EPDM Roofing Association (ERA) Cool Roof Heat Island Effects Research Summary and Recommendations for Improving Study Methods

Overview

ERA members contracted ICF to conduct analysis of the ambient temperature impacts associated with urban heat island (UHI) effects, and their correlation (or lack of correlation) with the installation of commercial cool roofs. ICF conducted two separate analyses whose results have been compared to derive initial and generalized conclusions about the effects of cool roofs on UHI.

ICF researched empirical trends in ambient temperatures and analyzed corresponding changes in urban land surface color in those localities, to estimate the incremental effect of commercial roof solar reflectance on urban heat island. Inconclusive results in a first study led to the development of a second alternate analysis constructed with the same research objectives.

This memorandum summarizes the work conducted along with the research study outcomes and limitations, and submits primary observations learned from those works as a set of conclusions. Further it provides recommendations where additional research is needed to validate these initial findings across a spectrum of local conditions to draw more significant conclusions.

Analysis of Select Cities with Cool Roof Mandates

ICF analyzed ambient temperatures in three urban areas that have had cool roof mandates in place, compared to temperatures in three similar localities that have not imposed such mandates, and analyzed corresponding changes in urban land surface color in those localities, to estimate the incremental effect of commercial roof solar reflectance on urban heat island effects.

City Selection

Experimental and control city pairs were selected to enable the comparison of impacts between cities with and without cool roof mandates. They were also selected in consultation with ERA members. Selection considered year of cool roof mandate implementation and mandate coverage; availability and resolution of air temperature and GIS (geographic information system) data, both before and after mandate implementation; and climate conditions, including a city's international climate zone and microclimate, to moderate impacts confounding weather effects. The selected experimental (or mandate) cities and control city pairs were:

- New York City, NY (mandate city) and Newark, NJ
- Chicago, IL (mandate city) and Indianapolis, IN
- Washington, DC (mandate city) and Baltimore, MD

Development of Urban Heat Island Intensity

Local estimates of urban heat island intensity for a given location and year were determined as the slope of the average summertime maximum air temperature (or minimum air temperature in the case of nighttime UHIs) and urban density (defined as percentage of impervious area), for all weather stations in and around the urban location, and was necessarily dependent upon a reliable source of weather data and methods to differentiate and classify such weather data as urban or rural.

Air temperature data from NOAA (National Oceanic Atmospheric Administration) was determined to be appropriate for the analysis due to the availability at the national level and therefore scalability; quantity of weather stations; quality, completeness, and frequency of available air temperature data; and uniformity in station installation conditions, compared to alternative data sources reviewed. Use of NOAA weather station data was further supported by its use in the Climate Central study[1], which used same data to estimate daytime and nighttime urban heat island impacts for the 60 largest US cities, providing a point of comparison and industry benchmark for this work.

For each location, multiple weather stations were selected to include both the urban area and surrounding rural areas. An average of seven weather stations were selected per city and was determined by those with available and mostly complete air temperature data and located within a 20-mile radius of the respective city center. High-resolution GIS imagery was used to classify the selected weather stations according to their location urban density, defined by their relative make up of impervious surface. Statistical methods were used to determine UHI intensity as the slope of the regression, or best fit line that correlates air temperature to urban density, following a procedure similar to the methodology used in the Environmental Research Letters[2].

Land Cover Change Detection

Satellite imagery was used to assess the change in land use cover, within the geographical boundary of each experimental and control city pair, to estimate changes in white reflective roofing, related to the imposition of local cool roof ordinances. Land cover change detection was performed for each city pair for three time periods: the cool roof mandate year and four and eight years thereafter, to elicit a trend for comparison with the temporal urban heat island data.

