Highly Solar Reflective "Cool" Roofs in Kansas City

The Effects of Excess Heat and Urban Cooling Strategies

Rising urban temperatures have broad and serious negative implications for nearly every aspect of urban life. This section captures some of the main negative effects of excess heat on cities including on:

- human health outcomes,
- resiliency of health,
- transportation, and energy systems,
- air and water quality,
- crime,
- equity, and
- economic prosperity.

By reducing urban heat and its negative effects, cool roofs and walls (among other cooling strategies) will produce quantifiable benefits to the same set of factors listed above. The body of existing scientific and observational research allows us to establish an approximate range of temperature impact from each solution. However, it is impossible to offer a specific answer to this question as each solution's effect will vary based on building characteristics, urban environment, land cover, and meteorological and geographical conditions. Combinations of solutions that might be highly effective in a temperate, humid climate may have little to no positive effect in a desert climate, for example.

A comprehensive review of studies evaluating the cooling ability of solar reflective and vegetated surfaces found that, if deployed at a city-scale, such strategies would substantially reduce urban air temperatures. The consensus of studies was that average ambient temperatures could be reduced by 0.3°C per 0.10 increase in solar reflectance across a city. Peak ambient temperature decreases by up to 0.9°C per each 0.10 increase in solar reflectance. Air temperature reductions possible with city scale green roof deployment ranged from 0.3°C to 3°C. Street tree deployment at scale would have a similar cooling effect of between 0.4°C and 3°C, with the greatest cooling effect occurring within 30 meters of the tree.

There are many societal benefits of adopting strategies to cool down urban temperatures. Some of these are economically quantifiable (e.g., human health, air quality, productivity) and others remain challenging to quantify (e.g., school performance, tourism effect) or primarily qualitative in nature (e.g., quality of life). Since these are societal benefits, they are often hidden from the building owner and may not factor into their buying decisions. Policymakers should consider these quantitative and qualitative benefits when considering incentives and regulatory actions. The positive effects of urban cooling are noted below in each subsection, with a focus on those benefits that are quantified by existing research.

Reflective infrastructure

The concept of creating cooler structures using a surface's ability to reflect sunlight and to efficiently emit absorbed heat dates back to ancient Sumerian and Egyptian construction. Every opaque urban surface (e.g., roofs, walls, pavements) reflects some incoming sunlight and absorbs the rest, turning it into heat. Some of this solar heat contributes to the heat island effect. Reflecting solar radiation into the sky, ideally through the atmosphere and into space, can reduce the amount of solar heat gain in cities. The effectiveness of so-called "cool surfaces" is measured by the fraction of solar radiation they reflect versus the fraction that they absorb and convert into heat (measured by solar reflectance or SR). Cool surfaces are also measured by how efficiently and quickly they shed heat. A surface absorbing solar radiation becomes hotter and releases some of that heat by conduction, convection, and radiation (measured by thermal emittance or TE). A cool urban surface is both highly reflective and highly thermally emissive to minimize the amount of solar radiation converted into heat and to maximize the amount of heat that is lost by the surface. However, solar reflectance is the predominant factor in determining whether a surface is cool. Figure 1 illustrates how sunlight is managed by different colored surfaces and the implications for building and community heat gain.

