

3.1. Overview of cool surface benefits

The benefits of cool surfaces have been the subject of numerous past studies and review papers. The novelty of the current review is that it explores barriers, opportunities, and models for cool-surface deployment, with an emphasis on building applications. We present a brief overview of the benefits of cool surfaces to provide context for the present review.

Generally, the benefits of cool surfaces applied to buildings are divided into two categories: direct effects on the building receiving the cool surface application, and indirect effects associated with reduced air temperatures at the neighborhood to city scales.

3.1.1. Direct (building-scale) effects of cool surfaces

Cool roofs and surfaces provide a direct benefit to the building and its occupants. This includes reducing the cooling required by the building to maintain indoor thermal comfort [10,11]. Synnefa et al. [12] evaluated the benefit of cool roofs on the peak cooling demand in air-conditioned, finding that increasing the roof solar reflectance reduces peak cooling demand in residential buildings by 11–27%.

Installation of cool roofs also provides direct benefits for buildings without insulation and without air conditioning [13]. For example, Dabaieh et al. [14] found that using high albedo material on flat roofs on residential buildings in Cairo reduces the number of cooling hours during the summer period from 1,735 to 850—a 52% decrease. In the same study, the average operative temperature (average of the mean radiant and ambient air temperatures) during August was reduced by 2.0 °C (3.6 °F) from 32.4 °C (90.3 °F) to 30.4 °C (86.7 °F). Another energy simulation study replacing the aged gray roof (albedo 0.2) to aged white roof (albedo 0.6) of standard-compliant office building prototypes in China in four cities (Chongqing, Shanghai, Wuhan, and Guangzhou) shows an annual savings per unit conditioned roof area of 4.1–10.2 kW h/m^2 source energy [15]. Furthermore, cool roofs have benefits for air-conditioned and buildings without insulation. For example, Rallapalli et al. [16] conducted a study comparing grey and white roofs. The results show the average daily air conditioning energy savings per unit roof area during the summer month of April is 0.15 kWh/m^2 per day (40%) and the minimum in the winter month of December is 0.07 kWh/m^2 per day (15%).

Akbari et al. [17] estimated the annual cooling energy saving (kWh) in 76 cities located in 49 countries for a house with a 100 m^2 roof area. Their results show a saving from 170 kWh/year for mild climates to over 700 kWh/year for very hot climates.

3.1.2. Indirect (neighborhood-scale) effects of cool surfaces

In addition to the direct impacts on the buildings to which they are applied, cool roofs have benefits for the surrounding urban area. For example, Baniassadi and Sailor [2] show that the maximum summer surface temperature of a high solar reflective roof material in Phoenix, AZ can be 20 °C (36 °F) lower than that of conventional roof materials, and can even be maintained below ambient air temperature for sufficiently high solar reflectance and thermal emittance. This can reduce the near-surface air temperature, particularly for widespread deployments [18]. This has been evaluated by numerous studies using multiple simulation tools including Weather Research and Forecasting Model (WRF) and Envi-Met [19–25].

A review [26] of the cooling effects of four mitigation strategies, including urban geometry, planting vegetation, using cool surfaces, and incorporating bodies of water found a reduction in summer air temperature of roughly 2 °C (3.6 °F) for each of these approaches, with some clear differences in diurnal timing of the cooling effect.

3.2. Overview of challenges and barriers

Cool surfaces are a cost-efficient and easy-to-install strategy for buildings and pavements. As noted above, the use of cool surfaces has multiple benefits for buildings and surroundings. However, some articles in the literature identify important barriers that hinder the use of cool surfaces. This section discusses the challenges and barriers associated with (1) performance, (2) policies and mandates, and (3) the product.

3.2.1. Challenges associated with performance

Winter penalty: Cool roofs reflect solar radiation which consequently reduces the need for cooling inside the building during summer. However, in colder months and cool climates, cool roofs have a penalty associated with increasing the need for heating to maintain indoor thermal comfort for occupants [27]. It is important to note that the net annual benefit or penalty depends on several factors.

In a very cold climate with snow or ice build-up on the roof, the snow will provide an added layer of insulation, while simultaneously making the radiative properties of the roof material irrelevant. Multiple studies have simulated the effect of snow accumulation on roofs [28–30] and demonstrated that the effect of snow greatly diminishes any winter penalty for heating associated with cool surfaces.

In winter, the combination of lower sun altitude, frequency of cloudy days, reduced day length and timing of demand for heating [29] all serve to reduce the importance of the winter penalty for cool roofs. Additionally, in commercial buildings, the low ratio of façade surface area to building volume offsets heat losses in winter by heat gains from interior heat sources such as occupants, and equipment [31].

Nevertheless, to overcome the winter heating penalty multiple studies have suggested the use of the switchable cool surfaces that reflect solar radiation during the summer months, and absorb it during the winter months [32]. This can be achieved by using thermochromic or electrochromic coatings. However, thermochromic coatings switch properties based on surface temperature alone, and can't be controlled manually, making them less flexible. While properties of electrochromic coatings are more easily controlled (e.g., by a switch), they inherently require a higher degree of active management/control [33].

Undervalued benefits: The perceived benefits of cool surfaces are often thought of as benefiting only energy use and associated energy costs. As cool surfaces can often be installed at zero or near-zero incremental cost, they compete well against other strategies for improving building energy efficiency [34]. There are other advantages of cool roofs that are often neglected. These include reductions in neighborhood/city temperatures, improved air quality, and reductions in CO_2 emissions associated with reduced energy demand. Some of these benefits are difficult to quantify, and as a result, often are ignored or undervalued in the creation of policies or incentives. Synnefa and Santamouris [35] provide detailed analysis of how the undervalued benefits of the cool surfaces adversely affect their adoption at the policy level.

Underlying climate and solar availability: Underlying climate and local solar availability are other barriers to widespread implementation. As noted earlier, there is a perception that cool roofs may have a net negative impact on building energy use in colder climates. Furthermore, building roof surfaces are often shaded by nearby trees and by adjacent taller buildings. These factors reduce the benefits of cool surface application and can be a barrier to the implementation of codes/mandates and overall deployment efforts [36].

Cool surface technologies can be applied across a range of climates and geographic regions. However, local climate should be taken into consideration in projecting performance. Local climate and geographic location can also factor into the availability and cost of raw materials for cool surface technologies [37].

3.2.2. Challenges associated with policies and mandates

Policies and education: Local and regional policies can be crucial tools for enforcing adoption and implementation of codes and standards related to cool surface deployment. Policies in conjunction with stakeholder engagement, education and awareness are crucial to ensuring consistent and widespread implementation. This barrier is particularly acute in the construction phase of projects as contractors are unlikely to install products with which they are not familiar [31].

While there are currently multiple programs to implement cool surfaces, there are few frameworks and limited understanding of best practices for implementing cool roofs [38]. Furthermore, there are also limited available local data for existing roof materials which might lead to developing best practices. For example, while the adoption of cool roofs has seen good progress in the commercial building sector, adoption in the residential sector has been slower. One reason may be that residential re-roofing and repair projects typically do not require building permits, and thus lack an enforcement mechanism for requiring cool roofing [31].

In Australia, as pointed out by Razzhigaeva [39], the lack of policy support and legal requirements is hampering the efforts and growth of the Australian cool roof industry. Razzhigaeva further suggests that financial support of the cool surfaces industry in Australia could generate 150,000 new jobs. Rallapalli and Gupta [40] argue that the availability of mandatory codes, policies, incentives, tax credits, and similar measures are necessary to increase the adoption of the technologies.

Funding: Lack of funding is another challenge for cool surface deployment [31,37]. For example, in Hyderabad (India) funding for cool surfaces is believed to be the primary barrier to expanding their widespread deployment [41]. This is likely due to the combined challenges of incremental costs of cool surfaces and lack of funds forcing building owners to delay roof replacement projects in general, relying instead on periodic repairs of existing roofs.

Existing incentives and related policies tend to focus on the benefits for end users. Kolokotsa and Synnefa [42] suggest that if these incentives are focused instead on cool materials market players such as architects, contractors, or construction companies they might play a stronger role in decision processes related to the use of cool materials.

3.2.3. Challenges associated with products

Preparation: Depending upon the type of cool roof being installed/deployed, there may be additional surface preparation required [43]. For example, the installation of elastomeric acrylic coatings requires that the installer first thoroughly clear any dirt, debris, gravel, sticks, or any other obstructions. Failure to clean the surface will result in the coating not adequately adhering to the roof surface [44].

Durability, maintenance, and life cycle: The solar reflectance of cool roofs is known to decrease over time due to exposure, including deposition of soot and dust, biological growth, and rain. Many studies have already discussed the issue including [27,36,37,45]. For example, Sleiman et al. [46] reviewed data from a large number of roofing products (n=586) for which surface reflectance was measured after initial installation and after 3 years of weathering. The data included samples installed in Florida, Arizona, and Ohio showing a reduction in aged reflectance in all tested cities. The study concludes in Florida (hot and humid climate) the performance losses are greater than in Arizona (hot and dry). Furthermore, Akbari et al. [45] found that light-colored roofing surfaces lose about 20% of their initial solar reflectance for several years of weathering.

However, to overcome this barrier, several studies suggest that a regular cleaning of the surface can maintain the solar reflectance over time. For example, Levinson et al. [47] and Aoyama et al. [48,49] explore a variety of methods for self-cleaning and manual cleaning of coatings, including wiping, washing, rinsing, and bleaching. Levinson et al. [47] tested 15 single-ply samples from 10 cities in the United States with 4 cleaning techniques wiping, rinsing, washing, and bleaching. Their results show the ratio of solar reflectance for each cleaning technique to unsoiled solar reflectance (R_n/R_0) ranged from 0.41 to 0.89 for the soiled samples; 0.53 to 0.95 for the wiped samples; 0.74 to 0.98 for the rinsed samples; 0.79 to 1.00 for the washed samples; and 0.94 to 1.02 for the bleached samples. The study concludes that rinsing and/or washing removed nearly all the effects of soiling. Another approach to overcome this barrier is to use specialized roof coatings that are self-cleaning [48,49]. However, such specialized coatings likely have higher first costs and require more frequent re-coating (perhaps every 5-10 years instead of every 10-15 years). Furthermore, this issue is more noticeable on a flat roof than on a sloped roof [50].

While cool coatings may require more maintenance to maintain their reflectance properties, they may have additional benefits with respect to the potential to extend the life of the surface and minimize maintenance costs [27]. This is mainly because more reflective surfaces result in lower peak surface temperature during the day and a smaller diurnal surface temperature swing. As a result, the material undergoes less severe temperature-induced expansion and contraction, potentially leading to improved material lifespan.

Condensation: Another issue associated with cool roofs is condensation as a result of moisture under the roof exterior surface [31]. A numerical study by Bludau et al. [51] in Holzkirchen, Germany and three U.S. cities—Phoenix, Chicago, and Anchorage—simulated buildings with white and black roof surfaces. The study showed seasonal variation of moisture content in the Oriented Strand Board (OSB) layer under the roof surface. For black roof surfaces, regardless of climate, the moisture content remained below 20% by mass throughout the year. The seasonal cycle of moisture content for black surfaces also remained relatively consistent over a five-year analysis period. However, for the white roof surfaces in cold climates, there was a clear positive trend over the same five year period, with moisture content in Holzkirchen and Anchorage both exceeding 20% by mass after the first annual cycle, reaching 30% for Holzkirchen and 40% for Anchorage after five years. This is an important finding, as moisture above 20% is considered to potentially lead to material degradation.

A similar study was conducted by Saber et al. [52] for modified-bitumen roofing systems in seven North American locations: Toronto (ON), Montreal (QC), St. John's (NL), Saskatoon (SK), Seattle (WA), Wilmington (NC), and Phoenix (AZ). The results show in St. John's and Saskatoon the use of reflective roofs creates the potential for developing long-term moisture problems.

Another study by Ennis and Kehrer [53] focused on ASHRAE climate zone 5 and found that the amount of condensation under white roofs is twice that for black roofs. The study also pointed out that both roofs (white and black) returned to a dry condition during the year.

Ahrab and Akbari [54] suggest that using ventilated air spaces along with vapor barriers can reduce the risk of adverse effects of condensation in colder climates.

Aesthetics and light pollution: Using cool surfaces alters the color of the outer surface of the building envelope. Surveys suggest that building occupants/owners tend to prefer darker colors [37]. This may be due in part to a preference for uniformity within neighborhoods that already have a preponderance of darker roofs. But it may also be because soiling and microbial growth are more evident on lighter-colored roofs. This is particularly an issue in more humid climates [46].

Testa and Krarti [33] noted that high-reflectance roofs in sloped roof applications also increase light pollution (artificial light at night that can be disruptive to natural circadian rhythms for people and animals) during the nighttime as these surfaces reflect visible light from artificial illumination. This concern may be partially offset by the fact that many of the more reflective coatings used in residential applications tend to exhibit diffuse reflection in which light rays scattered at many angles, as opposed to a more mirror-like (specular) reflection [31].