Change detection was conducted first by selecting satellite imagery for each analysis year at a similar timeframe, and controlling for changes in cloud cover, by limiting cloud cover to less than 10%. Next by classifying raw satellite composite imagery such that imagery with high surface reflectance and lighter color impervious were classified as light-urban, representing

---

[1] The Climate Central study (2014) has been an impetus for concern over the effects of urban heat islands in many state and local jurisdictions. ICF followed their methodology for using maximum and minimum daily air temperatures.

[2] The Environmental Research Letters paper (2015) provided the methodology for measuring urban heat island intensity as slope of temperature difference and % impervious area using land surface temperature. ICF adapted their approach to this study using air temperature.

potential cool roofing, and accordingly assigning the remainder of imagery as vegetative, dark-urban, and water according to infrared color. Changes in commercial cool roofing where then determined by proxy from comparison of changes from dark-urban to light-urban between two time periods and presented as percent of urban environment.

Study Limitations

Although the study met the objective of developing a replicable and scalable framework to assess the relative role of commercial cool roofs on local urban heat islands, the initial study and its results were also influenced by limitations, some of which were outside of the analysis scope and others a consequence of available data or decisions made in conjunction with ERA members:

- **Control of confounding environmental factors** – Control of anthropogenic or other locally inducted environmental variables such as green/vegetative ordinances was considered but determined to not be a primary factor in this initial analysis, whose focus was on the viability of developing reasonable methods to estimate impacts from cool roofs.
- **Spatial separation between urban areas** – By design, experimental and control cities were located within the same climate zone, and to the extent possible, within the same region, to limit influences of climate or other weather related effects; however, the close proximity of megacity pairs such as Washington, DC and Baltimore (and more so for New York City and Newark) could lead to inconclusive results as the cities themselves essentially blend together and the market for commercial roofs may also be similar.

These limitations are implicitly included in both the analysis and its outcomes and are an artifact of collective and informed decisions made during the design process to best assess the impacts of cool roof on urban heat islands, by way of comparing experimental and control city pairs. And while some limitations may be binary and may be more easily controlled, others are variable and interactive, and controlling or isolating their impacts requires availability of high quality and temporal data and poses risk of introducing additional uncertainty and error into the analysis due to their interplay with the urban environment.

Study Results and Conclusions

The analysis resulted in no discernable correlation between the imposition of cool roof mandates and urban heat islands, when mandate cities were compared to similar cities without mandates. For example

- None of the three city pairs exhibited a relative reduction in daytime urban heat island intensity after the experimental city imposed a cool roof mandate
- Only one of three city pairs exhibited a relative reduction in nighttime urban heat island intensity after the experimental city imposed a cool roof mandate, and
- Three out of 12 cases (daytime and nighttime urban heat island intensity for each of the six cities) showed negative trend between UHI intensity and relative change in cool roof,

indicating an uncertain, or at best, a low and localized impact on UHIs from the imposition of cool roof mandates.

- Nighttime urban heat island for all for three city pairs was always positive and on average stronger when compared to daytime UHI that exhibited comparatively lower UHIs and negative UHIs for two of the six cities.

At a more basic level, the results, however, were statistically inconclusive primarily because of air temperature but also because of land surface data resolution-induced error.

Low correlations were observed between weather station air temperature and urban density, the two variables used to determine urban heat island intensity, and similarity for UHIs over the analysis period. The lack of correlation has several implications.

- Firstly, it suggests air temperatures recorded at weather stations are influenced primarily by local conditions, and to a lesser degree, if at all, by the nearby surrounding areas, implying a large number of highly controlled locational or gridded weather stations are needed to accurately assess average urban and rural temperatures needed for a geographical assessment.
- Secondly, that urban density alone is not a good proxy for air temperature as anthropogenic and environmental factors such as tailpipe emissions and power density as well as quality or color of impervious surfaces will also influence temperature.
- Finally, the margin of error in the temporal urban heat island intensity analysis is significant in most cases to negate any trends observed in UHI over the analysis period.

Quality and coverage of satellite imagery also contributed to inconclusive results but the impacts are not as obvious as the air temperature, which underpins the whole analysis.