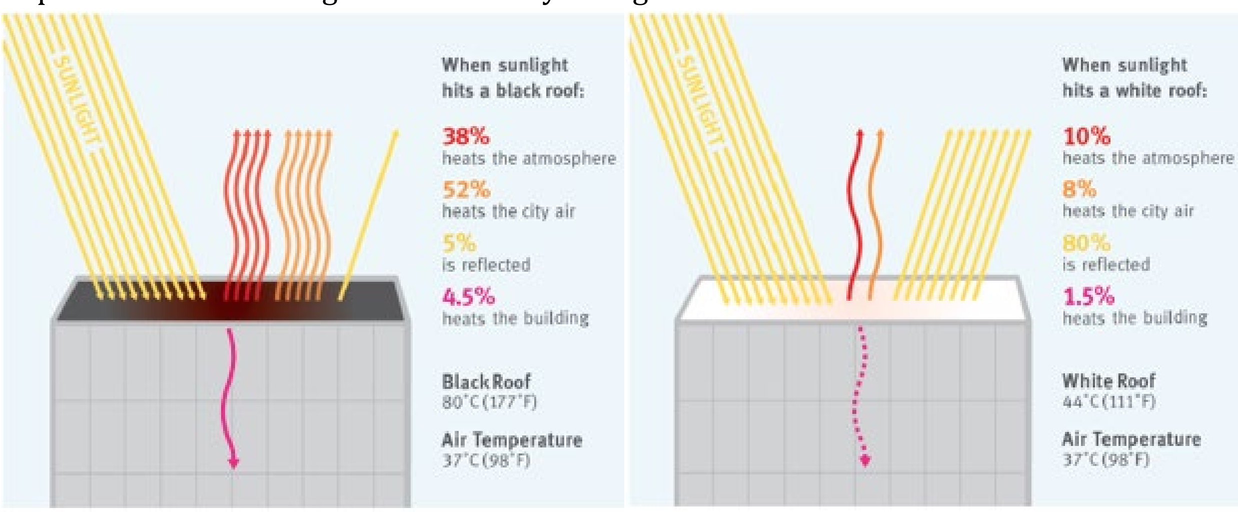


Figure 1 How solar energy interacts with dark and highly-reflective urban surfaces. Source: Lawrence Berkeley National Laboratory

Cool roofs

Measure	**Cool Roofs**
Cooling method	Cools by reducing the amount of solar energy absorbed by a building's roof
Benefits	· Net energy savings · Improved indoor thermal comfort · Air temperature reductions (at scale) · Global cooling
Considerations (effect)	· Net energy savings reduced by increased heating energy demand in very cold climates (minor) · Loss of some surface reflectivity over time (minor) · Potential for moisture build-up in cold climates (minor)
Economics	Cool roof installations generate a net economic benefit in all but the coldest climates. First costs for flat cool roofs are comparable to dark roofs. Slight first cost premium for steep slope cool roofs.
Applicable use cases	Cool roofs are globally applicable to all building types.
General Recommendation	Cool roofs should be encouraged/required as the minimum building standard.

Roofs typically make up 25% to 30% of an average city's urban surfaces[MB1] . Roofs may be either steep-sloped or nearly flat. There are a wide variety of highly reflective roofing products available today. As Figure 8 demonstrates, [MB2] there are now cool options for nearly every type of roof.

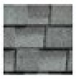
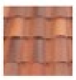
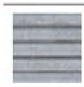
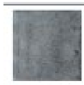
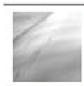
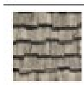
	Roof Type	Life Expectancy (years)	Roof Slope	Non-Cool Roof Options	Non-Cool Roof Solar Reflectance	Cool Roof Options	Cool Roof Solar Reflectance
	**Asphalt Shingle**	15 to 30	steep-sloped	black or dark brown with conventional pigments	0.05–0.15	"white" (actually light gray) or cool color shingle	0.25
	**Built-Up Roof**	10 to 30	low-sloped	with dark gravel	0.10–0.15	with white gravel	0.30–0.50
				with aluminum coating**	0.25–0.60	white smooth coating	0.75–0.85
	**Clay Tile**	50+	steep-sloped	dark color with conventional pigments	0.20	terracotta (unglazed red tile)	0.40
						color with cool pigments	0.40–0.60
						white	0.70
	**Concrete Tile**	30 to 50+	steep-sloped	dark color with conventional pigments	0.05–0.35	color with cool pigments	0.30–0.50
						white	0.70
	**Liquid Applied Coating**	5 to 20	low- or steep-sloped	smooth black	0.05	smooth white	0.70–0.85
	**Metal Roof** Uncoated corrugated metal is typically less durable than coated metal	20 to 50+	low- or steep-sloped	unpainted, corrugated**	0.30–0.50	white painted	0.55–0.70
				dark-painted corrugated	0.05–0.10	color with cool pigments	0.40–0.70
	**Modified Bitumen**	10 to 30	low-sloped	with mineral surface capsheet (SBS, APP)	0.10–0.20	white coating over a mineral surface (SBS, APP)	0.60–0.75
	**Single-Ply Membrane**	10 to 20	low-sloped	black (polyvinyl chloride (PVC) or ethylene propylene diene monomer rubber [EPDM])	0.05	white (PVC or EPDM)	0.70–0.80
						color with cool pigments	0.40–0.60
	**Wood Shake**	15 to 30	steep-sloped	painted dark color with conventional pigments	0.35–0.50	bare	0.40–0.55

