



**Global Cool Cities Alliance**

**Fact-Check of Arizona State University’s *Unintended Consequences***

The Global Cool Cities Alliance worked with a group of experts to review the statements made in Arizona State University’s *Unintended Consequences*. Each entry includes a direct quote from the paper, followed by a detailed explanation for why the quote is in error.

The review covered the 10 pages of the white paper between the executive summary through Section 6. We identified close to 60 major problems covered in 53 entries below.

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**Executive Summary**

1. **What they said:** “Despite perceived benefits, this review demonstrates substantial unintended consequences associated with widespread implementation of reflective pavements, including the potential for increased cooling loads in adjacent buildings; increased heating demands during cold weather; roadway snow and ice buildup during winter months; reduction in precipitation, runoff, and soil water content; and adverse human health impacts.”

**What they got wrong:** Careful examination of the literature does not show most of these effects to be substantial. Reflective pavements may increase or decrease cooling loads in neighboring buildings, and will tend to reduce heating loads in



neighboring buildings. Annual cooling energy savings from lowered urban air temperatures typically outweigh annual heating energy penalties. Reduction in global water runoff (precipitation – evaporation) from a worldwide cool pavement campaign is estimated at less than 0.5%. Pedestrian thermal stress may increase or decrease, depending on wind speed and the use of light-colored clothing.

2. **What they said:** “Although the reduction in surface temperature of high-albedo roofs has been documented to reduce summertime building cooling energy requirements, no similar effect has been documented with regards to high-albedo pavements.”

**What they got wrong:** *The authors missed a large body of research.* A comprehensive, [publicly available](#) research review done for the Department of Energy found 26 references that addressed the use of cool pavement technology to mitigate urban heat islands. Further, the DOE review found that “nine studies examined the effects of albedo and other design parameters on lowering the ambient temperature and thus the associated energy savings, peak power and power related emissions...”.

3. **What they said:** “Well publicized simulations by Lawrence Berkeley National Laboratory infer that hundreds of billions of dollars in savings due to reduced cooling energy demands can be realized through the deployment of reflective pavements. A review of these simulations, however, identifies the use of unrealistic assumptions, and the findings have not been confirmed by other modeling efforts or field studies.”

**What they got wrong:** *The authors misquote the available research and do not support their claims about unrealistic assumptions.* The LBNL simulations estimated that cool pavements could reduce the annual U.S. air conditioning energy bill by hundreds of millions of dollars, not hundred of billions of dollars. Further, the authors have not demonstrated significant errors in these LBNL simulations of cooling energy savings, nor shown that they are contradicted by other peer-reviewed scientific studies.

4. **What they said:** “On the contrary, a number of field studies and modeling efforts have found that while there can be an effect on surface temperature, there is no discernible difference in above-surface air temperature over sizeable pavements with differing albedos.”

**What they got wrong:** The recently completed ASU field research has a number of



problems that make it impossible to draw conclusions about above surface air temperature. See [53] for a more detailed description.

## Introduction

5. **What they said:** “Due to its ability to offset greenhouse gases, as identified by Akbari et al. (2009), in 2010 the U.S. Department of Energy launched a cool roof initiative to facilitate reducing carbon emission and potentially slowing some possible precursors to climate change.”

**What they got wrong:** *The authors fail to mention the other reasons DOE launched a cool roof initiative.* According to its July 19, 2010 release, DOE initiated the cool roofs initiative to save energy, lower outside air temperature, improve air quality, and to offset warming due to atmospheric greenhouse gas.

6. **What they said:** “Over the past few years, the use of reflective pavement materials has been promoted as a potential mitigation strategy for the UHI effect.”

**What they got wrong:** *The authors understate how long cool pavements have been studied.* A quick review finds research on cooler pavements as far back as 1988.

7. **What they said:** “...a recent study from Lawrence Berkeley National Laboratory (LBNL) indicates that large-scale deployment of reflective roofs in urban areas can lead to a measurable increase in temperatures in surrounding rural areas at local and regional scales (Millstein and Menon, 2011).”

**What they got wrong:** *Authors overstate the conclusion of the cited paper.* The paper ran a high-albedo scenario where temperatures in small portions of rural Texas, Oklahoma, and Arkansas were slightly elevated due to modeled changes in precipitation and cloud cover. Increases in rural temperatures were not occurring in areas surrounding highly reflective cities. No temperature increases were found in any major urban area across the country.