- Satellite data was limited to 30-meter resolution and provided less granularity for classifying imagery, discerning between objects, and distinguishing between land surface colors than higher-resolution (0.5- and 1.0-meter resolution) data that is generally less available and more process intensive.
- And the broad geographical boundary assessed for changes in land surface color includes cool roofs as well as other land use changes. The implication is not obvious as the relative impacts proxied to cool roofs could be over- or understated depending upon how other areas within the city's landscape also change over time. Aside from New York City and Newark, which both experienced significant decreases in reflective and light-colored land area, all other urban areas experienced a significant increase from dark to light land area but also an increase in vegetated landscape, a known urban heat island mitigation strategy.
- Lack of notable trends directly relatable to the cool roofs can be attributed to the geographical area of coverage and satellite resolution; and could be a result of differences in cloud cover between selected satellite imagery, changes in urban land use other than

from cool roofs, or loss of reflectivity or darkening of white surfaces (including roofs) due to surface degradation or inadequate surface cleaning.

Inconclusive results, primarily driven by lack of an observed correlation between urban density and ambient temperature and between urban heat island intensity and the imposition of cool roof mandates, and limitations with the initial study, resulted in development of an alternate analysis construct.

Analysis of Select Cities with High UHI and High Amounts of White Roofing

Research objectives for the second analysis were similar to the first study – to assess the relative role of commercial cool roofs on local urban heat islands; however, the second analysis was designed to both improve analytical rigor and incorporate ERA members' comments. ICF proposed the use of higher resolution imagery to enable more rigorous analysis of the commercial zoning areas of interest, to yield results more meaningful to ERA members. And ERA members recommended reframing the analysis to evaluate changes in UHIs for a city unto itself to enable direct assessment of correlation between UHIs and cool roofs, and to limit the UHI analysis to the weather stations used in the Climate Central study so the results and impacts could be more easily contrasted with the accepted industry source.

To date, ICF has researched empirical ambient temperatures and has evaluated the availability of high-resolution imagery for Chicago, IL and Portland, OR, but has not proceeded with the GIS analysis portion of work.

City Selection

In collaboration with ERA members, Chicago, IL and Portland, OR were selected for analysis because their high amounts of white roofing and high urban heat islands make them both good candidates for evaluating whether there are perceptible effects from the installation of commercial cool roofs on local UHI. In addition, ICF's preliminary analysis of NOAA weather station and GIS data indicated both cities have high availability of local weather stations with complete data and high-resolution GIS data with building layers available for commercially zoned areas of interest. Satellite imagery availability for these cities also indicated they are good candidates, as initial assessments identified there to be a range of available data over several years.

Development of Urban Heat Islands

To address concerns about the accuracy of weather station data in the initial analysis, ICF proposed a more straightforward "urban vs rural" comparison following the methods used in the Climate Central study. In their analysis, the Climate Central research team measured daytime urban heat island as the temperature difference between the average daily maximum temperature of one urban and three averaged rural NOAA weather stations. The purpose of following the Climate Central study methods was to approximate the researchers' results for daytime and nighttime UHI. Such an approximation to an accepted industry benchmark would provide confidence in the air temperature UHI analysis, which was subject to statistical uncertainty in our previous analyses, before proceeding to the more resource intensive GIS analysis.

ICF strictly followed the Climate Central research team's stated methodology for selection of NOAA weather stations and analysis of ambient temperatures for developing estimates of urban heat islands, in attempt to loosely replicate the benchmark study's results. First, ICF selected one urban and three rural weather stations that met each of their stipulated weather station criteria (i.e., distance from city center, brightness index, population, and eco-terrestrial region). Second, maximum and minimum daily air temperature data available from the selected weather stations were used to, respectively, calculate daytime and nighttime UHI as the average daily temperature over the three-month summer period from June to August. And finally, we calculated the daytime UHI, for example, as the difference between the urban and rural average maximum daily temperature, where the rural average maximum daily temperature is the average of maximum daily temperature of the three rural weather stations. We used a similar process for calculating the nighttime UHI from the average minimum daily temperature over the same timeframe.