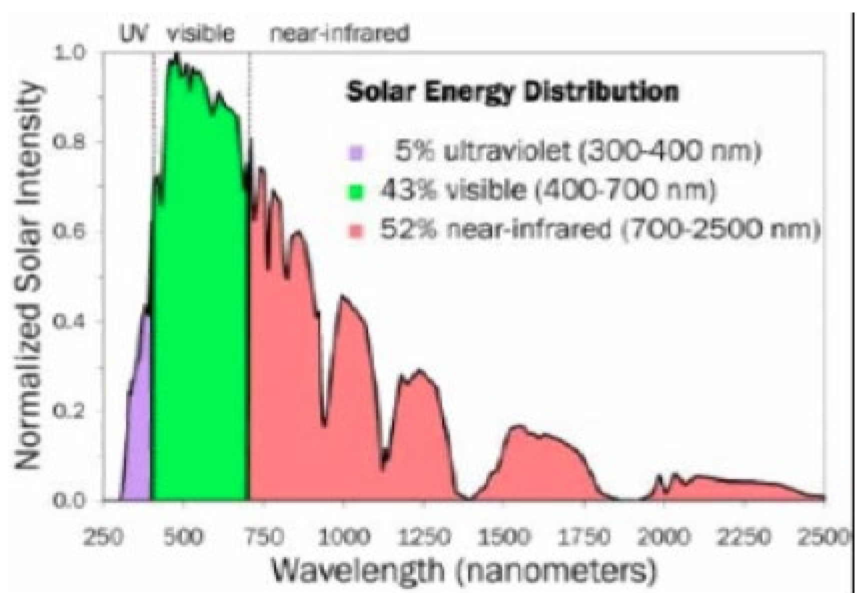
Figure 2 Common roof material options and their cool alternatives. Source: U.S. Department of Energy and Global Cool Cities Alliance

Most changes to roof solar reflectance will occur when making a decision to install a new roof or a replacement roof. At these times, it is much easier to design for and choose a cool option. There are also options to use coatings to increase the solar reflectance of an existing, functional roof. Coatings are typically applied to a functional roof to waterproof it or to extend its useful life. Table 3 highlights the coating options currently available and their strengths and weaknesses.

Coating	Strengths	Weaknesses
Acrylic	• Cost-effective • Good balance of cost to performance • UV resistant • Easy to apply	• Thickness loss with weathering • Applied and cure only above 10°C (day and night temp) • Poor in ponding water conditions
Elastomeric	• "Rubber" acrylic, but thicker and more flexible • Good for waterproofing	• Long cure in humid conditions • Applied and cure only above 10°C (day and night temp)
Polyurethane (aromatic base, aliphaltic top)	• Stays clean longer than most options • Durable and traffic resistant • Better with ponding water than acrylic	• More expensive than acrylic. • Noxious, potentially toxic gassing at application
Silicone	• Very durable and long lasting (25+ years) • Good in humid conditions and ponding water • Mold resistant	• Will remain dirty without rain/ washing • Cannot recoat over existing silicone • More expensive

Figure 3 Coating types and their characteristics

Cool surfaces are commonly created by lightening their color to reflect more solar energy in the visible spectrum (e.g., a white roof rather than a dark roof). However, slightly less than 50% of solar energy is contained in the visible spectrum.[i] The vast majority of the remaining solar energy is in the near infrared spectrum that is invisible to the naked eye (Figure 4). Certain technologies known as cool colors take advantage of that fact to allow colored surfaces (i.e., red, green, blue, grey) to be more highly reflective than traditional methods would allow.