Timescales and life cycle considerations: While jurisdictions are increasingly implementing codes and requirements for cool roofing (e.g., Atlanta and Washington, D.C [55]), the typical roof life is anywhere from 15 to 25 years. So, the roofs of existing building stock are being replaced at a rate of about 5% per year. As a result, a code implemented today takes about 10 years to affect half of the existing building stock, and another 10 years to fully affect existing buildings [37]. This can also be viewed as an opportunity—a code change can result in ongoing deployment of cool roofs over nearly all buildings within about two decades.

3.3. Overview of cool surface programs and policies

Many cities around the world and in the United States have initiated programs and heat action plans to increase the deployment of cool surfaces. This section provides an overview of some of these programs, their objectives, and their expected results.

3.3.1. United States

In the United States, there are currently multiple programs and entities that help to increase the deployment of cool surfaces. For example, the Global Cool Cities Alliance (GCCA) [56] is a non-profit organization that works with cities, regions, and national governments to speed the worldwide installation of cool roofs, pavements, and other surfaces. The alliance was launched in 2011, with a mission to advance the policies, and action plans to increase cool surface deployment to mitigate the effects of climate change. Cities and states have also developed programs to reduce the urban heat island effect and impact.

Boston is currently facing heat challenges as the average daily and nightly maximum temperature increased by 1.1 °C (2.0 °F), and 1.5 °C (2.7 °F) respectively from 1960 to 2020. It is anticipated that Boston will see an increase in the historical average of 10 days per year over 32.2 °C (90 °F) to 46 days per year by 2070 if current emission trends continue [7]. Just this year, Boston's mayor announced the Heat Resilience Strategies action plan to tackle the city's heat challenges. The strategies include the implementation of cool surfaces among other technologies. The plan consists of three phases: (1) Analysis & Information Review, (2) Heat Resilience Strategies, and (3) Implementation Roadmap & Report [7].

Phoenix is also facing heat challenges as the number of days each year the temperature exceeds 43.3 °C (110 °F) is expected to increase from 53 now to 70 by 2060. Phoenix has initiated multiple strategies to reduce the impact of climate change, including the use of highly reflective materials in infrastructure projects [57].

In 2019 the city of Los Angles issued a comprehensive plan "LA's Green New Deal" to tackle extreme urban heat and climate-related risks. This plan mandates the use of cool surfaces in all new construction. San Francisco is also developing its pilot program for using cool surfaces for roofs and pavements. Furthermore, as part of its 2015 Cool Neighborhood Plan, the city of New York provides no-cost and subsidized cool roof coatings to residents; this has helped coat millions of square feet of rooftop throughout the city [58].

A more recent implementation guide by the U.S. Department of Housing and Urban Development (HUD) was released in 2022. The guide is intended to provide step-by-step instructions to assist communities in implementing cool roof projects or programs [59]. The guide consists of six steps to (1) determine whether cool roofs are part of an existing local program; (2) identify and engage partners, collaborators, and community; (3) establish goals for the cool roof program; (4) design the cool roof program; (5) implement the cool roof program; and (6) measure success of the program as identified in step 3 and promote the outcome to funders and to the public.

Currently, in the United States, there are 25 heat island action plans distributed across 11 states that promote the deployment of cool surfaces to mitigate the urban heat island effect [60]. The heat action plan is to be able to mitigate the health, economic, cultural, ecological, and social impacts of increasing average temperatures and heat waves.

3.3.2. International

In 2015, South Korea started a new program to coat rooftops for free. Seoul allocated USD 13.6 million to support the program ("Cooling the Planet Could Start on Your Roof," 2020) [61].

India is also facing extreme heat challenges as the temperature in Ahmedabad reaches as high as 42 °C (108 °F) [62,63]. Ahmedabad initiated a heat action plan in 2017 aiming to install 500 cool roofs on slum households, and public buildings such as municipal buildings, and government schools [64]. The first heat action plan in Ahmedabad was initiated in 2013 to mitigate the effect of the urban heat island. In 2018 the program has been evaluated before and after the implementation of the heat action plan. The results show there was a decrease in all-cause mortality in the first two years (2014-2015) [65].

Similarly 2011 the city of Delhi started developing the "Cool Roofs for Cool Delhi" design manual to discuss the various technical and design considerations for the installation of cool surfaces [66]. In 2011, the cities of Indore and Surat in India were supported by the Rockefeller Foundation and a local research foundation, TARU Leading Edge, to conduct cost-benefit analyses of installing cool roofs for vulnerable populations [67].

Since 2000, the City of Tokyo has been taking measures to reduce the impact of urban heat islands. As a result, the Tokyo metropolitan government initiated the Nature Conservation Ordinance in 2001, requiring installation of green roofs on new buildings [68]. In 2006 Tokyo initiated a program to subsidize the installation of cool roofs with a total of 9.83 million yen (about U.S.$85.500) over three years [69].

The Million Cool Roofs Challenge is a project of the Clean Cooling Collaborative in partnership with the Global Cool Cities Alliance, Sustainable Energy for All (SEforALL), and Nesta's Challenge Prize Centre and with support from the World Resources Institute. It is a global challenge to increase and accelerate the affordable deployment of cool roofs material in developing countries. The challenge offered $100,000 to each of 10 teams to deploy cool reflective coating and/or materials. A team from Tangerang Indonesia won for its project "Driving Climate Action to Combat UHI". The team was awarded $750,000 for showing the best sustainable and transferable model and an example of the rapid deployment of cool roofs [38].

To date, through the Million Cool Roofs Challenge, there have been large scale deployment efforts of cool roof pilots in 10 cities around the world. These cities are located in South Africa, Niger, Cote D'Ivoire, Senegal, Mexico, Bangladesh, Rwanda, Indonesia, Philippines, and Kenya [70].

3.4. Overview of rebate and incentive programs

As early as 2001 the state of California and several California utilities began the development of cash rebate programs for installing cool roofs on non-residential buildings. However, most of these programs ended after cool roof installation became required in the building code in California's Title 24, Part 6 building energy efficiency standards [71].

Currently, several cities in the United States provide incentives to encourage homeowners, and commercial building developers to install cool roof products. These incentives range from $0.15/ft^2 to $1.00/ft^2 of conditioned space.

Table 1 shows some of these cities, incentives, and requirements. A complete list of incentives and rebates can be found at the Cool Roof Rating Council website [72].

Table 1. Examples of incentive and rebate programs in the United States, and their requirements.

City	Incentive/Rebate	Requirement	Application status	Reference
Austin, TX	\$0.15/ft² product	Solar reflectance >0.75	Open	[73]
Jacksonville, FL	- \$0.10/ft² product - \$0.15/ft² product (for Small Business Enhanced Rebate)	Energy Star Reflective Roof Products Requirements	Open	[74]
Los Angeles, CA	\$0.20 to \$0.30/ft² product	Solar reflectance >0.75 for \$0.20 Solar reflectance >0.85 for \$0.30	Open	[75]
Louisville, KY	\$1.00/ft² (up to \$2,000)	Solar reflectance >0.65	Open	[76]
Orlando Utilities Commission (FL)	\$0.12/ft² product	Solar reflectance >0.70	Open	[77]
Smyrna Beach, FL	\$0.14/ft² Conditioned Space up to \$375	Solar reflectance >0.70	Open	[78]
Texas-New Mexico Power	\$0.04/kWh energy saved	Energy Star Qualified Cool Roof Products	Open	[79]

There are incentive and rebate programs beyond those in the US cities listed in Table 4. For example, Toronto, Canada offers cool roof incentive and rebate programs for a range of building types, including existing residential, industrial, commercial, and institutional buildings, as well as new low-rise residential buildings with fewer than five units. The incentive is Can\$5/m² for a cool roof with a new membrane, or Can\$2/m² for a cool roof coating over an existing roof, with a limit of Can\$50,000 per project [80].

3.5. Overview of state and local codes, ordinances, and legislation

The adoption of cool surfaces started as a credit option for several major energy codes before becoming a requirement [31]. In 2001 California credited cool roofs in its building energy efficiency standard (Title 24, Part 6). In 2005 Title 24 prescribed minimum values of solar reflectance and thermal emittance for low-sloped roofs on non-residential buildings. In 2008 minimum values of solar reflectance and thermal emittance for low-sloped and steep-sloped roofs on residential buildings were prescribed [81]. Figure 2 shows how codes and standards have evolved in the last two decades [31].

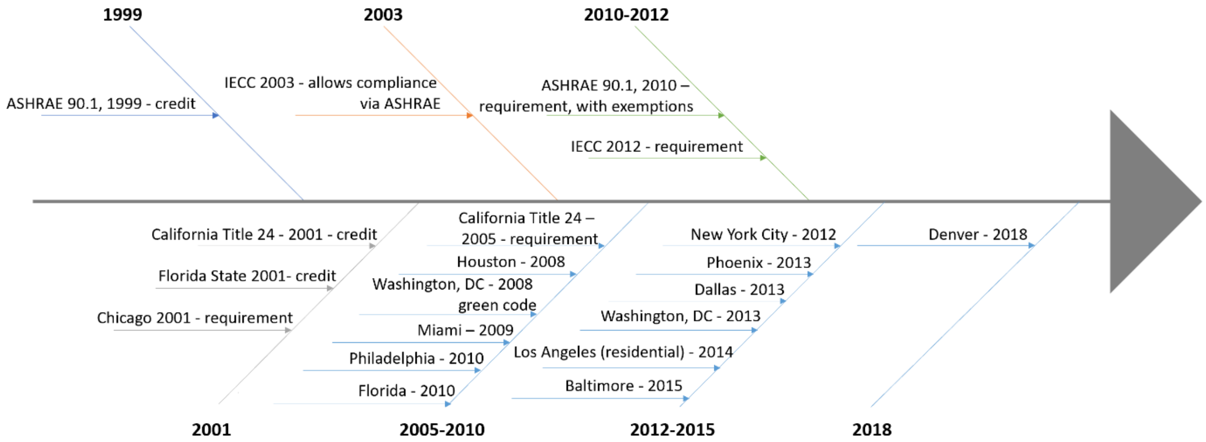

Figure 2*. Key moments in U.S. cool roof codes, standards, and policies. Modified from source [31].*

Currently, multiple cities in the United States enforce in their codes and standards the installation of cool roof products. Table 2 details some of these cities and their requirements. A complete list of building codes, standards, and green building programs can be found at the Cool Roof Rating Council website [82].

As of January 2022, 11 states have adopted cool roof codes and ordinances in the United States. Furthermore, as of February 2022, there are 6 cool roof model codes & standards in the United States [82].

Table 2. Cool surface requirements in several codes and standards.

Locations	Minimum requirement	Reference
Alabama	3-year aged solar reflectance of 0.55 and 3-year aged thermal emittance of 0.75	[83]
Atlanta, GA	All building and structural roofs shall be constructed of a heat-reflective material to achieve a minimum initial solar reflectance index (SRI) of 78 for a low-sloped roof (less than or equal to 2:12) and a minimum initial SRI of 29 for a steep-sloped roof (more than 2:12) except for those portions of roofing designated for vegetation.	[84]
California Title 24, Part 6	Aged solar reflectance ≥ 0.63 and thermal emittance ≥ 0.75, or SRI ≥ 75.	[85]
Chula Vista, FL	For steep slope roofs, install a roofing product rated by the Cool Roof Rating Council (CRRC) with an aged solar reflectance of 0.25 or higher and thermal emittance of 0.75 or higher.	[86]

3.6. Overview of national codes, programs, and legislation

The first national model adopting the installation of cool roofs in the energy code was ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Standard 90.1-1999 for non-residential and high-rise residential buildings. In 2004 ASHRAE included cool roofs in low-rise residential buildings in ASHRAE 90.2-2004 [81]. While the 2003 International Energy Conservation Code (IECC) does not address the use of cool roofs, section 801.2 allows commercial buildings to comply by meeting the ASHRAE 90.1 requirements. The IECC was updated in 2006 to include cool roof credits for residential buildings. Ongoing updates to these codes and standards, as well as their uptake by jurisdictions, continues to evolve. For example, from 2008 to 2010, Houston, Dallas, Washington (DC), Florida, Philadelphia, and Miami started to implement cool roof requirements in their codes [31,87]. Similarly, from 2010 to 2013, New York City, Phoenix, Los Angeles, and Washington (DC) require cool roofs installed in the code [31,87].

In addition to ASHRAE, programs such as Leadership in Energy and Environmental Design (LEED) and Green Globes, have included requirements or have allocated points for applying cool roofs [31,88]. For example, LEED requires 3-year aged solar reflectance of 0.64 on a low-slope roof or 0.32 on a steep roof.