Chicago Temperature / UHI Analysis

Analysis of daytime urban heat islands for Chicago was conducted to determine whether Chicago remained a viable and useful city for conducting the broader UHI/cool roof analysis, given the degree of uncertainty in results observed using the UHI intensity methods of the first study.

In contrast to the first study, which exhibited a decreasing trend in urban heat island, an increasing trend in UHI was exhibited in this second study over the same 10-year period used in the Climate Central study, 2004 to 2013. On an annual basis, the daytime UHI varied from year to year with more years of negative UHI than years of positive UHI and was neither strong when present nor when compared to the daytime UHI reported in the Climate Central study[3]. For these reasons, the presence of daytime UHI in Chicago was determined to be inconclusive and not suitable as analyzed for the UHI/cool roof analysis.

Portland Air Temperature / UHI Analysis

Like the analysis for Chicago, ICF conducted an urban heat island analysis for Portland following the same methodology and was unable to replicate the UHI values presented in the Climate Central study. As a result, ICF simulated varying arrangements of urban and rural weather stations to understand the range of possible results and the probability of any such combination resulting in UHIs equal to their 10-year average reported values of 4.8°F daytime and 8.9°F nighttime.

Daytime urban heat island was found to not be strong (when present) when compared to results presented in the Climate Central study, and the results vary wildly according to weather station selection. UHI also varied according to the quantity of weather stations and selected time period.

---

[3] The Central Study reported at 2.2°F 10-year average daytime UHI. In contrast, our analysis resulted in a 10-year daytime UHI average of 0.11°F, with six of the 10 years having negative UHIs.

For example, the probability of UHI being greatest occurred when a fewer number of weather stations were analyzed over a shorter time period, compared to more moderate impacts of UHI found when multiple weather stations and longer time periods are averaged. In contrast, nighttime UHI tracked closer with the Climate Central study. Although the analysis was unable replicate their published values, nighttime UHI was found to be both strong and significant.