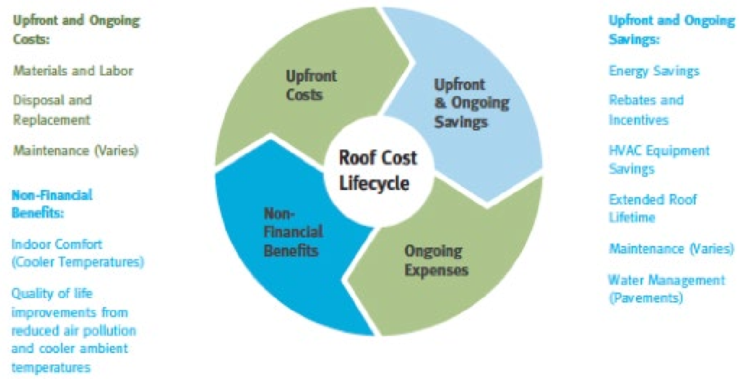
Cool colors are most often used on steep-sloped roofs, where the roof's aesthetics is more noticeable. Cool colored roofing products are available for conventional roofing materials such as tile, asphalt shingle, and steel. Figure 5 shows some examples of highly solar reflective color options.

Figure 5 Some cool reflective color options.

Cool roof economics

First cost premiums will vary, but highly reflective roof options are generally cost-competitive with traditional roofs.[MB4] The simple economic paybacks[1] of choosing highly reflective roof options range between 0 and 6 years based on building energy savings alone. The labor required to install cool roofs is about the same as for non-cool roofs. Other factors to consider when evaluating cost-effectiveness include changes in expected life of the roof, expected maintenance (i.e., regular roof inspections, repairs, or washing), roof material disposal, and replacement costs. For example, coating a functioning roof may have a high upfront cost but payback in energy savings, lengthened roof life, and other benefits. Figure 6 (above) illustrates some of the lifetime costs and benefits to consider when evaluating cool roofing installations.

To minimize cost premiums, the best time to install cool roofs is when a new roof will be installed or an existing roof needs to be replaced anyway. Repairs to an existing functional roof, especially when waterproofing, are also a cost-effective time to shift to a highly solar reflective roof.



Built-Up Roof	Mineral aggregate embedded in flood coat	Light-colored aggregate, like marble chips, gray slag	0.00
	Asphaltic emulsion	Field-applied coating on top of emulsion	0.80–1.50
	Mineral surfaced cap sheet	White mineral granules	0.50
Metal	Unpainted metal	May already be cool	0.00
		Factory-applied white paint	0.20
	Painted metal	Cool-colored paint	0.00–1.00+
Modified Bitumen	Mineral surface cap sheet	Factory-applied coating, white mineral granules	0.50
	Gravel surface in bitumen	Light colored gravel	0.00
	Metallic foil	May already be cool	0.00
		Field-applied coating	0.80–1.50
	Asphalt coating	Field-applied coating on top of asphaltic coating	0.80–1.50
Shingles	Mineral granules	White granules	0.00
		Cool-colored granules	0.35–0.75
Sprayed Polyurethane Foam	Liquid applied coating	Most coatings are already cool to protect the foam	0.00
	Aggregate	Light colored aggregate	0.00
Thermoplastic Membranes	White, colored, or dark surface	Choose a white or light colored surface	0.00
Thermoset Membranes	Dark membrane, not ballasted (adhered or mechanically attached)	Cool EPDM formulation	0.10–0.15
		Factory cool ply or coating on dark EPDM	0.50
Tiles	Non-reflective colors	Clay, slate (naturally cool)	0.00
		Cool colored coatings	0.00