Additionally, there are several local-level initiatives, often focused on K-12 education buildings. For example, the Washington D.C. Sustainable Schools Protocols [89] and Northeast Collaborative For High-Performance Schools Criteria [90] provide guidelines to design high-performance schools, including cool-roof implementation.

Multiple congressional bills advocate the use of cool surfaces on buildings to mitigate urban heat island effects. This includes an effort led by U.S. Senator Ben Cardin (D-Md.) called the "Energy-Efficient Cool Roofs Act," (S. 2388) introduced in 2014, this bill would have boosted job creation in the construction industry while improving building energy efficiency and reducing energy consumption [91]. Another bill, "The Excess Urban Heat Mitigation Act of 2022" (H.R. 7534), introduced by Representatives Gallego and Coleman in 2022 would create a competitive grant program through the U.S. Department of Housing and Urban Development (HUD) to provide funding for eligible entities to combat the causes and mitigate the effects of excess urban heat. This act was referred to the House Committee on Financial Services in April 2022. The act would authorize $30M each year from FY23 to FY30 [92].

3.7. Overview of demonstration projects

3.7.1. NYC CoolRoofs

The NYC CoolRoofs project has the goal of increasing the deployment of cool surfaces throughout New York City. The program provides New Yorkers with paid training to install and increase the deployment of reflective rooftops. This initiative is implemented by the NYC Department of Small Business Services through its "Workforce1" Industrial & Transportation Career Center [93].

Phase 1 of the program ran from 2009 to 2014. During phase 1, the program depended on the engagement of volunteers to coat rooftops with a reflective white coating. Through the help of more than 5,000 volunteers, they were able to coat 5.9 million ft^2 (0.55 million m^2) of rooftops with reflective materials [94]. Phase 2 of the program has been running since 2015. It supports local jobseekers through a paid and transitional work-based learning experience to install cool roofs [94]. Through 2016 the program was able to coat nearly 7 million ft^2 (0.65 million m^2) with reflective material [94]. The program aims to complete 10 million ft^2 (0.93 million m^2) by 2025 [95].

This NYC CoolRoofs program is a successful example that integrates volunteer service and non-profit groups to benefit low-income residents and public building owners, while passing on no costs or overhead during the installation process [95].

3.7.2. Philadelphia coolest block contest

The city of Philadelphia, in partnership with the Energy Coordinating Agency and the Dow Building & Construction business group, initiated a "Coolest Block" contest in 2010 [96]. The competition sought to retrofit 15% of housing stock in the city with insulation, air sealing, and cool roofs [97]. The competition culminated in May 2011 with the announcement of the 1200 Wolf Street block as the winner [98]. All 39 homes on the winning block received whole building (basement to rooftop) energy audits to identify opportunities for retrofit, and installation of Dow's sealants to improve the building efficiency.

3.7.3. Chelsea Massachusetts urban heat island program

Another urban heat mitigation demonstration program in the city of Chelsea, MA (near Boston) was initiated by GreenRoofs, a community-based organization in 2022. Currently, the program focuses on one small block. Its goal is to implement various urban heat mitigation strategies including cool roofs. The initial funding for the project is $350,000 from state grants [99].

3.7.4. Sustainable cooling for low-income housing in Mexico

As part of the Million Cool Roofs Challenge, the ARUP architecture firm is leading an effort to widely deploy cool roofs across Mexico. The project is a collaboration with two housing non-profits, Échale [100] and New Story [101]. The project is expected to complete 4,500 houses by the end of 2022 [102].

Throughout the program, ARUP was able to develop a growing network in which to share knowledge and experience that might lead to influence long-term policy decisions.

3.7.5. Indonesian team rises to cool roof challenge

The winning project of the Million Cool Roofs Challenge took place in Indonesia [103]. The project was a partnership of Universitas Pendidikan Indonesia (UPI), Tangerang Municipality, the University of Florida, and Millennium Solutions USA. The project was selected as the best sustainable and transferable model for the rapid deployment of cool roofs.

The winner was able to install cool roofs on 70 buildings in 15 cities, with a potential to benefit more than 10,000 people. The team were also able to pilot the cool roof solution on an affordable structure in a rural area. The team have also verified through measurement the reduction in indoor air temperature of over 5.5 °F (10 °C) in some of the pilot studies [104].

3.8. Lessons learned from other technology deployment efforts

Separate from past and current projects focused on deploying cool roofs, we can learn from various efforts with similar goals but for different technologies. The following examples highlight some successful technology deployment efforts that might offer lessons learned to the current cool surface deployment efforts.

3.8.1. New York City Housing Authority (NYCHA)

In 1996 the New York Power Authority persuaded housing officials to replace 180,000 inefficient refrigerators in New York City's public housing units over a period of nine years. The authority asked manufacturers to build more efficient refrigerators that would be distributed for free by the New York City Housing Authority (NYCHA) [105]. The existing refrigerators consumed 900 to 1,200 kilowatt-hours per year each. The Power Authority wanted to reduce that to 355 kilowatt-hours / year by 1999. The significant bulk purchasing power of public housing authorities combined with prospects of regulatory and other stimuli was expected to be enough to incentivize manufacturers to make the initial investment in the required redesign and participate in the competition.

One challenge to developing market pressure for more efficient apartment-size refrigerators was that landlords are not incentivized to replace existing refrigerators with new ones as their tenants pay the utility bills [106]. NYCHA therefore decided to announce a program to design an efficient refrigerator and promise to buy 20,000 refrigerators from the winner. The award went to General Electric [107]. The refrigerators were developed using existing technology to design 22-cubic-foot "super-efficient" refrigerators. At the time (1996), it was estimated that if all the Housing Authority refrigerators were replaced, the authority would save $5 million from its annual electric bill.

For the first few years, the energy cost savings were used to pay back the Power Authority for the new refrigerators; after that, savings went to the Housing Authority. The Authority set aside $40 million for the program and asked manufacturers to submit plans to build the refrigerators.

An evaluation report concluded that during the first year 20,000 14.4 cubic-foot refrigerators with an energy performance of 499 kWh per year were installed, with an energy savings of 47.9% [107]. The design was improved in the next program cycle in 1997 by Maytag for 15.0-cubic-foot with a label rating of 437 kWh per year.

In March 2022, NYCHA concluded a Home Energy Assistance program, to install air conditioners for low-income seniors. This program had the goal to help 440,000 families in New York City, including 1,900 in NYCHA buildings for low-income seniors [108].

A new program is now asking manufacturers to develop low-cost, easy-to-install heat-pump technologies for building retrofits. Learning from what was done to replace the inefficient refrigerators in 1996, this $30 million pilot program will support whole building energy retrofits [109].

3.8.2. Incandescent light bulbs

The incandescent light bulb (ILB), invented in 1802, generates heat and light by sending an electrical current through a thin strip of platinum [110]. In fact, more than 90% of the energy consumed by ILBs results in heat, while less than 10% is light [111]. Early in the 21st century, countries around the world started to ban the use of these highly inefficient ILBs, replacing them with more efficient compact fluorescent light bulbs (CFLBs). These early ILB bans were put in place in Europe [112], Canada [110], and Germany [113].

In the United States in 2007 a new national light bulb efficiency standard was signed into law. This standard required the new light bulb to be 25% more efficient than the current incandescent lights effective in 2012. The second phase of this standard, scheduled to be effective in 2020, only allowed the sale of light bulbs with light output greater than 45 lumens per watt [114].

Recently the U.S. Department of Energy announced a plan to implement this new requirement and phase out all incandescent light bulbs from production and sale in the United States by 2023 [115]. The requirement of a minimum of 45 lumens per watt is 300% better than the average incandescent bulb. The expected savings from this plan is about $3 billion per year, about $100 per year per family [116].

A few factors helped create the full ILB ban in European markets, including the European Commission’s climate target, and demand from consumers who wanted to save on energy costs. Furthermore, the transition to the new technology was amenable to consumers as it didn’t require extra cost over the life cycle of the bulb or behavioral change [117].

3.8.3. Shade tree and green roof programs

The use of street/shade trees and rooftop vegetation are strategies that have been adopted in various cities in the United States and globally to mitigate the urban heat island effect [118]. Multiple cities adopted planting trees and green roofs as strategies. For example, the Sacramento Municipal Utility District and the city of Los Angeles both offer a free shade tree program to residents [119–121].

Atlanta and Chicago have adopted and invested in green roof programs and requirements [122,123]. From 2008 to 2012 the city of Portland Oregon ran a green roof grant program in which building owners could qualify for a \$5 per ft^2 grant to install green roofs [124]. The city saw increased green roof coverage to have many potential benefits including reduced stormwater runoff, lower summertime air temperatures, and improved urban biodiversity. Although the program's primary goal was to reduce runoff into the city's combined stormwater/sewage system during heavy rain events, the program did not include any rainfall retention performance requirements for the installed green roofs. As a result, a wide range of roof designs were installed, with varying impact on the timing and magnitude of runoff. Nevertheless, the city saw the program as a valuable mechanism to boost awareness and implementation of green roofs, while providing a jump start to a forming industry. The hope was that by stimulating the market, green roof installers would be able to improve design and installation processes, reducing the cost premium associated with green roof installation.

4. Conclusion and Policy Implications

The goal of this report is to identify challenges and barriers associated with large scale deployment of cool surfaces, focusing primarily on buildings. We have investigated sources including academic peer-reviewed literature, conference papers, articles, websites, legislation, codes & standards, and industry reports related to cool surfaces. This report explores lessons learned to increase the deployment of the cool surfaces, as well as to understand from other technology deployment effort in the past.

These challenges include installing cool surfaces on buildings can lead to an increase in heating demand in winter in cold climates as well as increase the risk for condensation and mold growth. Shading from nearby structure and vegetation might limit the benefit of cool surfaces in some application. Using high reflectivity material on vertical or steep-sloped surfaces can introduce glare. Finally, the cool potentially requiring routine cleaning due to adversely affected by weathering.

Furthermore, public perception of aesthetic appeal of cool surfaces can be a barrier to individual adoption—this can include desire for uniformity in an otherwise dark-roofed neighborhood, or can be associated

With the visibility of soiling and microbial growth on lighter-colored surfaces. There is a lack of knowledge and awareness of cool surfaces and their life cycle benefits across all classes of decision-makers (general public, contractors, local officials). This lack of knowledge, combined with decision-making inertia, tends to favor conventional technologies and approaches. Financial pressures to extend the life of old or failing infrastructure can impede the deployment of cool surfaces, particularly in lower-income neighborhoods and countries where the need for cool surfaces may be the greatest, but current practice favors frequent patching of existing infrastructure rather than replacement or resurfacing.

However, cool surface policies and programs are increasingly being pursued and adopted by city and regional governments through their climate action plans and related planning efforts. There is potential for such efforts to spread organically as governments share best-practices, and to integrate information about successful efforts into educational activities to accelerate the transfer of knowledge. Technology research and development is currently addressing challenges ranging from soiling (amphiphobic/self-cleaning materials and coatings) to glare (retroreflective surfaces) and condensation (use of ventilated air spaces and vapor barriers). Over time, new products resulting from these efforts will diminish concerns related to current challenges facing cool surface products. Investment in R&D is a long-term strategy for accelerating widespread adoption of cool surfaces. There are well-established models for implementing cool surfaces in codes and standards (e.g., California Title 24). These can form the foundation to accelerate nationwide cool surface deployment through continued integration in codes and standards and their subsequent adoption. In the short-term, public incentive and rebate programs can help to expand growing markets until education, technology, and codes/standards are in place to adequately address the range of challenges and barriers facing efforts to expand use of cool surfaces.

The other technologies introduced above offer valuable lessons for developing a roadmap for future efforts to greatly expand deployment of cool surfaces. These can be summarized as follows:

- Energy savings can be used to repay costs of incentive programs.
- Vulnerable groups are increasingly in need of energy efficiency and thermally resilient homes due to an increase in work-from-home sparked by pandemic-related lockdowns.
- Local/state governments can encourage innovation/deployment by leveraging market size and bulk purchasing power.
- The benefits of new technologies must be measurable and must be communicated.
- Co-benefits of technologies should be quantified and communicated to increase attractiveness of large-scale deployment.

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References

[1] F. Barringer, White Roofs Catch on as Energy Cost Cutters, The New York Times. (2009). https://www.nytimes.com/2009/07/30/science/earth/30degrees.html (accessed August 7, 2022).

[2] A. Baniassadi, D.J. Sailor, G.A. Ban-Weiss, Potential energy and climate benefits of super-cool materials as a rooftop strategy, Urban Climate. 29 (2019) 100495. https://doi.org/10.1016/j.uclim.2019.100495.

[3] P. Singh, N. Kikon, P. Verma, Impact of land use change and urbanization on urban heat island in Lucknow city, Central India. A remote sensing based estimate, Sustainable Cities and Society. 32 (2017) 100–114. https://doi.org/10.1016/j.scs.2017.02.018.