8. **What they said:** “More recently, additional adverse effects, such as decreased precipitation at regional levels, are also reported (Bala and Nag, 2013; Doughty et al., 2011; Georgescu et al., 2012). Taking these adverse effects into consideration, large scale planning of reflective roofs needs a more comprehensive study and thorough assessment before its implementation...”.

**What they got wrong:** *The papers cited are addressing the impact of reflectivity*

***increases that are far greater than could be achieved by raising the reflectivity of every roof and pavement. The authors also incorrectly assume plant reflectivity and roof/pavement reflectivity are interchangeable.*** Bala and Nag (2013) enhanced cloud albedo over land to provide a global negative radiative forcing sufficient to counter global warming that would be impossible to achieve by increasing building and pavement modifications alone. To put it in perspective, the radiative forcing assumed in the paper is 66 times that assumed by Akbari et al. (2009) for cool roofs and cool pavements, and 165 times that assumed by Akbari et al. (2009) for cool pavement alone. The paper indicates that raising roof and pavement reflectivity is less than a tenth of the increase in reflectivity studied in this paper. Based on their findings, Bala and Nag (2012) implies that a global cool roof and pavement campaign would decrease global land-mean runoff (evaporation - by 0.3% or by 0.1% for a global cool pavement campaign.

Doughty (2011) finds that increases in crop albedo may decrease temperature above the 30<sup>th</sup> parallel and may increase it below the 30<sup>th</sup> parallel due to precipitation changes. Almost none of the U.S. is below the 30<sup>th</sup> parallel (small portions of southern Texas, Louisiana, and Florida). As with Bala and Nag, the global albedo increase assumed is several orders of magnitude greater than what could be achieved through urban reflectivity. Bala and Nag (2013) show the change in global reflectivity from changing crops is 50 times that of change roofs. Further, changing the reflectivity of a wet surface like a plant will have different impact on global runoff than changing the reflectivity of a typically dry surface like a roof or road.

Georgescu (2012) does not answer the question: "how does converting dark roofs to cool roofs alter the climate?" The paper is comparing (1) a scenario with lots of urbanization and use of cool roofs, with (2) a scenario WITHOUT urbanization. So, they are answering the question: "Can using cool roofs in an urbanized city (of the future) bring the climate back to the pre-urbanized climate?" This paper shows that cool roofs do not perfectly counter the effects of urbanization. Still, the overwhelming evidence indicates that cool roofs are better than dark roofs.

9. **What they said:** "Existing summaries of reflective roofs are largely limited to either site-specific field testing or general overviews, which do not compare between historical and recent work, let alone the results from large scale modeling (ARMA, 2011)."

**What they got wrong:** *The cited white paper does not support this conclusion. The authors neglected to mention or were not aware of a large number of studies that contradict this statement.* The authors cite a white paper on low



slope cool roofing by the Asphalt Roof Manufacturers Association that does not say anything about the state of urban heat island or cool roofing research. The Department of Energy published and widely publicized a nearly [200 page review of urban heat island research](#) in 2009 that contradicts the authors' assertion. Other similarly exhaustive literature reviews were published as part of recent peer-reviewed [research](#).

10. **What they said:** “Although the albedo of both pavement and roofing materials may act similarly in terms of generic physics, i.e., as reflectivity increases, the surface temperature of the material decreases, heat transfer mechanisms can be vastly different due to building interactions. For example, roofs reflect solar radiation mostly back toward space, while reflected radiation from roads and walls can be absorbed by urban facets due to “radiative trapping.” Therefore, it is essential to study reflective pavements and investigate their impacts on urban environment independently from roofing materials.”

**What they got wrong:** *The authors ignore 20 years of studies looking at the effect of buildings on reflected radiation.* For example, these peer-reviewed studies from [1997](#) and this one from [2013](#). As noted above, the DOE literature review presented 26 papers on cool pavements and their impact on the urban environment.

## Section 2: Potential Benefits of Cool Roofs and Pavements

11. **What they said:** This section claims that three studies (Akbari (2003), Akbari (2005), Wray and Akbari (2008)) that found energy savings as a result of increased roof reflectivity did not study energy savings during winter months and thus missed the winter heating penalty and are incomplete.

**What they got wrong:** *The authors cherry pick papers to make their point, omitting a number of studies that do look at winter conditions.* The paper fails to cite [Levinson and Akbari](#) (2011) that found that winter heating penalties exceeded cooling savings benefits in only in the very coldest parts of the US.