Figure 1 - Daytime UHI in Portland

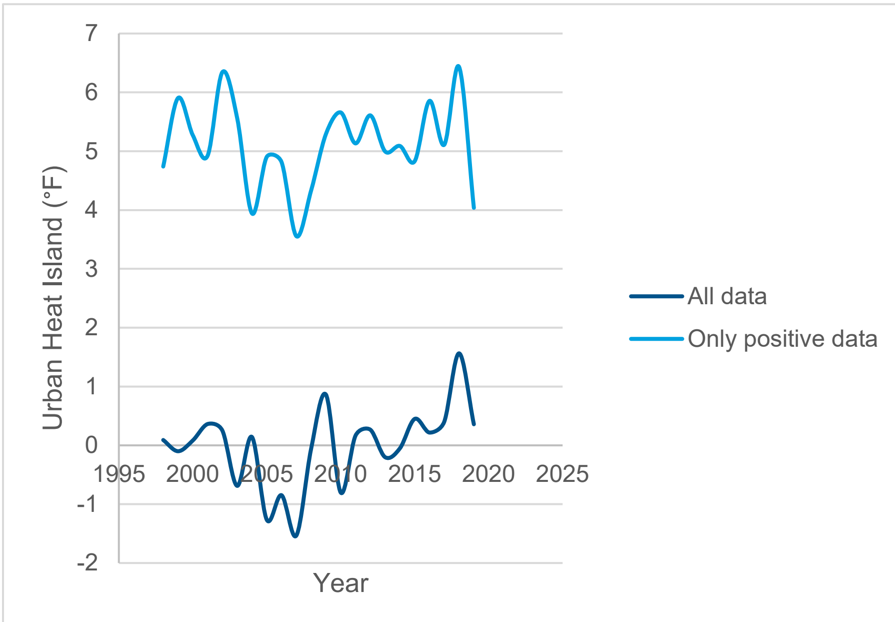
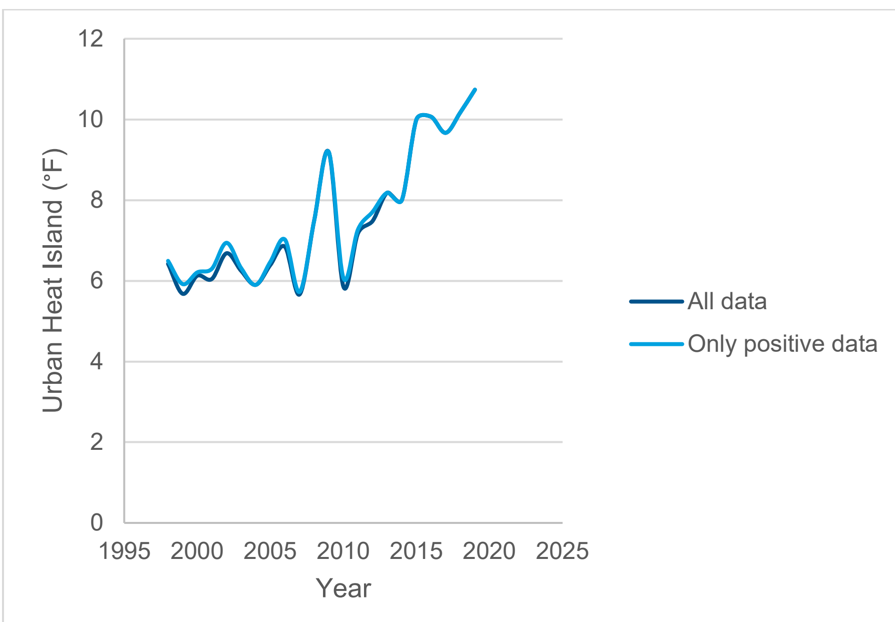


Figure 2 – Nighttime UHI in Portland



Interestingly, daytime and nighttime urban heat islands were found to be closest to those of the Climate Central study when all nonpositive UHI's were filtered from the dataset as illustrated in

Figure 1 and Figure 2; and if the Climate Central study did this, then its results would be, questionable, if not unjustifiable. This is not to say that there are no conditions that could exhibit similar or higher UHIs under different conditions, but rather the UHIs reported in their study could not be replicated when strictly following their criteria for selecting urban and rural weather stations and methods for air temperature analysis.

Other urban heat island studies were researched to validate Portland's findings. Our research found that while Portland does not have a significant amount of air temperature-based UHI analysis for comparison, the studies and data reviewed, including NOAA's Climate Explorer web-based resource and tool (which is based on same air-temperature data used in our analysis – albeit only through 1990), did not indicate the presence of significant UHI in Portland, in spite of the Climate Central study.

Study Limitations

Study limitations herein are related to conclusions that can be drawn from the analysis results due to environmental factors rather than study design.

- **Control of confounding environmental factors** – Two aspects common to the referenced cities are the prevalence of local ordinances and double-digit population growth, both of which have potentially interactive and/or confounding, but opposite impacts with urban heat island. Vegetative roof mandates and tree planting, for example, are complimentary UHI mitigation strategies to cool roofing ordinances. Counteracting those initiatives are the impacts from anthropogenic activities as a result of urban population growth. While the general effects of these strategies can be anticipated, they cannot not necessarily or easily be accounted for (e.g., quantified or removed from the analysis), using the current UHI/Cool Roof approach or data sources. While the impacts of complimentary UHI policies may moderate the impacts of population growth; after city selection, the best course of action to reduce potential bias is to select analysis periods that both cover significant installations of cool roofs and limit the change in environmental conditions from related UHI policies.
- **Representative weather stations** – While there is a sufficient quantity of available weather stations, the analysis is limited both by the geographic availability of those used in the Climate Central study, which consisted of those generally to the south that are in non-mountainous areas, the number of weather stations used in the Climate Central study, which is limited to one urban and three rural stations, and location of the weather stations. While the airport station has a high urban density, it is located close to a body of water (river) that may exert influence over the air temperature in a way that counters the analysis.