[4] N. Kikon, P. Singh, S.K. Singh, A. Vyas, Assessment of urban heat islands (UHI) of Noida City, India using multi-temporal satellite data, Sustainable Cities and Society. 22 (2016) 19–28. https://doi.org/10.1016/j.scs.2016.01.005.

[5] D. Zhou, L. Zhang, L. Hao, G. Sun, Y. Liu, C. Zhu, Spatiotemporal trends of urban heat island effect along the urban development intensity gradient in China, Science of The Total Environment. 544 (2016) 617–626. https://doi.org/10.1016/j.scitotenv.2015.11.168.

[6] M. Alhazmi, D.J. Sailor, J. Anand, A new perspective for understanding actual anthropogenic heat emissions from buildings, Energy and Buildings. 258 (2022) 111860. https://doi.org/10.1016/j.enbuild.2022.111860.

[7] Preparing for heat, Boston.Gov. (2021). https://www.boston.gov/departments/environment/preparing-heat (accessed August 5, 2022).

[8] T. Hong, M. Ferrando, X. Luo, F. Causone, Modeling and analysis of heat emissions from buildings to ambient air, Applied Energy. 277 (2020) 115566. https://doi.org/10.1016/j.apenergy.2020.115566.

[9] R. Levinson, H. Akbari, S. Konopacki, S. Bretz, Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements, Energy Policy. 33 (2005) 151–170. https://doi.org/10.1016/S0301-4215(03)00206-4.

[10] P.J. Rosado, R. Levinson, Potential benefits of cool walls on residential and commercial buildings across California and the United States: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants, Energy and Buildings. 199 (2019) 588–607. https://doi.org/10.1016/j.enbuild.2019.02.028.

[11] R. Levinson, H. Akbari, Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants, Energy Efficiency. 3 (2010) 53–109. https://doi.org/10.1007/s12053-008-9038-2.

[12] A. Synnefa, M. Santamouris, H. Akbari, Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions, Energy and Buildings. 39 (2007) 1167–1174. https://doi.org/10.1016/j.enbuild.2007.01.004.

[13] V. Garg, R. Kotharkar, J. Sathaye, H. Rallapalli, N. Kulkarni, N. Reddy, P. Rao, Assessment of the Impact of Cool Roofs in Rural Buildings in India, in: 3rd International Conference on Countermeasures to Urban Heat Islands, 2014: pp. 1668–1680.

[14] M. Dabaieh, O. Wanas, M.A. Hegazy, E. Johansson, Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings, Energy and Buildings. 89 (2015) 142–152. https://doi.org/10.1016/j.enbuild.2014.12.034.

[15] Y. Gao, J. Xu, S. Yang, X. Tang, Q. Zhou, J. Ge, T. Xu, R. Levinson, Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments, Energy Policy. 74 (2014) 190–214. https://doi.org/10.1016/j.enpol.2014.05.036.

[16] H. Rallapalli, N. Reddy, P. Rao, V. Garg, J. Sathaye, R. Levinson, Cool Roof Monitoring Experiment in a Real Building in Nagpur, India, in: 4th International Conference on Countermeasures to Urban Heat Islands, 2016.

[17] H. Akbari, R. Levinson, A. Rosenfeld, M. Elliot, Global Cooling: Policies to Cool the World and Offset Global Warming from CO2 Using Reflective Roofs and Pavements, Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States), 2009. https://www.osti.gov/biblio/984960/ (accessed June 28, 2022).

[18] M. Santamouris, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, Solar Energy. 103 (2014) 682–703. https://doi.org/10.1016/j.solener.2012.07.003.

[19] J. Yang, E. Bou-Zeid, Scale dependence of the benefits and efficiency of green and cool roofs, Landscape and Urban Planning. 185 (2019) 127–140. https://doi.org/10.1016/j.landurbplan.2019.02.004.

[20] D.– D. Kolokotsa, G. Giannariakis, K. Gobakis, G. Giannarakis, A. Synnefa, M. Santamouris, Cool roofs and cool pavements application in Acharnes, Greece, Sustainable Cities and Society. 37 (2018) 466–474. https://doi.org/10.1016/j.scs.2017.11.035.

[21] M. Georgescu, Challenges Associated with Adaptation to Future Urban Expansion, Journal of Climate. 28 (2015) 2544–2563. https://doi.org/10.1175/JCLI-D-14-00290.1.

[22] D. Millstein, S. Menon, Regional climate consequences of large-scale cool roof and photovoltaic array deployment, Environ. Res. Lett. 6 (2011) 034001. https://doi.org/10.1088/1748-9326/6/3/034001.

[23] E. Morini, A.G. Touchaei, B. Castellani, F. Rossi, F. Cotana, The Impact of Albedo Increase to Mitigate the Urban Heat Island in Terni (Italy) Using the WRF Model, Sustainability. 8 (2016) 999. https://doi.org/10.3390/su8100999.

[24] F. Salamanca, M. Georgescu, A. Mahalov, M. Moustaoui, A. Martilli, Citywide Impacts of Cool Roof and Rooftop Solar Photovoltaic Deployment on Near-Surface Air Temperature and Cooling Energy Demand, Boundary-Layer Meteorol. 161 (2016) 203–221. https://doi.org/10.1007/s10546-016-0160-y.

[25] T. Sinsel, H. Simon, A.M. Broadbent, M. Bruse, J. Heusinger, Modeling impacts of super cool roofs on air temperature at pedestrian level in mesoscale and microscale climate models, Urban Climate. 40 (2021) 101001. https://doi.org/10.1016/j.uclim.2021.101001.

[26] D. Lai, W. Liu, T. Gan, K. Liu, Q. Chen, A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces, Science of The Total Environment. 661 (2019) 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062.

[27] B. Ashtari, M. Yeganeh, M. Bemanian, B. Vojdani Fakhr, A Conceptual Review of the Potential of Cool Roofs as an Effective Passive Solar Technique: Elaboration of Benefits and Drawbacks, Frontiers in Energy Research. 9 (2021). https://www.frontiersin.org/articles/10.3389/fenrg.2021.738182 (accessed August 5, 2022).

[28] M. Hosseini, H. Akbari, Effect of cool roofs on commercial buildings energy use in cold climates, Energy and Buildings. 114 (2016) 143–155. https://doi.org/10.1016/j.enbuild.2015.05.050.

[29] M. Hosseini, H. Akbari, Heating energy penalties of cool roofs: the effect of snow accumulation on roofs, Advances in Building Energy Research. 8 (2014) 1–13. https://doi.org/10.1080/17512549.2014.890541.

[30] H. Akbari, M. Hosseini, Cool Roofs In Cold Climates: Savings Or Penalties?, in: 3rd International Conference on Countermeasures to Urban Heat Islands, 2014: pp. 986–997.

[31] M. Santamouris, A.M. Papadopoulos, R. Paolini, A. Khan, C. Koc, S. Haddad, S. Garshasbi, S. Arasteh, J. Feng, Cool Roofs Cost Benefit Analysis UNSW – Sydney Volume 1 - Cool Roofs : International Progress, Technology, Market, and Legislative Frame, University of New South Wales, 2022. https://www.unsw.edu.au/content/dam/pdfs/unsw-adobe-websites/arts-design-architecture/built-environment/our-research/high-performance-architecture-research-cluster/2022-04-Volume-1.pdf (accessed August 18, 2022).

[32] Y. Wu, H. Zhao, H. Sun, M. Duan, B. Lin, S. Wu, A review of the application of radiative sky cooling in buildings: Challenges and optimization, Energy Conversion and Management. 265 (2022) 115768. https://doi.org/10.1016/j.enconman.2022.115768.

[33] J. Testa, M. Krarti, A review of benefits and limitations of static and switchable cool roof systems, Renewable and Sustainable Energy Reviews. 77 (2017) 451–460. https://doi.org/10.1016/j.rser.2017.04.030.

[34] H. Akbari, M. Pomerantz, H. Taha, Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas, Solar Energy. 70 (2001) 295–310. https://doi.org/10.1016/S0038-092X(00)00089-X.

[35] A. Synnefa, M. Santamouris, Advances on technical, policy and market aspects of cool roof technology in Europe: The Cool Roofs project, Energy and Buildings. 55 (2012) 35–41. https://doi.org/10.1016/j.enbuild.2011.11.051.

[36] M. Kolokotroni, R. Levinson, A. Mahdavi, A. Salvati, H. Teufl, M. Zinzi, IEA Annex 80 (Resilient Cooling of Buildings) State of the Art Report, Chapter 4: Reduce heat loads to people and indoor environments (preprint), 2021. https://bit.ly/3AK0ItP.

[37] M. Lafrance, Review and Critical Analysis of International UHI Studies, 2009. https://www.yumpu.com/en/document/view/5061518/review-and-critical-analysis-of-international-uhi-studies (accessed July 10, 2022).

[38] Million Cool Roofs Challenge, (n.d.). https://www.coolroofschallenge.org/purpose (accessed August 5, 2022).

[39] N. Razzhigaeva, Are cool roofs the future for Australian cities?, UNSW Newsroom. (2022). https://newsroom.unsw.edu.au/news/art-architecture-design/are-cool-roofs-future-australian-cities (accessed August 5, 2022).

[40] H. Rallapalli, J. Gupta, Cool Roof initiatives in India: An evaluation of the existing conditions and lessons to be learnt from global best practices, in: 5th International Conference on Countermeasures to Urban Heat Islands, 2019: pp. 270–279.

[41] S. Sengupta, In India, Summer Heat May Soon Be Literally Unbearable, The New York Times. (2018). https://www.nytimes.com/2018/07/17/climate/india-heat-wave-summer.html (accessed August 6, 2022).

[42] J.G. Kolokotsa, A. Synnefa, eds., Policy Aspects of Cool Materials, in: Advances in the Development of Cool Materials for the Built Environment, BENTHAM SCIENCE PUBLISHERS, 2013: pp. 273–309. https://doi.org/10.2174/9781608054718113010013.

[43] C. Challener, Cool roof coatings market heating up, Jct Coatings Tech. 4 (2007) 50–55. https://www.paint.org/wp-content/uploads/2022/01/Cool-Roof-Coatings-Market-Heating-Up.pdf.

[44] How to Apply Elastomeric Roof Coating in 3 Easy Steps, Rugged Coatings. (2021). https://ruggedcoatings.com/how-to-apply-elastomeric-roof-coating/ (accessed July 31, 2022).

[45] H. Akbari, A. Berhe, R. Levinson, S. Graveline, K. Foley, A. Delgado, R. Paroli, Aging and Weathering of Cool Roofing Membranes, in: Cool Roofing - Cutting Through the Glare, Roof Consultants Institute Foundation, Atlanta, GA, 2005. https://escholarship.org/uc/item/3qb8j3k7.

[46] M. Sleiman, G. Ban-Weiss, H.E. Gilbert, D. François, P. Berdahl, T.W. Kirchstetter, H. Destaillats, R. Levinson, Soiling of building envelope surfaces and its effect on solar reflectance—Part I: Analysis of roofing product databases, Solar Energy Materials and Solar Cells. 95 (2011) 3385–3399. https://doi.org/10.1016/j.solmat.2011.08.002.

[47] R. Levinson, P. Berdahl, A.A. Berhe, H. Akbari, Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane, Atmospheric Environment. 39 (2005) 7807–7824. https://doi.org/10.1016/j.atmosenv.2005.08.037.

[48] T. Aoyama, T. Sonoda, Y. Nakanishi, J. Tanabe, H. Takebayashi, Study on aging of solar reflectance of the self-cleaning high reflectance coating, Energy and Buildings. 157 (2017) 92–100. https://doi.org/10.1016/j.enbuild.2017.02.021.

[49] T. Aoyama, T. Sonoda, T. Hamamura, Y. Nakanishi, L. Peeters, H. Takebayashi, Development of self-cleaning top-coat for cool roof, in: 3rd International Conference on Countermeasures to Urban Heat Islands, 2014: pp. 1157–1167.