There are other studies ([this](#) and [this](#) to name a few) not cited by the authors that look specifically at winter heating penalty in northern climates and find them to be non-existent or lower than cooling energy savings.

12. **What they said:** “Cool roofs are defined by the Cool Roof Rating Council as a product with solar reflectivity ( $\rho$ ) at least 0.70 and infrared emissivity ( $\epsilon$ ) of at least



0.75.”

**What they got wrong:** *The Cool Roof Rating Council (CRRC) does not provide a definition of cool roofs.* CRRC provides the protocols to rate surface characteristics of any roof surface. Codes, ordinances, and programs define performance requirements to be “cool.” This is a relatively minor error but indicates a lack of familiarity with the reflective roof market the authors are critiquing.

13. **What they said:** “Further, Akbari et al. (2009) postulated that respectively increasing roof and pavement albedo an additional 0.25 and 0.15 across all urban areas on the Earth, could lead to a change in annual global radiative forcing (RF) of about  $-4.0 \times 10^7$  kW. This change is estimated to be equivalent to saving 44 Gt of CO<sub>2</sub> emissions annually, which is worth approximately \$1.1 trillion.”

**What they got wrong:** *Authors make two major errors in reporting the findings of the cited paper.* First, cited paper calculated a change in radiative forcing that is 500 times greater than what the authors claim. Second, Akbari estimated that widespread adoption cool roofs and pavements would have a one-time cooling impact equivalent to 44 Gt of CO<sub>2</sub> emissions, not annually.

14. **What they said:** “Although these types of findings and observations provide evidence of energy savings from the use of reflective roofs, the studies were all conducted during summer periods, thus heating penalty data was not collected.”

**What they got wrong:** The statement is false. Simulations of cool roof energy savings and estimations of global cooling are annual.

## Section 3: Major Limitations of Cool Roofs and Pavements

### Section 3.1: Roof Condensation

15. **What they said:** “Although not necessarily applicable to reflective pavements, when a roof’s albedo is increased, it also causes moisture accumulation and condensation problems under the roof.”

**What they got wrong:** *It is unclear why the authors included a section on roof condensation in a paper about cool pavements.* The authors’ caveat leaves open the possibility that roof condensation could have some applicability to pavements which seems absurd, to put it charitably.

16. **What they said:** “In warm regions like Phoenix, accumulated moisture from winter can dry during the summer with reflective roofs. However, in cool-to-cold regions,



numerical simulations show that reflective roofing material could increase water content in roofs more than 20% after 5 years (Bludau et al., 2009).”

**What they got wrong:** *Conclusion is not supported by the cited study and other research that contradicts authors’ conclusion is not mentioned.* Bludau et al 2009 modeled reflective and black roofs using conditions from 3 U.S. cities: Phoenix (defined by Bludau as “warm”), Chicago (“temperate”), and Anchorage (“cold”). In Chicago and Phoenix, more moisture was found under cool roofs than black roofs through the year. In Chicago, the white roof showed moisture content in the insulation of 17-23% compared to 10-15% for black roofs. *However, in Chicago and Phoenix, the cool roofs fully dried over the year.* The cold region in this paper is not representative of weather conditions in most areas.

Roofs that can fully dry in the summer months do not lead to long term moisture build up or structural roof damage. The Anchorage example (where a cool roof would almost never be deployed) was the only field site where long term moisture build-up occurred.

17. **What they said:** “A field study by Ennis and Kehrer (2011) also reports that condensation is only found on the back side of highly reflective membranes.”

**What they got wrong:** *The authors’ summary of the work omits key information, leading to a misleading conclusion.* The field study component of Ennis and Kehrer 2011 ONLY studied white roofs in climate zone 5 (cold climates) in winter. The field study did not include black roofs.

Ennis and Kehrer (2011) performed moisture simulations on both black and white roofs. Their models found that both black and white roofs dry out over the course of a year. As a worst-case scenario test, they also did a field sample of 10 reflective membranes with a single layer of insulation during the winter in locations in cold climates in Climate Zone 5 (upstate NY, for example). Three roof assemblies had some evidence of moisture. None showed damage.

18. **What they said:** “Condensation in roofing systems can lead to severe deterioration in metal roof decks, wet spots on the floor, mold growth on the rooftop, and ice build up in the lap seams, resulting in costly mitigation efforts (Hutchinson, 2008, 2009)”.