Based on the work conducted to date, these limitations which include potentially confounding environmental factors such as changes in anthropogenic activity, interrelated energy and climate policy mandates, and unequal exertion of local influences on weather stations conditions are seemingly common occurrences and; therefore, similar conditions are likely to be present within other cities of interest.

Study Results and Conclusions

Air temperature analyses conducted for Chicago and Portland for daytime urban heat islands were inconclusive because they resulted in considerably lower estimates of urban heat islands than presented in the Climate Central study, and the scenarios analyzed exhibited variable trends with uncertainty. As a result, for Portland, varying combinations of urban and rural weather stations were simulated to understand the range of possible results and the probability of any such combination resulting in UHIs equal to their 10-year average reported values. The analysis revealed

- Daytime urban heat island was found to not be strong (when present) when compared to results presented in the Climate Central study, and the results vary wildly according to weather station selection, likely due to local influences.
- Daytime urban heat island also varied according to the quantity of weather stations and selected time period. The probability of UHI being greatest occurred when a fewer number of weather stations were analyzed over a shorter period, compared to more moderate impacts of UHI found when multiple weather stations and longer time periods are averaged.
- Daytime urban heat islands, for Portland, approached the 10-year average UHI values in the Climate Central study only under a limited number of conditions that deviated from their stated weather station selection criteria and used shorter summertime analysis periods. For example,
  - Combinations of one urban and three rural weather stations and the option to use one or more summertime months resulted in a maximum daytime UHI was 4.25°F, with an average UHI of 0.64°F and 67% probability of the UHI being less than 1°F.
  - Combinations of one urban and two rural weather stations and one summertime month resulted in a maximum daytime UHI increased to 4.39°F, with an average UHI of 0.24°F and 70% probability of the UHI being less than 1°F.
  - And, combinations of one urban and one rural weather station and one summertime month, the maximum daytime UHI increased to 8.57°F (only 11 of 86 conditions were greater than zero), with an average UHI of 0.05°F and 80% probability of the UHI being less than 1°F.
- On a day-to-day basis, daytime urban heat island was highly variable with instances where consecutive days flipped between positive and negative UHI, suggesting local conditions may exert nonuniform influences on selected weather stations.

- Daytime urban heat islands were found to be closest to those reported in the Climate Central study when all nonpositive UHI's were filtered from the dataset.
- Nighttime urban heat islands in Portland, for example, tracked with the Climate Central study and was found to be both strong and significant with no nonpositive UHIs over the analysis period.

Our findings may be reasonable and accurate even if they contradict findings in the Climate Central study. According to EPA and urban heat island studies researched, UHI is often the strongest at nighttime because the built environment cools down and releases heat to the atmosphere much slower than the surrounding rural areas, and daytime UHI can even be negative as the rural landscape heats up faster than the urban environment. Similar impacts were noted in our analysis, where the daytime day-to-day UHI was highly variable with as many days exhibiting positive as negative UHI.

Because there is no standardized method for determining urban heat island, UHIs are contextual and based on the researchers' needs and objectives. While multiple definitions and methods are used by researchers to quantify UHI, we believe it is probable and reasonable to conclude that Chicago and Portland's daytime UHI (as determined through air-temperature analysis) is less pronounced than indicated in the Climate Central report when following their methodology, while the selective use of alternate stations under shorter summertime conditions can produce UHI in excess of their stated values. Even so, the Climate Central report provides the most detail of any urban heat island methodology of any air-temperature-based methods ICF reviewed and their general approach is supported by sound reasoning.