[50] Cooling the Planet Could Start on Your Roof, Alliance for an Energy Efficient Economy. (2020). https://aeee.in/sharing_posts/cooling-the-planet-could-start-on-your-roof/ (accessed August 4, 2022).
[51] C. Bludau, D. Zirkelbach, H. M. Künzel, Condensation problems in cool roofs, in: 11th International Conference on Durability of Building Materials and Components (DBMC), 2008. https://iibec.org/wp-content/uploads/2016/04/2009-08-bludau-zirkelbach-kunzel.pdf.
[52] H.H. Saber, M.C. Swinton, P. Kalinger, R.M. Paroli, Long-term hygrothermal performance of white and black roofs in North American climates, Building and Environment. 50 (2012) 141–154. https://doi.org/10.1016/j.buildenv.2011.10.022.
[53] Mike Ennis, Manfred Kehrer, The Effects of Roof Membrane Color on Moisture Accumulation in Low-slope Commercial Roof Systems, in: National Roofing Contractors Association, Washington, D.C., 2011. https://nrcawebstorage.blob.core.windows.net/files/staticcontent/masterpages/technical/symposium/pdf/25_ennis_paper.pdf.
[54] M.A. Moghaddaszadeh Ahrab, H. Akbari, Hygrothermal behaviour of flat cool and standard roofs on residential and commercial buildings in North America, Building and Environment. 60 (2013) 1–11. https://doi.org/10.1016/j.buildenv.2012.11.003.
[55] S. Schneider, Cool Roof Policy Updates Trend in US Cities : PaintSquare News, (2020). https://www.paintsquare.com/news/view/?22271 (accessed July 31, 2022).
[56] Global Cool Cities Alliance, Energy.Gov. (n.d.). https://www.energy.gov/eere/buildings/global-cool-cities-alliance (accessed July 21, 2022).
[57] City of Phoenix, Climate Action Plan, 2021. https://www.phoenix.gov/oepsite/Documents/2021ClimateActionPlanEnglish.pdf.
[58] T. Lamm, L. Blumberg, E. Elkind, Insuring Extreme Heat Risks, 2020. https://www.law.berkeley.edu/research/clee/research/climate/california-climate-action/insuring-extreme-heat-risks/ (accessed July 31, 2022).
[59] U.S. Department of Housing and Urban Development, Climate Resilience Implementation Guide: Cool Roofs, U.S. Department of Housing and Urban Development, 2022. https://www.hudexchange.info/resource/6729/climate-resilience-implementation-guide-cool-roofs (accessed August 22, 2022).
[60] US Environmental Protection Agency, Heat Island Community Actions Database, (2014). https://www.epa.gov/heatislands/heat-island-community-actions-database (accessed August 7, 2022).
[61] Seoul lowers temperature with ‘Cool Roof Campaign,’ The Official Website of Seoul. (2015). https://english.seoul.go.kr/seoul-lowers-temperature-cool-roof-campaign/ (accessed August 6, 2022).
[62] A. Jaiswal, N. Kaur, 5 Reasons Why the Ahmedabad Heat Action Plan Saves Lives, NRDC. (2017). https://www.nrdc.org/experts/anjali-jaiswal/5-reasons-why-ahmedabad-heat-action-plan-saves-lives (accessed August 6, 2022).
[63] S. Sahoo, Study of Cool Roof on Low Income House Group, 2012. https://coolrooftoolkit.org/wp-content/uploads/2012/10/Cool-roof-CEPT.pdf.
[64] N. Kaur, Ahmedabad: Cool Roofs Initiative with 5th Heat Action Plan, NRDC. (2017). https://www.nrdc.org/experts/nehmat-kaur/ahmedabad-cool-roofs-initiative-5th-heat-action-plan (accessed August 6, 2022).
[65] Ahmedabad Heat Action Plan 2019, (2019). https://www.c40knowledgehub.org/s/article/Ahmedabad-Heat-Action-Plan-2019?language=en_US (accessed August 6, 2022).
[66] Cool Roofs for Cool Delhi, Shakti Sustainable Energy Foundation. (n.d.). https://shaktifoundation.in/report/cool-roofs-cool-delhi/ (accessed August 6, 2022).
[67] Cool roofs protecting local communities from extreme heat, 2017. https://iiphg.edu.in/images/pdfs/NRDC/cool-roofs-2018.pdf.

[68] Nature Conservation Ordinance is Greening Tokyo's Buildings, C40 Cities. (2015). https://www.c40.org/case-studies/nature-conservation-ordinance-is-greening-tokyo-s-buildings/ (accessed August 21, 2022).
[69] Tokyo Government Announces 2006 Cool-Roof Project, JFS Japan for Sustainability. (2006). https://www.japanfs.org/en/news/archives/news_id026405.html (accessed August 7, 2022).
[70] Million Cool Roofs Challenge, Finalists, Cool Roofs Challenge. (n.d.). https://www.coolroofschallenge.org/finalists (accessed August 18, 2022).
[71] R. Levinson, M. André, E. Arens, E. Bozonnet, F. Chtioui, V. Corrado, E. Costanzo, A. Deralla, L.G. Eli, H. Gilbert, M. Hamdy, P. Holzer, K. Ismail, P. Jaboyedoff, A. Krelling, R. Lamberts, A. Machard, S. Rahmani, P. Salagnac, S. Selkowitz, B. Sodagar, P. Stern, Annex 80 Subtask D: Analysis of existing policy resources, including standards, programs, and guidelines (draft), 2022. https://bit.ly/3q4u8Nn.
[72] Financial Incentives, Cool Roof Rating Council. (n.d.). http://coolroofs.org/resources/financial-incentives (accessed July 13, 2022).
[73] Rebates and incentive, reflective roof coating, (2013). https://savings.austinenergy.com/rebates/commercial/offerings/property-improvements/reflective-roof/ (accessed June 28, 2022).
[74] Rebates for Businesses, JEA. (n.d.). http://www.jea.com/business_resources/rebates_for_businesses/ (accessed June 28, 2022).
[75] Rebates & Programs, (n.d.). https://www.ladwp.com/ladwp/faces/ladwp/residential/r-savemoney/r-sm-rebatesandprograms?_adf.ctrl-state=vzce82lz1_89&_afrLoop=1205865557373237 (accessed June 28, 2022).
[76] Cool Roof Incentive Program, LouisvilleKY.Gov. (n.d.). https://louisvilleky.gov/government/sustainability/cool-roof-incentive-program (accessed June 28, 2022).
[77] Business Rebates Information, (n.d.). https://www.ouc.com/business/business-rebates-programs/business-rebates-information#coolbus (accessed June 28, 2022).
[78] Conservation Programs, Utilities Commission City of New Smyrna Beach. (2020). https://www.ucnsb.org/conservation-programs (accessed June 28, 2022).
[79] Texas New Mexico Power - Rebate Program, (n.d.). https://tnmpefficiency.com/commercial.php (accessed July 13, 2022).
[80] City of Toronto, Eco-Roof Incentive Program, City of Toronto. (n.d.). https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/green-your-roof/ (accessed June 28, 2022).
[81] H. Akbari, R. Levinson, Evolution of Cool-Roof Standards in the US, Advances in Building Energy Research. 2 (2008) 1–32. https://doi.org/10.3763/aber.2008.0201.
[82] Codes, Programs & Standards, Cool Roof Rating Council. (n.d.). http://coolroofs.org/resources/codes-programs-standards (accessed July 13, 2022).
[83] Alabama State Energy Code, UpCodes. (n.d.). https://up.codes/viewer/alabama/iecc-2015/chapter/CE_4/ce-commercial-energy-efficiency#C402.3 (accessed July 13, 2022).
[84] GA - Atlanta, CHAPTER 16-18P. - SPI-16 MIDTOWN SPECIAL PUBLIC INTEREST DISTRICT REGULATIONS | Code of Ordinances | Atlanta, GA | Municode Library, (n.d.). https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=PTIIICOORANDECO_PT16ZO_CH16-18PSPMISPPUINDIRE_S16-18P.010DECO (accessed July 13, 2022).
[85] California - Title 24, 2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings for the 2019 Building Efficiency Standards, California Energy Commission. (2019). https://www.energy.ca.gov/publications/2008/2019-building-energy-efficiency-standards-residential-and-nonresidential (accessed July 13, 2022).
[86] City of Chula Vista, Municipal Code, Section 15.26.040 Mandatory energy efficiency requirements for additions to single-family homes and condos, (2020). https://chulavista.municipal.codes/CVMC/15.26.040 (accessed July 13, 2022).

[87] Cool Policy Review, (n.d.). https://coolroofs.org/documents/Exhibit_4_-_Global_Cool_Roof_Policy_and_Code_Update_Shickman.pdf (accessed August 26, 2022).
[88] M. van Tijen, R. Cohen, Features and Benefits of Cool Roofs: The Cool Roof Rating Council Program, Journal of Green Building. 3 (2008) 13–19. https://doi.org/10.3992/jgb.3.2.13.
[89] Washington Sustainable Schools Protocol Criteria for High-Performance Schools, 2018. https://www.k12.wa.us/sites/default/files/public/schfacilities/programs/highperformanceschools/WSSP%202018%20Final.pdf.
[90] Northeast Collaborative For High Performance Schools Criteria (NE-CHPS), 2014. https://www.ride.ri.gov/Portals/0/Uploads/Documents/Funding-and-Finance-Wise-Investments/SchoolBuildingAuthority/NE-CHPS-3-1-Criteria-Update-8-15-18.pdf.
[91] Cardin "Cool Roofs" Bill Would Create Jobs By Eliminating Barriers To Energy Efficient Retrofits, U.S. Senator Ben Cardin. (2014). https://www.cardin.senate.gov/press-releases/cardin-cool-roofs-bill-would-create-jobs-by-eliminating-barriers-to-energy-efficient-retrofits/ (accessed August 7, 2022).
[92] Gallego and Watson Coleman Introduce Bill to Combat the Causes and Impacts of Excess Urban Heat, (2022). http://rubengallego.house.gov/media-center/press-releases/gallego-and-watson-coleman-introduce-bill-combat-causes-and-impacts (accessed August 7, 2022).
[93] NYC CoolRoofs - NYC Business, (n.d.). https://www1.nyc.gov/nycbusiness/article/nyc-coolroofs (accessed June 28, 2022).
[94] NYC CoolRoofs, n.d. https://coolroofs.org/documents/NYC_CoolRoofs_6-14-17_Presentation.pdf.
[95] NYC CoolRoofs, C40 Cities. (n.d.). https://www.c40.org/case-studies/nyc-coolroofs/ (accessed August 7, 2022).
[96] RetroFIT Philly "Coolest Block" Contest, (n.d.). http://retrofitphilly.com/ (accessed July 19, 2022).
[97] H.A. Bulkeley, V.C. Broto, G.A.S. Edwards, V.C. Broto, An Urban Politics of Climate Change: Experimentation and the Governing of Socio-Technical Transitions, Taylor & Francis Group, London, UNITED KINGDOM, 2014. http://ebookcentral.proquest.com/lib/asulib-ebooks/detail.action?docID=1818201 (accessed August 19, 2022).
[98] Philadelphia Mayor Nutter Announces the Winner of the "Coolest Block" Contest, PRWeb. (2010). https://www.prweb.com/releases/2010/05/prweb4000564.htm (accessed August 22, 2022).
[99] M. Bebinger, In Chelsea, cooling an urban heat island one block at a time, (n.d.). https://www.wbur.org/news/2022/05/12/chelsea-massachusetts-heat-island-cooling (accessed July 21, 2022).
[100] ÉCHALE, ÉCHALE. (n.d.). https://echale.mx/en/ (accessed November 10, 2022).
[101] New Story - we pioneer solutions to end homelessness | Home, New Story. (n.d.). https://newstorycharity.org/ (accessed November 10, 2022).
[102] Million Cool Roofs Challenge - Arup, (n.d.). https://www.arup.com/en/projects/million-cool-roofs-challenge (accessed August 7, 2022).
[103] N. Everitt, Indonesian team rises to cool roof challenge, Cooling Post. (2022). https://www.coolingpost.com/features/indonesian-team-rises-to-cool-roof-challenge/ (accessed August 7, 2022).
[104] K.S. is the E.D. of the G.C.C. Alliance, Announcing the winners of the Million Cool Roofs Challenge, Challenge Works. (n.d.). https://challengeworks.org/blog/announcing-the-winners-of-the-million-cool-roofs-challenge/ (accessed October 26, 2022).
[105] M. Wald, Public Housing Efficiency Plan, Step 1: Get New Refrigerators, The New York Times. (1995). https://www.nytimes.com/1995/06/20/nyregion/public-housing-efficiency-plan-step-1-get-new-refrigerators.html (accessed July 13, 2022).
[106] E. Pontecorvo, How NYC's housing authority plans to transform the market for clean heat, Grist. (2022). https://grist.org/buildings/how-nycs-public-housing-authority-plans-to-transform-the-market-for-clean-heat/ (accessed July 20, 2022).

[107] L.F. Kinney, G. Lewis, R.G. Pratt, J. Miller, New York Power Authority/New York City Housing Authority Refrigerator Replacement Program, First Program Year Evaluation. Final Report, Other Information: PBD: Aug 1997. (1997). https://doi.org/10.2172/527929.

[108] Get Cool NYC: Mayor de Blasio Updates New Yorkers on COVID-19 Summer Heat Plan, (2020). http://www1.nyc.gov/office-of-the-mayor/news/433-20/get-cool-nyc-mayor-de-blasio-new-yorkers-covid-19-summer-heat-plan (accessed July 18, 2022).