**What they got wrong:** *It is true that condensation causes these problems, but the studies cited do not isolate cool roofs as cause of the build up of condensation.* Most of the studies of roof failures identify a host of design and



installation problems that combine to cause moisture problems. It is not possible to conclude that reflective roofs are the cause of the moisture problem from these studies. In Hutchinson's more recent [work](#), he says "Today's cool-roofing materials have stabilized formulations and improved weathering packages and, for the most part, sufficiently address the physics of reduced thermal downward moisture drive and condensation."

### Section 3.2: Snow and Ice Build Up on Reflective Roofs and Pavements

19. **What they said:** "Besides condensation, a lower surface temperature of reflective roofs slows the melting of snow and ice, and makes a roof more susceptible to deeper snow, ice, and icicle formation (Carter and Stangl, 2012)."

**What they got wrong:** *The cited white paper conflates the effect of increased insulation and cool roofing.* Carter and Stangl (2012) is a building design guide that defines cool roofing as a combination of highly reflectance roof surfaces and increased insulation so it is impossible to assess which factor has the greatest impact. Snow is opaque at depths of 1 inch or more; snow covered roofs, no matter their underlying color, will have the same albedo. A bare dark roof will hold more energy on a sunny winter day than a bare white roof, but this extra energy does not actually melt that much snow. Roof color will affect snow melting once the roof surface is exposed, while insulation will reduce heat transfer from the building to the surface of the roof.

A recent [study](#) by found that rooftop snow significantly reduces annual heating penalties in cold climates.

20. **What they said:** "The buildup of snow and ice damages roof components and poses dangers to people working on roofs or walking below them (Ibrahim, 2013)."

**What they got wrong:** The authors are citing a blog post that provides no research or evidence that higher albedo roofs increase snow buildup.

### Section 3.3: Heating Penalty for Reflective Roofs and Pavements

21. **What they said:** "Taha et al. (1999) conducted simulations with a three-dimensional Eulerian mesoscale meteorological model (CSUMM) using DOE-2 to calculate energy loads. The predicted annual gas penalties in residential neighborhoods were 9.67 kWh/m<sup>2</sup> and in office areas were 5.86 kWh/m<sup>2</sup>."

**What they got wrong:** *The authors neglect to tell us what climate the simulation assumed.* It is impossible to talk about heating penalty figures without including





where the buildings are located. In general, this section of the paper takes the heating penalties out of context with the cooling energy savings, thus giving the impression that the heating penalties indicated are net energy balances. In fact, the vast majority of the research indicates that reflective roofs lead to significant net energy savings in buildings, even in heating energy-dominated climates.

22. **What they said:** “Bianchi et al. (2007) applied a numerical model (STAR) to address the impact of cool roofs and found an increase of 8.09% in heating penalty during winter.”

**What they got wrong:** *Again, the authors neglect to provide the climate assumptions for the model and neglect to provide the net energy impact.* The model in the cited paper assumes a roof in Sacramento with a reflectivity going from 0.55 to 0.7. The authors neglect to mention that cooling savings were 2.5 times higher than the heating penalty in this analysis.

23. **What they said:** “Modeling over 27 cities around the world with TRNSYS thermal simulation software, Synnefa et al. (2007) observed heating penalties in all cities up to 20 kWh/m<sup>2</sup>/year after the application of cool roof coatings.”

**What they got wrong:** *Again, the authors neglect to report the net energy balance of reflective roofs in the study.* The Synnefa found that cooling energy savings exceeded heating penalties in 26 of the 27 cities studied.

24. **What they said:** “According to the Commercial Buildings Energy Consumption Survey by U.S. Energy Information Administration (2003), heating accounts for 36% of commercial buildings’ annual energy consumption, while air conditioning only accounts for 8% in the United States. The U.S. Green Building Council (USGBC) also identifies that across the United States, more energy is consumed heating buildings than used to cool them (Enlink Geoenergy, 2012).”

**What they got wrong:** *Authors draw an incorrect and misleading conclusion from the cited analysis.* The fact that more energy is used to heat buildings than to cool them does not mean that cool roofs don’t create a net energy savings. As a standalone comment, this statement is accurate, however it is being used in a section to make an argument that cool roofs have winter heating energy penalties that exceed cooling energy savings. The authors confuse heating use as a percentage of total building energy use with net energy balance changes resulting from the installation of a cool roof.