And while it is conceivable that even while following the Climate Central's stated methods that the analysis may have resulted in the selection of one or more different weather stations, it is possible that the calculated UHI differs significantly for reasons beyond the specific criteria the Climate Central study research team defined for selecting weather stations. Approximate replication of Portland's nighttime UHI supports this conclusion.

Overall Conclusions

Overall, the analysis produced varied results, leading one not to question the presence of direct and indirect impacts of the urban heat islands, but rather the methods used to define measurement of UHI that produces reasonably consistent results to fit the analysis construct and research objectives, and methods used to control or contextually account for environmental factors that can exert opposing forces on local UHI when evaluating ensuing results.

Because confidence in estimating UHI is central to the research, it is discussed first that:

- Daytime urban heat islands, the presumed metric for assessing the impacts of cool roofs on UHIs, were found to be less pronounced and more variable when compared to nighttime UHIs, which tend to be strong, significant, and always positive for conditions analyzed. Results of both studies support this general finding.

- Air temperatures recorded at weather stations tend to be influenced primarily by local conditions, and to a lesser degree, if at all, by the nearby surrounding areas. Variability in estimated UHI based on quantity and location of weather stations implies a larger number of highly controlled locational or gridded weather stations may allow for more accurately assessing average urban and rural temperatures.
- There is no standardized method for determining urban heat island, and while the Climate Central report's methods were found to be supported by sound reasoning, their daytime estimates of UHI could only be approximated when all nonpositive UHI values are omitted from the analysis and under a limited number of select alternate conditions that deviated from their methodology.
- Additional confidence in the strength and quality of daytime UHI calculations is needed before a similar GIS-based UHI/cool roof analysis can be conducted for the second study.

Methods used to control or contextually account for environmental factor are discussed below:

- Inconclusive results in the first study were also primarily driven by lack of an observed correlation between urban density and ambient temperature and lack of correlation between urban heat island intensity and the imposition of cool roof mandates. Three out of 12 cases showed negative trends between urban heat island and relative change in cool roof, indicating an uncertain, or at best a low and localized, impact on urban heat island from the imposition of cool roof mandates.
- Analysis results should be moderated with control of anthropogenic or other locally inducted environmental variables such as population growth, related tailpipe emissions and power density, and green/vegetative ordinances that coexist with cool roof mandates or penetration of cool roof installations can exert opposing forces on urban heat island should be investigated as part of the discourse.
- And, the quality and coverage of satellite imagery should be improved (as recommended for the second study) to account for differences in cloud cover between selected satellite imagery, changes in urban land use other than from cool roofs, or loss of reflectivity or darkening of white or cool roofs due to degradation or inadequate surface cleaning.

Recommendations for Additional Works

The recommendations below indicate where additional research may be warranted to draw more significant conclusions.

- Determine whether the use of nighttime rather than daytime urban heat island could reasonably be used to support the UHI/cool roof analysis, first by determining the capacitance of roofing systems and their ability to store and release heat at night, and second by replicating the nighttime UHI for at least three city locations to confirm the strength and significance.

- Assess the strength and significance of daytime UHI for the top 10 US cities with UHIs following the Climate Central study. Document the extent of daytime UHI compared to nighttime UHI and the probability of UHI being as prominent as indicated in the Climate Central study using alternate weather stations and summertime periods, including replications the analysis to confirm if they also match closest when nonpositive UHIs are filtered from the dataset.
- For each analyzed city, conduct limited research to indicatively assess the magnitude and timing of impact from other environmental factors that may influence urban heat islands over the analysis period. Such information would support interpreting and understanding observed UHI trends in the context of increased penetration of white or cool roofing.
- Conduct high-resolution GIS analysis evaluating building level changes in white roofing and nearby landscape changes in vegetation that may influence local urban heat islands.

END OF MEMO