[109] P. Sisson, The future of urban housing is energy-efficient refrigerators, MIT Technology Review. (2022). https://www.technologyreview.com/2022/06/23/1053662/energy-efficient-refrigerators-urban-housing/ (accessed July 18, 2022).

[110] M. Ivanco, B.W. Karney, K.J. Waher, To Switch, or Not to Switch: A Critical Analysis of Canada's Ban on Incandescent Light Bulbs, in: 2007 IEEE Canada Electrical Power Conference, 2007: pp. 550–555. https://doi.org/10.1109/EPC.2007.4520391.

[111] Energystar, Lighting technologies: a guide to energy-efficient illumination, n.d. https://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact%20Sheet_Lighting%20Technologies.pdf.

[112] G. Perino, T. Pioch, Banning incandescent light bulbs in the shadow of the EU Emissions Trading Scheme, Climate Policy. 17 (2017) 678–686. https://doi.org/10.1080/14693062.2016.1164657.

[113] N.A.A. Howarth, J. Rosenow, Banning the bulb: Institutional evolution and the phased ban of incandescent lighting in Germany, Energy Policy. 67 (2014) 737–746. https://doi.org/10.1016/j.enpol.2013.11.060.

[114] N. Popovich, America's Light Bulb Revolution, The New York Times. (2019). https://www.nytimes.com/interactive/2019/03/08/climate/light-bulb-efficiency.html, https://www.nytimes.com/interactive/2019/03/08/climate/light-bulb-efficiency.html (accessed July 20, 2022).

[115] Biden Administration Implements New Cost-Saving Energy Efficiency Standards for Light Bulbs, Energy.Gov. (n.d.). https://www.energy.gov/articles/biden-administration-implements-new-cost-saving-energy-efficiency-standards-light-bulbs (accessed July 19, 2022).

[116] M. Osborne, The United States Will Phase Out Incandescent Light Bulbs, Smithsonian Magazine. (2022). https://www.smithsonianmag.com/smart-news/the-us-is-phasing-out-incandescent-light-bulbs-180979992/ (accessed July 19, 2022).

[117] Z. Koretsky, Phasing out an embedded technology: Insights from banning the incandescent light bulb in Europe, Energy Research & Social Science. 82 (2021) 102310. https://doi.org/10.1016/j.erss.2021.102310.

[118] N. Dietsch, R. Bell, B. Drumheller, Emphasizing the Co-Benefits of Heat Island Mitigation: Lessons from U.S. Local Governments Engaged in Climate Protection, in: ACEEE Summer Studies on Energy Efficiency in Buildings, 2002. https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel9_Paper06.pdf#:~:text=The%20major%20co-benefits%20of%20heat%20island%20reduction%20measures,island%20mitigation%20strategies%20are%20sound%20investments.%20Energy%20savings.

[119] M. Sarkovich, SMUD Shade Tree and Cool Roof Programs: Case Study in Mitigating the Urban Heat Island Effects, Cool Roofs and Cool Pavements Toolkit. (2009). https://coolrooftoolkit.org/knowledgebase/smud-shade-tree-and-cool-roof-programs-case-study-in-mitigating-the-urban-heat-island-effects/ (accessed June 28, 2022).

[120] City Plants – Get Free Trees! (n.d.). https://www.cityplants.org/ (accessed August 8, 2022).

[121] Shading Sacramento, Improve air quality and cool your home, Free Shade Tree Program. (n.d.). https://www.smud.org/en/Going-Green/Free-Shade-Trees (accessed August 8, 2022).

[122] Planning and Development, promotes the comprehensive growth and sustainability of the City and its neighborhoods, Chicago Green Roof Map. (n.d.). https://www.chicago.gov/content/city/en/depts/dcd/supp_info/chicago_green_roofs.html (accessed August 8, 2022).

[123] J. Faust, Atlanta City Hall Pilot Green Roof, Greenroofs.Com. (2003). http://www.greenroofs.com/projects/atlanta-city-hall-pilot-green-roof/ (accessed August 8, 2022).
[124] Cost Analysis for the Portland Ecoroof Incentive, EcoMetrix Solutions Group, 2014. https://www.portlandoregon.gov/bes/article/522380.

Supplementary Material

***Table S3**. Highly relevant articles from the peer-reviewed literature focused on benefits, challenges, and demonstrations of cool surfaces.*

Publication Year	Title	Authors	Journal	Reference
2022	A review of the application of radiative sky cooling in buildings: Challenges and optimization	Wu Y, Zhao H, Sun H, et al.	*Energy Conversion and Management*	[1]
2021	A Conceptual Review of the Potential of Cool Roofs as an Effective Passive Solar Technique: Elaboration of Benefits and Drawbacks	Ashtari B, Yeganeh M, Bemanian M, et al.	*Frontiers in Energy Research*	[2]
2021	Phasing out an embedded technology: Insights from banning the incandescent light bulb in Europe	Koretsky Z	*Energy Research & Social Science*	[3]
2019	A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces	Lai D, Liu W, Gan T, et al.	*Science of The Total Environment*	[4]
2019	Potential benefits of cool walls on residential and commercial buildings across California and the United States: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants	Rosado PJ, Levinson R	*Energy and Buildings*	[5]
2019	Scale dependence of the benefits and efficiency of green and cool roofs	Yang J, Bou-Zeid E	*Landscape and Urban Planning*	[6]
2019	Potential energy and climate benefits of super-cool materials as a rooftop strategy	Baniassadi A, Sailor DJ, Ban-Weiss	*Urban Climate*	[7]
2018	Cool roofs and cool pavements application in Acharnes, Greece	Kolokotsa DD, Giannariakis G, Gobakis K	*Sustainable Cities and Society*	[8]
2017	Banning incandescent light bulbs in the shadow of the EU Emissions Trading Scheme	Perino G, Pioch T	*Climate Policy*	[9]
2017	A review of benefits and limitations of static and switchable cool roof systems	Testa J, Krarti M	*Renewable and Sustainable Energy Reviews*	[10]
2017	Study on aging of solar reflectance of the self-cleaning high reflectance coating	Aoyama T, Sonoda T, Nakanishi Y, et al.	*Energy and Buildings*	[11]

2016	Effect of cool roofs on commercial buildings energy use in cold climates	Hosseini M, Akbari H	*Energy and Buildings*	[12]
2015	Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings	Dabaieh M, Wanas O, Hegazy H, et al.	*Energy and Buildings*	[13]
2015	Challenges Associated with Adaptation to Future Urban Expansion	Georgescu M	*Journal of Climate*	[14]
2014	Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments	Yafeng Gao, Jiangmin Xu, Shichao Yang, et al.	*Energy Policy*	[15]
2014	Heating energy penalties of cool roofs: The effect of snow accumulation on roofs	Hosseini M, Akbari H	*Advances in Building Energy Research*	[16]
2014	Banning the bulb: Institutional evolution and the phased ban of incandescent lighting in Germany	Howarth N, Rosenow J	*Energy Policy*	[17]
2014	Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments	Santamouris M	*Solar Energy*	[18]
2013	Policy Aspects of Cool Materials	Kolokotsa JG, Synnefa A	*Advances in the Development of Cool Materials for the Built Environment*	[19]
2012	On the thermal performance of low income housing during heat waves	Sakkaa A, Santamourisa M, Livada I, et al.	*Energy and Buildings*	[6]
2012	Advances on technical, policy and market aspects of cool roof technology in Europe: The Cool Roofs project	Synnefa A, Santamouris M.	*Energy and Buildings*	[20]
2011	Soiling of building envelope surfaces and its effect on solar reflectance—Part I: Analysis of roofing product databases	Sleiman M, Ban-Weiss G, Gilbert HE, et al.	*Solar Energy Materials and Solar Cells*	[21]
2010	Potential benefits of cool roofs on commercial buildings: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants	Levinson R, Akbari H	*Energy Efficiency*	[22]
2008	Evolution of Cool-Roof Standards in the US	Akbari H, Levinson R	*Advances in Building Energy Research*	[23]

2007	Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions	Synnefa A, Santamouris M, Akbari H	*Energy and Buildings*	[24]
2005	Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements	Ronnen Levinson, Hashem Akbari, Steve Konopacki, et al.	*Energy Policy*	[25]
2005	Aging and weathering of cool roofing membranes	Akbari H, Berhe A, Levinson R, et al.	Lawrence Berkeley National Laboratory	[26]
2005	Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane	Levinson R, Berdahl P, Asefaw Berhe A, et al.	*Atmospheric Environment*	[27]

***Table S4**. Highly relevant conference papers and presentations focused on benefits, challenges, and demonstrations of cool surfaces.*

Year	Title	Authors	Conference name	Reference
2019	Cool Roof initiatives in India: An evaluation of the existing conditions and lessons to be learnt from global best practices	Rallapalli H, Gupta J,	*5th International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[28]
2016	Cool Roof Monitoring Experiment in a Real Building in Nagpur, India	Rallapalli H, Reddy N, Rao P, et al.	*4th International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[29]
2014	Development of self-cleaning top-coat for cool roof	Aoyama T, Sonoda T, Hamamura T, et al.	*3rd International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[30]
2014	Cool Roofs in Cold Climates: Savings or Penalties?	Akbari H, Hosseini M.	*3rd International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[31]
2014	Assessment of the Impact of Cool Roofs in Rural Buildings in India	Garg V, Kotharkar R, Sathaye J, et al.	*3rd International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[32]
2009	Global Cooling: Policies to Cool the World and Offset Global Warming from CO2 Using Reflective Roofs and Pavements	Akbari H, Levinson R, Rosenfeld A, et al.	*2nd International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[33]
2009	SMUD Shade Tree and Cool Roof Programs: Case Study in Mitigating the Urban Heat Island Effect	Sarkovich M	*2nd International Conference on Countermeasures to Urban Heat Islands (IC2UHI)*	[34]
2008	Condensation problems in cool roofs	Bludau C, Zirkelbach D, Künzel, H	*International Conference on Durability of Building Materials and Components (DBMC)*	[35]
2007	To Switch, or Not to Switch: A Critical Analysis of Canada's Ban on Incandescent Light Bulbs	Ivanco M, Karney BW, Waher KJ	*Institute of Electrical and Electronics Engineers (IEEE)*	[36]
2002	Emphasizing the Co-Benefits of Heat Island Mitigation: Lessons from U.S. Local Governments Engaged in Climate Protection	Nikolaas D, Ryan B, Bill D	*American Council for an Energy-Efficient Economy (ACEEE)*	[37]

***Table S5**. Other resources and gray literature focused on benefits, challenges, and demonstrations of cool surfaces.*

Year	Title	Reference
2022	Are cool roofs the future for Australian cities?	[38]
2022	The future of urban housing is energy-efficient refrigerators	[39]
2022	Cool Roofs Cost Benefit Analysis UNSW – Sydney Volume 1 - Cool Roofs: International Progress, Technology, Market, and Legislative Frame	[40]
2022	Utilities Commission City of New Smyrna Beach	[41]
2022	How NYC's housing authority plans to transform the market for clean heat.	[42]
2022	Indonesian team rises to cool roof challenge	[43]
2022*	Alabama State Energy Code	[44]
2022*	Biden Administration Implements New Cost-Saving Energy Efficiency Standards for Light Bulbs	[45]
2022*	Business Rebates Information.	[46]
2022*	Ch. 15.26 Energy Code | Chula Vista Municipal Code	[47]
2022*	Cool Roof Rating Council	[48]
2022*	Cool Roof Incentive Program (LouisvilleKY.Gov)	[49]
2022*	Cool Roofs for Cool Delhi	[50]
2022*	Cool roofs protecting local communities from extreme heat	[51]
2022*	Cooling the Planet Could Start on Your Roof	[52]
2022*	Midtown Special Public Interest District Regulations: Code of Ordinances | Atlanta, GA	[53]
2022*	Gallego and Watson Coleman Introduce Bill to Combat the Causes and Impacts of Excess Urban Heat	[54]
2022*	Global Cool Cities Alliance	[55]
2022*	In Chelsea, cooling an urban heat island one block at a time	[56]
2022*	Ahmedabad: Cool Roofs Initiative with 5th Heat Action Plan	[57]
2022*	New York Power Authority/New York City Housing Authority Refrigerator Replacement Program, First Program Year Evaluation. Final Report	[58]
2022*	LEED v4.1 | U.S. Green Building Council	[59]
2022*	The United States Will Phase Out Incandescent Light Bulbs. Smithsonian Magazine	[60]
2022*	Million Cool Roofs Challenge—Arup	[61]
2022*	NYC CoolRoofs—NYC Business	[62]
2022*	Million Cool Roofs Challenge	[61]
2022*	Rebates & Programs.	[63]
2022*	Rebates for Businesses	[64]
2022*	RetroFIT Philly "Coolest Block" Contest	[65]
2022*	Texas New Mexico Power - Rebate Program	[66]
2022*	Eco-Roof Incentive Program	[67]
2022*	Chicago Green Roofs	[68]
2022*	Atlanta City Hall Pilot Green Roof	[69]
2022*	Los Angles – City Plants	[70]
2022*	Sacramento - Free Shade Tree Program	[71]
2021	Phoenix Climate Action Plan	[72]
2021	Preparing for heat	[73]
2021	How to Apply Elastomeric Roof Coating in 3 Easy Steps	[74]
2020	Get Cool NYC: Mayor de Blasio Updates New Yorkers on COVID-19 Summer Heat Plan	[75]
2020	Insuring Extreme Heat Risks	[76]
2020	Cool Roof Policy Updates Trend in US Cities: PaintSquare News	[77]