25. **What they said:** “In climates with less than 1,000 cooling degree days (CDD), Akbari and Konopacki (2005) found that reflective surfaces, including reflective pavements, can negate any summertime electricity savings due to wintertime heating penalties.”

**What they got wrong:** *The authors are cherry-picking findings of the cited paper and thus draw an overly broad and inaccurate conclusion.* The paper looks at pre- and post-1980 residential, office, and retail net energy savings from UHI measures, assuming both gas and electric heat. Taking the least favorable scenario (residential building, electric heat), there is a very slight net energy increase for cool roofs below 1000 cooling degree days (CDD). For every other scenario, reflective roofs generate some net savings, even in climates with under 200 CDD (as a reference, Minneapolis has 600 CDD). In post-1980 office buildings with gas heat and 500 – 1000 CDD<sup>65F</sup>, the annual cooling primary energy savings were about 5 times greater than the annual heating primary energy penalty.

Heating/cooling degree days indicate the intensity of the annual heating/cooling demand in a location, as a function of how far the outdoor air temperature is below/above a “comfortable” temperature and how much of the year is spent below/above that threshold. But because these measures are based on outdoor air temperature and do not account for the sun’s ability to heat buildings, they can paint a misleading picture.

### 3.4 Reflected Solar Radiation

26. **What they said:** “Reflective pavements lead to greater reflected solar radiation, which can be absorbed by surrounding surfaces and subsequently increases their temperatures.”

**What they got wrong:** *The authors do not cite specific research.* Levinson (2007) found that raising pavement albedo can increase or decrease the temperature of near-ground surfaces, depending on the albedo of these surfaces, and the wind speed.

27. **What they said:** “Brender and Lindsey (2008) conducted experiments in Las Vegas and observed hotter interior temperatures (5°C at maximum) in the conduit over a white roof as compared to dark-colored roofs. Without proper design, this could result in serious overheating or even failure of electrical cables inside the conduit.”

**What they got wrong:** *The authors summary of the cited work is incomplete and misleading.* The conduits studied by Brender and Lindsey are bare metal. It is well known that bare metal gets very hot in the sun. The excess heat from solar



radiation could have been easily avoided by painting the bare metal conduit white. Brender and Lindsey found that conduit temperatures are elevated over both white and black roofs, with conduits over white slightly higher between 10AM – 4PM but the same or lower at other times. Maximum temperature difference does not appear to be higher than 5°C at any time.

28. **What they said:** “Ibrahim (2012) carried out a field study to explore the impact of roof color on ambient air temperatures and reported a significantly increased air temperature over a white-thermoplastic membrane roof.”

**What they got wrong:** *The authors do an inadequate job assessing the validity of the cited paper.* The authors accurately summarized the cited work but failed to identify fundamental flaws in survey design and implementation that are serious enough to debunk the paper’s conclusions.

Ibrahim (2012) purports to measure ambient air temperature above white and dark roofs. However, the study was not peer reviewed nor does it employ widely-accepted testing procedures (in this cases, by using unshielded temperature sensors). Using unshielded sensors means that the study actually measured the temperature of the sensor itself and not the surrounding air. (The sensor absorbs sunlight; the air does not.) Studies that use accepted testing procedures (for example, the [Akbari and Wray](#) paper cited earlier in *Unintended Consequences*) found reductions in air temperature above cool roofs versus dark roofs.

29. **What they said:** “Pierce (2012) pointed out that the temperature of the membrane below a highly reflective wall surface could be 20°C higher in extreme cases.”

**What they got wrong:** *The authors should make clearer that this is not based on a study.* Pierce 2012 is an industry white paper where this statement is made, but not supported by any specific study or anecdote. Further, in the limited cases where this phenomenon is possible, it would not heat up the whole whole roof but rather just a small section near the wall.

30. **What they said:** “And results of experiments by Li (2012, as part of the LBNL research effort on reflective pavements) implied that the temperature of the building wall would be heated up by the reflected energy from the pavement surface, which could be at maximum  $\approx 2$  to 5°C higher around noon. Subsequently, the increased temperature makes air conditioning units work harder, accelerates the heat aging of the membrane, damages surrounding building components, and causes heat discomfort for pedestrians.”