Price Premiums for Cool Roofs on New Roofs (Premiums are the extra cost of installing the cool alternative)

Roof Materials	Typical Non-Cool Surface	Cool Alternative	Price Premium (US$ per ft²)
Built-Up Roof	Mineral aggregate embedded in flood coat	Light-colored aggregate, like marble chips, gray slag	0.00
	Asphaltic emulsion	Field-applied coating on top of emulsion	0.80–1.50
	Mineral surfaced cap sheet	White mineral granules	0.50
Metal	Unpainted metal	May already be cool	0.00
		Factory-applied white paint	0.20
	Painted metal	Cool-colored paint	0.00–1.00+
Modified Bitumen	Mineral surface cap sheet	Factory-applied coating, white mineral granules	0.50
	Gravel surface in bitumen	Light colored gravel	0.00
	Metallic foil	May already be cool	0.00
		Field-applied coating	0.80–1.50
	Asphalt coating	Field-applied coating on top of asphaltic coating	0.80–1.50
Shingles	Mineral granules	White granules	0.00
		Cool-colored granules	0.35–0.75
Sprayed Polyurethane Foam	Liquid applied coating	Most coatings are already cool to protect the foam	0.00
	Aggregate	Light colored aggregate	0.00
Thermoplastic Membranes	White, colored, or dark surface	Choose a white or light colored surface	0.00
Thermoset Membranes	Dark membrane, not ballasted (adhered or mechanically attached)	Cool EPDM formulation	0.10–0.15
		Factory cool ply or coating on dark EPDM	0.50
Tiles	Non-reflective colors	Clay, slate (naturally cool)	0.00
		Cool colored coatings	0.00

Figure 13 shows approximate cost premiums for cool products by roofing type in the U.S.. Prices are similar in other mature markets but please note that these costs will vary greatly in developing countries..

Cool roofs: Issues to consider

Winter heating penalty – Cool roofs may increase demand for building heating in the winter. With the exception of extremely cold/polar climates, the additional energy for heating demand in winter is more than offset by the cooling energy savings in the summer. A number of factors minimize the “winter heating penalty” of cool roofs in many cases.

- The sun is generally at a lower angle in winter months than it is in summer months, which means that solar radiation is less intense during the winter.

- In some areas, snow cover during the winter makes the underlying roof color irrelevant because it prevents sunlight from reaching the roof surface.
- Heating loads and expenditures are typically more pronounced in evenings and are not aligned with the daytime benefit of a darker roof in winter.
- Many commercial buildings have a high volume-to-surface-area ratio, so heat losses in winter are often fully offset by interior heat sources from human bodies, electric lighting, and office equipment. Occupancy patterns in some commercial buildings may be such that space cooling is used year-round and therefore reducing solar heat gain contributes to building energy savings year-round.

Changes in solar reflectance over time - The solar reflectance of roofs declines as they age, weather, and become soiled (i.e., a combination of accumulated soot, dust, salt, and, in some climates, mold and moss growth). Lowered solar reflectance performance reduces a roof's ability to reflect sunlight and increases the potential for heat transfer into buildings. The reduction in solar reflectance due to weathering and aging will vary based on the composition of the accumulated soil and precipitation patterns that help to wash the roof. In general, though, a roof may lose approximately 25% of its initial solar reflectance over the first 3 years after installation, with minimal additional loss in solar reflectance afterwards. Cool roof products have improved solar reflectance longevity by making products resistant to water (hydrophobic) and biological growth. Roofs may also be periodically washed to restore their solar reflectivity.