2019	Ahmedabad Heat Action Plan 2019	[78]
2019	California - Title 24	[79]
2018	In India, Summer Heat May Soon Be Literally Unbearable	[80]
2017	5 Reasons Why the Ahmedabad Heat Action Plan Saves Lives	[81]
2015	Seoul lowers temperature with ‘Cool Roof Campaign	[82]
2014	Cardin “Cool Roofs” Bill Would Create Jobs By Eliminating Barriers To Energy Efficient Retrofits	[83]
2014	Heat Island Community Actions Database	[84]
2014	Washington Sustainable Schools Protocol Criteria for High-Performance Schools	[85]
2014	Northeast Collaborative For High Performance Schools Criteria (NE-CHPS)	[86]
2013	Heating and cooling no longer majority of U.S. home energy use	[87]
2013	Reflective Roof Coating	[88]
2012	Study of Cool Roof on Low Income House Group	[89]
2009	White Roofs Catch On as Energy Cost Cutters	[90]
2009	Review and Critical Analysis of International UHI Studies.	[91]
2009	America’s Light Bulb Revolution	[92]
2008	Features and Benefits of Cool Roofs: The Cool Roof Rating Council Program	[93]
2007	Cool roof coatings market heating up	[94]
2006	Tokyo Government Announces 2006 Cool-Roof Projects	[95]
1995	Public Housing Efficiency Plan, Step 1: Get New Refrigerators—The New York Times	[96]

* Date accessed

Supplementary Material References

[1] Y. Wu, H. Zhao, H. Sun, M. Duan, B. Lin, S. Wu, A review of the application of radiative sky cooling in buildings: Challenges and optimization, Energy Convers. Manag. 265 (2022) 115768. https://doi.org/10.1016/j.enconman.2022.115768.

[2] B. Ashtari, M. Yeganeh, M. Bemanian, B. Vojdani Fakhr, A Conceptual Review of the Potential of Cool Roofs as an Effective Passive Solar Technique: Elaboration of Benefits and Drawbacks, Front. Energy Res. 9 (2021). https://www.frontiersin.org/articles/10.3389/fenrg.2021.738182 (accessed August 5, 2022).

[3] Z. Koretsky, Phasing out an embedded technology: Insights from banning the incandescent light bulb in Europe, Energy Res. Soc. Sci. 82 (2021) 102310. https://doi.org/10.1016/j.erss.2021.102310.

[4] D. Lai, W. Liu, T. Gan, K. Liu, Q. Chen, A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces, Sci. Total Environ. 661 (2019) 337–353. https://doi.org/10.1016/j.scitotenv.2019.01.062.

[5] P.J. Rosado, R. Levinson, Potential benefits of cool walls on residential and commercial buildings across California and the United States: Conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants, Energy Build. 199 (2019) 588–607. https://doi.org/10.1016/j.enbuild.2019.02.028.

[6] J. Yang, E. Bou-Zeid, Scale dependence of the benefits and efficiency of green and cool roofs, Landsc. Urban Plan. 185 (2019) 127–140. https://doi.org/10.1016/j.landurbplan.2019.02.004.

[7] A. Baniassadi, D.J. Sailor, G.A. Ban-Weiss, Potential energy and climate benefits of super-cool materials as a rooftop strategy, Urban Clim. 29 (2019) 100495. https://doi.org/10.1016/j.uclim.2019.100495.

[8] D.– D. Kolokotsa, G. Giannariakis, K. Gobakis, G. Giannarakis, A. Synnefa, M. Santamouris, Cool roofs and cool pavements application in Acharnes, Greece, Sustain. Cities Soc. 37 (2018) 466–474. https://doi.org/10.1016/j.scs.2017.11.035.

[9] G. Perino, T. Pioch, Banning incandescent light bulbs in the shadow of the EU Emissions Trading Scheme, Clim. Policy. 17 (2017) 678–686. https://doi.org/10.1080/14693062.2016.1164657.

[10] J. Testa, M. Krarti, A review of benefits and limitations of static and switchable cool roof systems, Renew. Sustain. Energy Rev. 77 (2017) 451–460. https://doi.org/10.1016/j.rser.2017.04.030.

[11] T. Aoyama, T. Sonoda, Y. Nakanishi, J. Tanabe, H. Takebayashi, Study on aging of solar reflectance of the self-cleaning high reflectance coating, Energy Build. 157 (2017) 92–100. https://doi.org/10.1016/j.enbuild.2017.02.021.

[12] M. Hosseini, H. Akbari, Effect of cool roofs on commercial buildings energy use in cold climates, Energy Build. 114 (2016) 143–155. https://doi.org/10.1016/j.enbuild.2015.05.050.

[13] M. Dabaieh, O. Wanas, M.A. Hegazy, E. Johansson, Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings, Energy Build. 89 (2015) 142–152. https://doi.org/10.1016/j.enbuild.2014.12.034.

[14] M. Georgescu, Challenges Associated with Adaptation to Future Urban Expansion, J. Clim. 28 (2015) 2544–2563. https://doi.org/10.1175/JCLI-D-14-00290.1.

[15] Y. Gao, J. Xu, S. Yang, X. Tang, Q. Zhou, J. Ge, T. Xu, R. Levinson, Cool roofs in China: Policy review, building simulations, and proof-of-concept experiments, Energy Policy. 74 (2014) 190–214. https://doi.org/10.1016/j.enpol.2014.05.036.

[16] M. Hosseini, H. Akbari, Heating energy penalties of cool roofs: the effect of snow accumulation on roofs, Adv. Build. Energy Res. 8 (2014) 1–13. https://doi.org/10.1080/17512549.2014.890541.

[17] N.A.A. Howarth, J. Rosenow, Banning the bulb: Institutional evolution and the phased ban of incandescent lighting in Germany, Energy Policy. 67 (2014) 737–746. https://doi.org/10.1016/j.enpol.2013.11.060.

[18] M. Santamouris, Cooling the cities – A review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments, Sol. Energy. 103 (2014) 682–703. https://doi.org/10.1016/j.solener.2012.07.003.

[19] J.G. Kolokotsa, A. Synnefa, eds., Policy Aspects of Cool Materials, in: Adv. Dev. Cool Mater. Built Environ., BENTHAM SCIENCE PUBLISHERS, 2013: pp. 273–309. https://doi.org/10.2174/9781608054718113010013.

[20] A. Synnefa, M. Santamouris, Advances on technical, policy and market aspects of cool roof technology in Europe: The Cool Roofs project, Energy Build. 55 (2012) 35–41. https://doi.org/10.1016/j.enbuild.2011.11.051.

[21] M. Sleiman, G. Ban-Weiss, H.E. Gilbert, D. François, P. Berdahl, T.W. Kirchstetter, H. Destaillats, R. Levinson, Soiling of building envelope surfaces and its effect on solar reflectance—Part I: Analysis of roofing product databases, Sol. Energy Mater. Sol. Cells. 95 (2011) 3385–3399. https://doi.org/10.1016/j.solmat.2011.08.002.

[22] R. Levinson, H. Akbari, Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants, Energy Effic. 3 (2010) 53–109. https://doi.org/10.1007/s12053-008-9038-2.

[23] H. Akbari, R. Levinson, Evolution of Cool-Roof Standards in the US, Adv. Build. Energy Res. 2 (2008) 1–32. https://doi.org/10.3763/aber.2008.0201.

[24] A. Synnefa, M. Santamouris, H. Akbari, Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions, Energy Build. 39 (2007) 1167–1174. https://doi.org/10.1016/j.enbuild.2007.01.004.

[25] R. Levinson, H. Akbari, S. Konopacki, S. Bretz, Inclusion of cool roofs in nonresidential Title 24 prescriptive requirements, Energy Policy. 33 (2005) 151–170. https://doi.org/10.1016/S0301-4215(03)00206-4.

[26] H. Akbari, A. Berhe, R. Levinson, S. Graveline, K. Foley, A. Delgado, R. Paroli, Aging and Weathering of Cool Roofing Membranes, in: Lawrence Berkeley National Laboratory, 2005. https://escholarship.org/uc/item/3qb8j3k7.

[27] R. Levinson, P. Berdahl, A. Asefaw Berhe, H. Akbari, Effects of soiling and cleaning on the reflectance and solar heat gain of a light-colored roofing membrane, Atmos. Environ. 39 (2005) 7807–7824. https://doi.org/10.1016/j.atmosenv.2005.08.037.

[28] H. Rallapalli, J. Gupta, Cool Roof initiatives in India: An evaluation of the existing conditions and lessons to be learnt from global best practices, in: 5th International Conference on Countermeasures to Urban Heat Islands, 2019: pp. 270–279.

[29] H. Rallapalli, N. Reddy, P. Rao, V. Garg, J. Sathaye, R. Levinson, Cool Roof Monitoring Experiment in a Real Building in Nagpur, India, in: 4th International Conference on Countermeasures to Urban Heat Islands, 2016.

[30] T. Aoyama, T. Sonoda, T. Hamamura, Y. Nakanishi, L. Peeters, H. Takebayashi, Development of self-cleaning top-coat for cool roof, in: 3rd International Conference on Countermeasures to Urban Heat Islands, 2014: pp. 1157–1167.

[31] H. Akbari, M. Hosseini, Cool Roofs In Cold Climates: Savings Or Penalties?, in: 3rd International Conference on Countermeasures to Urban Heat Islands, 2014: pp. 986–997.

[32] V. Garg, R. Kotharkar, J. Sathaye, H. Rallapalli, N. Kulkarni, N. Reddy, P. Rao, Assessment of the Impact of Cool Roofs in Rural Buildings in India, in: 3rd International Conference on Countermeasures to Urban Heat Islands, 2014: pp. 1668–1680.

[33] H. Akbari, R. Levinson, A. Rosenfeld, M. Elliot, Global Cooling: Policies to Cool the World and Offset Global Warming from CO2 Using Reflective Roofs and Pavements, Lawrence Berkeley National Lab. (LBNL), Berkeley, CA (United States), 2009. https://www.osti.gov/biblio/984960/ (accessed June 29, 2022).

[34] Kurt, SMUD Shade Tree and Cool Roof Programs: Case Study in Mitigating the Urban Heat Island Effects, Cool Roofs Cool Pavements Toolkit. (2009). https://coolrooftoolkit.org/knowledgebase/smud-shade-tree-and-cool-roof-programs-case-study-in-mitigating-the-urban-heat-island-effects/ (accessed June 29, 2022).

[35] C. Bludau, D. Zirkelbach, H. M. Künzel, Condensation problems in cool roofs, in: 11th Int. Conf. Durab. Build. Mater. Compon. DBMC, 2008. https://iibec.org/wp-content/uploads/2016/04/2009-08-bludau-zirkelbach-kunzel.pdf.

[36] M. Ivanco, B.W. Karney, K.J. Waher, To Switch, or Not to Switch: A Critical Analysis of Canada's Ban on Incandescent Light Bulbs, in: 2007 IEEE Can. Electr. Power Conf., 2007: pp. 550–555. https://doi.org/10.1109/EPC.2007.4520391.

[37] N. Dietsch, R. Bell, B. Drumheller, Emphasizing the Co-Benefits of Heat Island Mitigation: Lessons from U.S. Local Governments Engaged in Climate Protection, in: 2002. https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel9_Paper06.pdf#:~:text=T

he%20major%20co-benefits%20of%20heat%20island%20reduction%20measures,island%20mitigation%20strategies%20are%20sound%20investments.%20Energy%20savings.

[38] N. Razzhigaeva, Are cool roofs the future for Australian cities?, UNSW Newsroom. (2022). https://newsroom.unsw.edu.au/news/art-architecture-design/are-cool-roofs-future-australian-cities (accessed August 6, 2022).

[39] P. Sisson, The future of urban housing is energy-efficient refrigerators, MIT Technol. Rev. (2022). https://www.technologyreview.com/2022/06/23/1053662/energy-efficient-refrigerators-urban-housing/ (accessed July 19, 2022).