**What they got wrong:** *The authors do an inadequate job of describing the research.* Li's work is supported by UC Davis, not Lawrence Berkeley National Lab. Li studied wooden stud walls erected immediately adjacent to the pavement edge, a condition that is not common in real cities and communities. Lawns, landscaping, and sidewalks often separate walls from roads, reducing reflections from road to wall. No building simulations were undertaken as part of this work. [Yaghoobian and Kleissl](#) modeled this scenario for Phoenix AZ and found that reflected energy could make a difference in old, poorly insulated buildings with big, poor quality windows. It is a consideration, but not a big one for most locales.

Furthermore, increasing the amount of light in buildings improves natural daylighting and requires less artificial lighting to be used. This effect can at least partially offset increases in cooling energy from increased thermal loads, if any.

### Section 3.5: Health Risks

31. **What they said:** "High reflectivity from light-colored surface can increase the intensity of indirect ultraviolet (UV) radiation to people."

**What they got wrong:** *The authors provide no supporting citation for the link between color and UV reflectivity. Studies that contradict this statement have been omitted.* Nearly all nonmetallic surfaces, whether light or dark in color, have low UV reflectance (Levinson et al. 2007). The only important exceptions are bare cement concrete, whose UV reflectance is comparable to its albedo, and white ceramic, whose UV reflectance is about half its albedo. Cementitious pavement and envelope surfaces should be engineered to minimize UV reflection.

There is no evidence that white pigments reflects more than black. Indeed the ubiquitous white colorant titanium dioxide rutile strongly absorbs UV radiation. In fact, both white and colorless versions of this pigment are routinely incorporated in coatings to provide UV protection. Further, a study from LBNL detailing the reflectance of a common white pigment used in reflective roofing, shows that it is highly absorptive in the UV wavelengths. [Research from Auburn University](#) also contradicts the link between color and UV reflection.

32. **What they said:** "Therefore the amount of reflected radiation should be taken into consideration when planning for ground and building pavements, especially in schoolyards and playgrounds (CDCP, 2011)."

**What they got wrong:** *The cited paper does not support the authors assertion*



***that reflective pavement causes more UV radiation than a standard pavement.***

The cited document notes a modest difference in UV reflection between smooth and rough surfaces but makes no mention of color impacts.

33. **What they said:** "Reflection from light-colored surfaces can disturb occupants of taller neighboring buildings when applied to roofs (LBNL, online source), make pedestrians on nearby sidewalks suffer when applied to walls (Marvin, 2013) and provide less lane demarcation due to the poor visibility of white lines when applied to light-colored roads, potentially increasing driving risks (City of Chula Vista, 2012)."

**What they got wrong:** *The authors incorrectly compare the reflection from mirrored wall to a standard cool wall.* The presentation by Marvin (2013) did not quantify pedestrian comfort; it just noted that the highly polished ('mirror-like') metal outer walls of the Disney Concert Hall in Los Angeles reflected and focused sunlight on neighboring buildings and sidewalks. Cool walls are typically nonmetallic, and diffuse, rather than focus, reflected sunlight.

The Chula Vista study did not quantify the visibility of lane markings on light-colored roads; it just commented that white lines *might* be less visible on brightly colored pavements than on dark pavements.

### Section 3.6 Light Pollution

34. **What they said:** "With its high reflectivity, a high-albedo roof or pavement reflects not only radiation in daytime but also visible lights from artificial illumination at nighttime. In natural environments, stray and obtrusive lights at night, regardless of their purpose, are generally referred to as light pollution. Shaflik (2007) notes that 35% to 50% of all light pollution is estimated to be attributable to roadway lighting and that 95% of light directed toward pavements is reflected upwards at reflectance rates that range from 6% for asphalt to 25% for concrete."

**What they got wrong:** *The authors make a bad assumption that the same amount of artificial light would be used before and after installing reflective pavements.* Increasing the visible reflectance of adequately lit roads, parking lots, and walkways could reduce the need for artificial lighting (saving energy and money), rather than increase light pollution.

## Section 4: Potential Energy Cost Considerations

35. **What they said:** “Both cooling savings and heating penalties are widely accepted as consequences of reflective roofs. However, their relative magnitude, which serves as a crucial parameter in evaluating the performance of reflective roofs, is unclear.”

**What they got wrong:** *The authors are not aware of or neglected to mention a vast body of work that study both cooling and heating energy impacts of cool roofs.* Most studies that evaluate both the cooling energy savings and heating energy penalties of cool roofing also report net annual energy cost savings, net annual conditioning (heating + cooling) load savings, and/or the ratio of heating load penalty to cooling load savings (Some examples include: [Akbari et al. 1999](#); [Taha et al. 1999](#); [Synnefa et al. 2007](#); [Levinson and Akbari 2010](#); [Bhatia et al. 2011](#); [Boixo et al. 2012](#)).