Condensation - Moisture from indoor air can condense within roof structures/systems. If allowed to accumulate over years, moisture could damage those materials and negatively affect the roof's durability and service life. In consistently hot and dry climates, there is little risk of moisture buildup. In winter months in cooler climates, all roof structures will develop some moisture that will then dry out in warmer summer months. This "self-drying principle" is a long-standing roof design feature. Without proper design and installation, both dark and cool roofs can accumulate moisture in colder climates. Highly solar reflective roofs maintain lower temperatures than dark roofs and will typically take longer to dry out over the course of an annual cycle than a dark roof. In all but the coldest climates, though, the cool roofs reach the same level of dryness as a dark roof over the course of a year.[xxxviii]

Effects of insulation – Both roof solar reflectance and insulation in the roof structure reduce heat flow into a building. The similarity in their effect on heat flows has, in some cases, led to policies that allowed increased surface solar reflectance to be traded off for lower insulation levels. Indeed, some building codes allow for a reduction in insulation levels when a solar reflective surface is installed. Recent research finds that insulation and surface reflectance are complementary, not substitute, solutions for building efficiency and comfort. Building heat flows during summertime are driven by roof surface color and heat flows during winter are correlated to insulation level.[xxxix]

Cool walls

Measure	Cool Walls
Cooling method	Cools by reducing the amount of solar energy absorbed by a building's walls.
Benefits	· Energy savings · Improved indoor thermal comfort · Air temperature reductions (at scale)
Considerations (effect)	· Increased solar energy reflected into neighboring buildings (minor) · Pedestrian thermal comfort (minor) · Aesthetics (minor)
Economics	Choosing lighter colored coatings will be cost neutral to dark color options. Dark colors that increase solar reflectance have some cost premiums, particularly in developing markets.
Applicable use cases	Cool walls are globally applicable to all building types. Additional analysis on effect recommended when buildings are close to each other and unshaded.
General Recommendation	Cool walls should be encouraged as the minimum building standard.

Cool walls are very similar to cool roofs but applied to vertical building surfaces. There are many cool-wall products available commercially and they tend to stay clean and reflective over time.[xxxx]

Cool walls mitigate urban heat islands like cool roofs. Simulations predict that increasing wall solar reflectance throughout Los Angeles County by 0.40[1] would lower daily average outside air temperature in the "urban canyon" between buildings by about 0.2 °C in July (a hot summer period). This is comparable to about 84% of the air temperature reduction provided by the same countywide increase in roof albedo.[xxxxi]

Cool wall economics
As with highly solar reflective roofs, there are cool alternatives for most wall material types, including metal cladding, vinyl siding and exterior paint. Based on the limited evidence currently available on cool wall products, color does not appear to affect price. Some advanced cool color technology does carry a cost premium, however. An estimate of cost premiums for dark, cool colors over traditional dark colors for California found substituting them for conventional dark paint colors would yield a median cost premium per liter of about $4, with a range between $0.50 to $16. Cool walls generate economic value by improving building energy efficiency. In warm United States climates, cool walls lowered annual energy costs by up to to $1.1/m^2 in single-family homes, up to $1.8/m^2 in medium offices, and up to $3.7/m^2 in stand-alone retail stores.[2] Energy cost savings would be more substantial in markets with higher energy costs.[xxxxii]

Cool walls: Things to Consider
Increased reflectance into neighboring buildings Cool walls reflect more sunlight between urban surfaces than dark walls, potentially leading to increased heat transfer. This effect may increase cooling load, decrease heating load, and reduce the need for artificial lighting in nearby buildings. The size of the effect will vary based on the solar reflectance of wall surfaces (both the wall reflecting the sunlight and the wall absorbing it) and the view factor between them. View factor is explained in the Urban Geometry section below.

Pedestrian thermal comfort. Walls are made more reflective to reduce building solar heat gain, but cool walls also affect the thermal environment of pedestrians by (a) increasing the solar radiation striking nearby pedestrians; (b) decreasing longwave (thermal infrared) radiation incident on the pedestrian; and (c) lowering the outside air temperature. The magnitude of these often opposing effects on pedestrians can be quantified by human comfort models, but research indicates that that the pedestrian thermal comfort change induced by raising wall solar reflectance is small.[xxxxiii]

Aesthetics. Because walls are highly visible, color choices will often be based on aesthetic preference over other benefits.