[40] M. Santamouris, A.M. Papadopoulos, R. Paolini, A. Khan, C. Koc, S. Haddad, S. Garshasbi, S. Arasteh, J. Feng, Cool Roofs Cost Benefit Analysis UNSW – Sydney Volume 1 - Cool Roofs : International Progress, Technology, Market, and Legislative Frame, University of New South Wales, 2022. https://www.unsw.edu.au/content/dam/pdfs/unsw-adobe-websites/arts-design-architecture/built-environment/our-research/high-performance-architecture-research-cluster/2022-04-Volume-1.pdf (accessed August 19, 2022).

[41] Conservation Programs, Util. Comm. City New Smyrna Beach. (2020). https://www.ucnsb.org/conservation-programs (accessed June 29, 2022).

[42] How NYC's housing authority plans to transform the market for clean heat, Grist. (2022). https://grist.org/buildings/how-nycs-public-housing-authority-plans-to-transform-the-market-for-clean-heat/ (accessed July 21, 2022).

[43] N. Everitt, Indonesian team rises to cool roof challenge, Cool. Post. (2022). https://www.coolingpost.com/features/indonesian-team-rises-to-cool-roof-challenge/ (accessed August 7, 2022).

[44] Alabama State Energy Code, UpCodes. (n.d.). https://up.codes/viewer/alabama/iecc-2015/chapter/CE_4/ce-commercial-energy-efficiency#C402.3 (accessed July 13, 2022).

[45] Biden Administration Implements New Cost-Saving Energy Efficiency Standards for Light Bulbs, Energy.Gov. (n.d.). https://www.energy.gov/articles/biden-administration-implements-new-cost-saving-energy-efficiency-standards-light-bulbs (accessed July 20, 2022).

[46] Business Rebates Information, (n.d.). https://www.ouc.com/business/business-rebates-programs/business-rebates-information#coolbus (accessed June 29, 2022).

[47] Ch. 15.26 Energy Code | Chula Vista Municipal Code, Chula Vista CA. (n.d.). https://chulavista.municipal.codes/CVMC/15.26.040 (accessed July 13, 2022).

[48] Codes, Programs & Standards, Cool Roof Rat. Counc. (n.d.). http://coolroofs.org/resources/codes-programs-standards (accessed July 13, 2022).

[49] Cool Roof Incentive Program, LouisvilleKY.Gov. (n.d.). https://louisvilleky.gov/government/sustainability/cool-roof-incentive-program (accessed June 29, 2022).

[50] Cool Roofs for Cool Delhi, Shakti Sustain. Energy Found. (n.d.). https://shaktifoundation.in/report/cool-roofs-cool-delhi/ (accessed August 6, 2022).

[51] Cool roofs protecting local communities from extreme heat, 2017. https://iiphg.edu.in/images/pdfs/NRDC/cool-roofs-2018.pdf.

[52] Cooling the Planet Could Start on Your Roof, Alliance Energy Effic. Econ. (2020). https://aeee.in/sharing_posts/cooling-the-planet-could-start-on-your-roof/ (accessed August 4, 2022).

[53] GA - Atlanta, CHAPTER 16-18P. - SPI-16 MIDTOWN SPECIAL PUBLIC INTEREST DISTRICT REGULATIONS | Code of Ordinances | Atlanta, GA | Municode Library, (n.d.). https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=PTIIICOORANDECO_PT16ZO_CH16-18PSPMISPPUINDIRE_S16-18P.010DECO (accessed July 13, 2022).

[54] Gallego and Watson Coleman Introduce Bill to Combat the Causes and Impacts of Excess Urban Heat, Represent. Ruben Gallego. (2022). http://rubengallego.house.gov/media-center/press-releases/gallego-and-watson-coleman-introduce-bill-combat-causes-and-impacts (accessed August 7, 2022).
[55] Global Cool Cities Alliance, Energy.Gov. (n.d.). https://www.energy.gov/eere/buildings/global-cool-cities-alliance (accessed July 21, 2022).
[56] In Chelsea, cooling an urban heat island one block at a time, (n.d.). https://www.wbur.org/news/2022/05/12/chelsea-massachusetts-heat-island-cooling (accessed July 21, 2022).
[57] N. Kaur, Ahmedabad: Cool Roofs Initiative with 5th Heat Action Plan, NRDC. (2017). https://www.nrdc.org/experts/nehmat-kaur/ahmedabad-cool-roofs-initiative-5th-heat-action-plan (accessed August 6, 2022).
[58] L.F. Kinney, G. Lewis, R.G. Pratt, J. Miller, New York Power Authority/New York City Housing Authority Refrigerator Replacement Program, First Program Year Evaluation. Final Report, Inf. PBD Aug 1997. (1997). https://doi.org/10.2172/527929.
[59] Leadership in Energy and Environmental Design (LEED), U.S. Green Building Council, (n.d.). https://www.usgbc.org (accessed July 13, 2022).
[60] S. Magazine, M. Osborne, The United States Will Phase Out Incandescent Light Bulbs, Smithson. Mag. (n.d.). https://www.smithsonianmag.com/smart-news/the-us-is-phasing-out-incandescent-light-bulbs-180979992/ (accessed July 20, 2022).
[61] Million Cool Roofs Challenge - Arup, (n.d.). https://www.arup.com/en/projects/million-cool-roofs-challenge (accessed August 7, 2022).
[62] NYC CoolRoofs - NYC Business, (n.d.). https://www1.nyc.gov/nycbusiness/article/nyc-coolroofs (accessed June 29, 2022).
[63] Rebates & Programs, (n.d.). https://www.ladwp.com/ladwp/faces/ladwp/residential/r-savemoney/r-sm-rebatesandprograms?_adf.ctrl-state=vzce82lz1_89&_afrLoop=1205865557373237 (accessed June 29, 2022).
[64] Rebates for Businesses, Www.Jea.Com. (n.d.). http://www.jea.com/business_resources/rebates_for_businesses/ (accessed June 29, 2022).
[65] RetroFIT Philly “Coolest Block” Contest, (n.d.). http://retrofitphilly.com/ (accessed July 20, 2022).
[66] Texas New Mexio Power - Rebate Program, (n.d.). https://tnmpefficiency.com/commercial.php (accessed July 13, 2022).
[67] City of Toronto, Eco-Roof Incentive Program, City Tor. (n.d.). https://www.toronto.ca/services-payments/water-environment/environmental-grants-incentives/green-your-roof/ (accessed June 29, 2022).
[68] Planning and Development, promotes the comprehensive growth and sustainability of the City and its neighborhoods, Chic. Green Roof Map. (n.d.). https://www.chicago.gov/content/city/en/depts/dcd/supp_info/chicago_green_roofs.html (accessed August 8, 2022).
[69] J. Faust, Atlanta City Hall Pilot Green Roof, Greenroofs.Com. (2003). http://www.greenroofs.com/projects/atlanta-city-hall-pilot-green-roof/ (accessed August 8, 2022).
[70] City Plants – Get Free Trees. (n.d.). https://www.cityplants.org/ (accessed August 8, 2022).
[71] Shading Sacramento, Improve air quality and cool your home, Free Shade Tree Program. (n.d.). https://www.smud.org/en/Going-Green/Free-Shade-Trees (accessed August 8, 2022).
[72] City of Phoenix, Climate Action Plan, 2021. https://www.phoenix.gov/oepsite/Documents/2021ClimateActionPlanEnglish.pdf.
[73] Preparing for heat, Boston.Gov. (2021). https://www.boston.gov/departments/environment/preparing-heat (accessed August 6, 2022).

[74] How to Apply Elastomeric Roof Coating in 3 Easy Steps, Rugged Coat. (2021). https://ruggedcoatings.com/how-to-apply-elastomeric-roof-coating/ (accessed August 1, 2022).

[75] Get Cool NYC: Mayor de Blasio Updates New Yorkers on COVID-19 Summer Heat Plan, (2020). http://www1.nyc.gov/office-of-the-mayor/news/433-20/get-cool-nyc-mayor-de-blasio-new-yorkers-covid-19-summer-heat-plan (accessed July 19, 2022).

[76] T. Lamm, L. Blumberg, E. Elkind, Insuring Extreme Heat Risks, 2020. https://www.law.berkeley.edu/research/clee/research/climate/california-climate-action/insuring-extreme-heat-risks/ (accessed July 31, 2022).

[77] S. Schneider, Cool Roof Policy Updates Trend in US Cities : PaintSquare News, (2020). https://www.paintsquare.com/news/view/?22271 (accessed August 1, 2022).

[78] Ahmedabad Heat Action Plan 2019, (2019). https://www.c40knowledgehub.org/s/article/Ahmedabad-Heat-Action-Plan-2019?language=en_US (accessed August 6, 2022).

[79] California - Title 24, 2019 Building Energy Efficiency Standards for Residential and Nonresidential Buildings for the 2019 Building Efficiency Standards, Calif. Energy Comm. (2019). https://www.energy.ca.gov/publications/2008/2019-building-energy-efficiency-standards-residential-and-nonresidential (accessed July 13, 2022).

[80] S. Sengupta, In India, Summer Heat May Soon Be Literally Unbearable, N. Y. Times. (2018). https://www.nytimes.com/2018/07/17/climate/india-heat-wave-summer.html (accessed August 6, 2022).

[81] A. Jaiswal, N. Kaur, 5 Reasons Why the Ahmedabad Heat Action Plan Saves Lives, NRDC. (2017). https://www.nrdc.org/experts/anjali-jaiswal/5-reasons-why-ahmedabad-heat-action-plan-saves-lives (accessed August 6, 2022).

[82] Seoul lowers temperature with ‘Cool Roof Campaign,’ Off. Website Of. (2015). https://english.seoul.go.kr/seoul-lowers-temperature-cool-roof-campaign/ (accessed August 6, 2022).

[83] Cardin “Cool Roofs” Bill Would Create Jobs By Eliminating Barriers To Energy Efficient Retrofits, US Senator Ben Cardin. (2014). https://www.cardin.senate.gov/press-releases/cardin-cool-roofs-bill-would-create-jobs-by-eliminating-barriers-to-energy-efficient-retrofits/ (accessed August 7, 2022).

[84] US Environmental Protection Agency, Heat Island Community Actions Database, (2014). https://www.epa.gov/heatislands/heat-island-community-actions-database (accessed August 7, 2022).

[85] Washington Sustainable Schools Protocol Criteria for High-Performance Schools, 2018. https://www.k12.wa.us/sites/default/files/public/schfacilities/programs/highperformanceschools/WSSP%202018%20Final.pdf.

[86] Northeast Collaborative For High Performance Schools Criteria (NE-CHPS), 2014. https://www.ride.ri.gov/Portals/0/Uploads/Documents/Funding-and-Finance-Wise-Investments/SchoolBuildingAuthority/NE-CHPS-3-1-Criteria-Update-8-15-18.pdf.

[87] Heating and cooling no longer majority of U.S. home energy use, (2013). https://www.eia.gov/todayinenergy/detail.php?id=10271 (accessed August 1, 2022).

[88] Rebates and incentive, reflective roof coating, (2013). https://savings.austinenergy.com/rebates/commercial/offerings/property-improvements/reflective-roof/ (accessed June 29, 2022).

[89] S. Sahoo, Study of Cool Roof on Low Income House Group, 2012. https://coolrooftoolkit.org/wp-content/uploads/2012/10/Cool-roof-CEPT.pdf.

[90] F. Barringer, White Roofs Catch On as Energy Cost Cutters, N. Y. Times. (2009). https://www.nytimes.com/2009/07/30/science/earth/30degrees.html (accessed August 7, 2022).

[91] M. Lafrance, Review and Critical Analysis of International UHI Studies, 2009. https://www.yumpu.com/en/document/view/5061518/review-and-critical-analysis-of-international-uhi-studies (accessed July 10, 2022).

[92] N. Popovich, America’s Light Bulb Revolution, N. Y. Times. (2019). https://www.nytimes.com/interactive/2019/03/08/climate/light-bulb-efficiency.html, https://www.nytimes.com/interactive/2019/03/08/climate/light-bulb-efficiency.html (accessed July 21, 2022).

[93] M. van Tijen, R. Cohen, Features and Benefits of Cool Roofs: The Cool Roof Rating Council Program, J. Green Build. 3 (2008) 13–19. https://doi.org/10.3992/jgb.3.2.13.

[94] C. Challener, Cool roof coatings market heating up, Jct Coat. Tech. 4 (2007) 50–55.

[95] Tokyo Government Announces 2006 Cool-Roof Project, JFS Jpn. Sustain. (2006). https://www.japanfs.org/en/news/archives/news_id026405.html (accessed August 7, 2022).

[96] M. Wald, Public Housing Efficiency Plan, Step 1: Get New Refrigerators, N. Y. Times. (1995). https://www.nytimes.com/1995/06/20/nyregion/public-housing-efficiency-plan-step-1-get-new-refrigerators.html (accessed July 13, 2022).