36. **What they said:** “Contrary to LBNL’s work, several studies reported larger heating penalties than cooling savings. Matter (2008) pointed out that heating (29%) accounted for more energy consumed within a building than cooling (6%) based on the building energy data book and concluded that dark-colored membrane roof systems were at least 10% more energy efficient per year based on the DOEa 2 energy calculator.”

**What they got wrong:** *The authors are comparing apples and oranges.* Matter (2008) points out that, nationwide, buildings use more energy for heating than for cooling. That does not address or contradict LBNL’s finding that heating penalties rarely outweigh the cooling energy savings of reflective roofs.

Matter 2008 reported calculations of cool roof performance in West Virginia (WV) only. When this paper was written, commercial-sector electricity prices in WV were about 30% lower and commercial-sector natural gas prices were about 45% higher than in 2012. — the latest year with complete annual energy price data from the U.S. Energy Information Administration. With this energy pricing, Matter 2008 used the DOE Cool Roof Calculator to determine that the 20-year energy cost for a building with a white roof was about 10% higher than that of a comparable building with a black roof. Using 2012 EIA WV commercial-sector energy prices, the DOE Cool Roof Calculator predicts net annual energy cost *savings* in West Virginia.

37. **What they said:** “Reale (2009) illustrated that heating was a much more significant factor in energy usage than cooling through a comparison of heating degree days (HDD) and cooling degree days (CDD) at three major U.S. cities: Boston; Grand Rapids, Mich.; and Albuquerque, N.M.”



**What they got wrong:** *Heating and cooling degree days are not a valid way to measure whether cool roofs are appropriate for a given climate.* A common assumption is that reflective roofs are unsuitable wherever heating degree days exceed cooling degree days. Heating/cooling degree days indicate the intensity of the annual heating/cooling demand in a location, as a function of how far the outdoor air temperature is below/above a “comfortable” temperature and how much of the year is spent below/above that threshold. But because these measures are based on outdoor air temperature and do not account for the sun’s ability to heat buildings, they paint a misleading picture. To illustrate this point, consider a cool sunny day during which the outdoor temperature approaches, but never exceeds, the comfort threshold (meaning zero cooling degree days). The sun may nevertheless heat the building enough throughout the day to require air conditioning by late afternoon, and cooling degree days would then underestimate actual cooling energy use. Conversely, the sun’s heat on a cold sunny day may cause heating degree days to overstate the true demand for heating energy. This suggests that reflective roofs can save energy over the course of a year even if heating degree days exceed cooling degree days. This simple comparison is an unreliable rule of thumb for the suitability of reflective roofs.

Using 2012 EIA commercial-sector energy prices by state, the DOE Cool Roof Calculator predicts net annual energy cost savings in each of these cities.

38. **What they said:** “Though the program is validated and widely used by many professional societies and industry groups, DOE-2 is a single building-based model that neglects physical interactions between buildings and the surrounding microclimate in the built environment; the same premise holds for experiments discussed in the cool roof benefits section. With that being said, all conclusions drawn from DOE-2 simulations come with the implicit assumption that the impact of the surrounding environment and microclimate on building’s energy consumption is insignificant. However, this assumption is questionable.”

**What they got wrong:** DOE-2 was used to evaluate cool roof energy savings and penalties. Unless trapped between taller buildings, a roof sees mostly sky. For example, when buildings are of equal height, the view factor from one 5:12 pitched roof (slope 22°) to its neighbor is less than 2%.

39. **What they said:** “Therefore, energy cost estimation by DOE-2 simulations, without consideration of thermal interactions in the built environment, is suspicious and inadequate to support large scale deployment of reflective pavements; it requires further and more thorough investigations. This phenomena is supported by Lynn et al. (2009) who identifies that increasing pavement albedo is not a prudent UHI



mitigation strategy due to the roughness (multiple reflections) of typical cityscapes."