Laying a Solid Foundation for Cool City Policy

Awareness of excess heat as a critical resiliency challenge for cities is growing. Fortunately, the methods for cooling cities are well known and increasingly available across the globe. There are many examples of progress and good practice on urban heat mitigation—several of which are included as case studies in this handbook.

Still, implementing heat mitigation strategies presents unique challenges for city practitioners that has resulted in slower progress than the urgency of the heat problem dictates. The biggest obstacle to implementing urban heat mitigation measures is that there is no single entity within the city responsible for heat. Many different municipal departments may be affected by heat including agencies responsible for health, public works, water and electric utilities, parks, capital and budget planning, emergency response, building and zoning codes, and sustainability/resiliency strategy. Each department may address those challenges without looking beyond their own programs, resources, or budgets.

A systems approach to developing and implementing urban cooling policy and programs matches the uniquely cross-cutting nature of challenges and opportunities posed by excess urban heat. Integrating efforts across departments and agencies allows for community scale action with a mix of solutions optimized to mitigate heat. A systems approach requires a great deal more coordination and communication to be successful than an opportunistic, department by department, approach. Cities will also need inputs from relevant stakeholders such as academic institutions, the private sector, and local NGOs.[MB1]

Though it requires a significant commitment of time and effort to pursue, a systems approach to urban cooling is helpful to encourage coordinated planning for multiple hazards. Integrated hazard planning can uncover opportunities for heat mitigation strategies to serve multiple benefits, such as siting green infrastructure in areas prone to stormwater challenges. There are a number of steps cities can take to foster a systems approach to heat. These steps can be taken in any order, but each is an important part of developing popular, measurable, and successful urban cooling programs.

Identify existing local priorities and characterize how heat mitigation efforts could aid in achieving them. This exercise helps reframe the issue of heat in the context of existing issues that have stronger political influence and awareness within municipal government and the public at large. The effort to identify local priorities also helps to build communication and collaboration between government agencies. Often, city officials that deal most directly with excess heat have few resources and wield advisory power only. Though they take time to develop, a cohort of representatives from various agencies that understand and are willing to incorporate heat into their planning, targets, and budgets can drive substantial progress.

Evaluate existing city policies, programs, partnerships or research that could support or advance heat mitigation implementation and better understand the local potential of urban cooling strategies. This might include existing academic partnerships, major upcoming land developments, and building codes.

Singapore has also experienced a 1.1° C increase in temperature since 1972.[i] This warming is amplified by the urban heat island effect that can increase temperatures in urban zones by as much as 7° C as compared to nearby non-urban zones.[ii]

Measure the many aspects of urban cooling initiatives to track progress. Identify successes and areas for improvement and raising awareness within the community and beyond. Evaluate how existing policies that indirectly affect heat mitigation are measured and determine whether those metrics are relevant for tracking urban cooling. Identify new metrics that highlight the physical changes brought by successful urban cooling strategies (e.g., neighborhood air temperature reductions, vegetated cover changes over time, surface solar reflectance changes over time) as well as more "people-oriented" metrics that highlight the human effect of cooler cities (e.g., reduced emergency room visits, reduced mortality, improved air quality). The first step is establishing a baseline of data and performance for each metric. Cities should also identify resources needed to monitor changes in each metric over time (e.g., a network of weather monitors or reporting requirements for hospitals). Chart XX summarizes the types of data that are useful to collect.

	Data to Collect
Roofs and Walls	· Estimates of the percentage of surface area covered by roofs. · Total roof area by building type (e.g, commercial, residential, institutional, and municipal buildings) and roof type (e.g., flat and steep-sloped) · Characteristics of common building types including building height and window to wall ratios. · Existing building codes for roofs, walls, and insulation requirements · Estimated roof life of locally available products · Market share of local roof types and materials

Weather	· Average solar insolation (the amount of solar radiation energy received on a given surface in a given time, usually given in watts per meter squared) · Wind speeds and direction · Seasonal, annual, and peak rainfall · Maximum and minimum daily temperatures, cooling degree days, heating degree days, or average temperature by day for several years · Air quality · Frequency and intensity of extreme heat or extreme rain events.

Build local support and relevant stakeholders outside of municipal government. Engaging the local ecosystem of non-government actors such as community organizations, developers, contractors, hospitals, and foundations will bring important insight into policy development and program implementation. Early engagement also improves acceptance of new programs and makes it easier to raise public awareness. Promoting academic or scientific partnerships for cooler cities is of particular value. Technical partners significantly bolster the ability of municipal governments to gather and analyze data to understand where they are hot, where vulnerable populations live, and what combination of mitigation strategies perform best in a local context. Beyond helping to prioritize action on heat, this information is important for tracking progress and effects over time.

There is also a need to engage and coordinate with other levels of government. In some cities, new urban areas are outside municipal control but nevertheless have an effect on heat in areas that are under their control. Additionally, decisions on some policy options that support urban cooling, such as building codes, may be outside of municipal control and require collaborative effort to change.

Activity	**Questions to Ask**	**Actions**

Identify existing priorities	· Are urban cooling strategies a part of existing plans, codes, laws, regulations, or incentives? · To what extent have cool city materials been widely deployed in your region? · Are there any high-profile local examples?	· Identify existing climate, sustainability, or resiliency plans for your city/state/region. · Research existing building and energy codes, stormwater programs, and incentives. · Review existing aerial and satellite imagery to determine areas of excess surface heat, heat vulnerable populations, and penetration of cool city solutions.
Evaluate existing activities and potential	· Is there existing local research on heat mitigation and what institution produced it? · What types of buildings and pavements are common in your city? · What types of green spaces or parks exist? · What are the climate and weather characteristics? · What is the market availability of cool city solutions today?	· Identify weather and air quality data files as well as building construction and pavement characteristics. · Work with utilities/grid operators to secure energy use and pricing data and compare to temperature data. · Engage local contractors, distributors, and manufacturers to determine availability of heat mitigation measures. · Develop the economic case for cool surfaces.

Build local support and capacity	· How can cool city champions and stakeholders be identified and organized? · What are the relevant funding opportunities? · What existing resources and networks are available for technical support, training, and good practices? · What policies are within municipal control and which require other levels of government to pursue?	· Find supporters and attract funding. · Identify technical resources locally and globally. · Join or leverage existing memberships in city/regional organizations. · Develop local training and education programs[KS5] [DB6] .

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[1] An increase of 0.4 is roughly equivalent to changing from a black surface to a medium gray surface.
[2] Based on energy costs for Florida (warm, humid climate) and New Mexico (warm, desert climate). Residential electricity costs during the analysis period were between $0.12 and $0.13/kWh in both states. Commercial electricity costs were between $0.09 and $0.10/kWh.

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[1] Payback is defined as the amount of time it takes for benefits to equal costs

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[1] The effect of urban cooling strategies on human health is substantial but is decreasing as the use of electrical space cooling to keep buildings comfortable is increasing (though the effect on energy use has increased for the same reason).
[2] In this case, this is the payoff, in U.S. dollars, for $1 invested in each cooling strategy scenario.

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[i] Santamouris 2014
[ii] Santamouris 2014
[iii] Planting Healthy Air, TNC
[iv] Perera, E., Sanford, T., White-Newsome, J., Kalkstein, L., Vanos, J., and Weir, K. 2012. "Heat in the Heartland: 60 Years of Warming in the Midwest." Union of Concerned Scientists.
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[viii] Weather and the transmission of bacillary dysentery in Jinan, northern China: a time-series analysis. Zhang Y, Bi P, Hiller JE Public Health Rep. 2008 Jan-Feb; 123(1):61-6.
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