**What they got wrong: *The authors misrepresent the findings of the paper cited.***

Lynn et al simulated 3 UHI mitigation strategies in New York City: (1) planting trees on streets, (2) planting trees on grassy areas, and (3) raising the albedo of impervious surfaces (streets and roofs) by 0.35. They found that "The most effective strategy to reduce the surface radiometric and 2-m surface air temperatures was to increase the albedo of the city (impervious) surfaces." However, they also reported concern about increased thermal stress on a hypothetical pedestrian. "Perhaps the most pertinent result is that increasing the albedo of the street, while serving as an effective means for reducing surface air temperatures, increased the noontime thermal stress on a hypothetical individual at street level as the result of reflected solar radiation and emitted thermal radiation from below."

Thus, Lynn et al. (2009) confirmed that increasing roof and pavement albedo was an effective way to reduce 2 m surface air temperature, which is the basis of the 'indirect' energy savings reported in various LBNL studies (Rosenfeld et al. 1998; Taha et al. 1999). Furthermore, Lynn et al. (2009) may have overestimated the increase in pedestrian stress by using a 10m wind speed assumption.

40. **What they said:** "Yaghoobian et al. (2010) applied a three-dimensional heat transfer model (TUF3D) and found a substantial reduction in short-wave radiative heat transfer from ground to building by using low-albedo ground surfaces. This reduction leads to a consequent savings in the daily design cooling load of nearby buildings by 17% using low-albedo pavements."

**What they got wrong: *The authors incompletely describes the cited work and thus misses key details.*** The cited paper demonstrates the possibility for increased thermal loads on nearby buildings as a result of using more reflective pavement materials. However, the magnitude of this effect depends on many factors of building envelope design and urban geometry. This study only tests a single configuration with single values of urban canyon aspect ratio and wall-to-window ratio—performing simulations for a range of values of these parameters could show different results.

There are three points to take away from this study. First, reducing ground albedo heated the local air. Second, for the wall modeled (albedo 0.3), replacing grass with artificial turf minimally changed net radiation flux between ground and building. Third, replacing asphalt concrete pavement (albedo 0.18) by cement pavement (albedo 0.35) increased the wall's short-wave (solar) radiative heat gain by about twice as much as it decreased the wall's long-wave (thermal infrared)





radiative heat gain. This suggests that if the wall were painted a dull-white (albedo 0.65), then raising the pavement albedo would not change the net radiation flux from ground to wall.

Finally, and most importantly, increasing the influx of sunlight through windows can either increase or decrease a building's energy use, depending on how it changes demand for artificial lighting.

41. **What they said:** "Later in 2012, Yaghoobian and Kleissl (2012) adopted a three-dimensional building-to-canopy model (TUF-IOBES) to investigate the effects of reflective roofs on energy usage. Focusing on the physical interactions between buildings and surrounding microclimate in the urban canyon, the study found that increasing ground pavement solar reflectivity from 0.1 to 0.5 near a four-story office building (1,820 m<sup>2</sup> floor area, 47% window-to-wall ratio) in Phoenix would increase annual cooling loads up to 11% (33.1 kWh/m<sup>2</sup>). These results illustrate the potential of increased cooling loads in adjacent buildings by reflected solar radiation from high albedo reflective surfaces."

**What they got wrong:** It is worth noting that Yaghoobian and Keissl made two points clarifying their results in a press release after publication.

First, consequences of changing pavement albedo depend on building construction, location, and operation. "The worst-case scenario is when these new cooler pavements are used in office park settings with many mid-rise buildings with large window areas. The best-case scenario would be to use the new paving materials near buildings without windows; on roads or large parking lots that are not surrounded by buildings; or in warehouse districts where structures don't have air conditioning, Kleissl said."

Second, the reflected light entering the windows could actually reduce, rather than increase, the building's energy use. "A watt of daylight can replace up to two watts of fluorescent lighting, depending on the lighting needs of a building. In the best-case scenario, each watt of extra daylight could reduce lighting power demand by two watts. This would also decrease the building's heat gain by one watt (net), saving another third of a watt in cooling power. Further study is needed to quantify these potential savings."

42. **What they said:** "Additionally, Ryu and Baik (2012) identified heat radiating from building walls as having a greater impact on nighttime temperatures than heat radiating from horizontal surfaces. If reflective pavements add to heat storage in vertical surfaces, this effect would be intensified."



**What they got wrong:** *The authors misrepresent the findings of the cited paper.*

Ryu and Baik (2012) did not compare heat radiating from building walls to heat radiating from horizontal surfaces. Rather, they evaluated contributions to daytime and nighttime urban heat island intensities of (a) additional heat stored in vertical walls, (b) radiation trapping, and (c) wind speed reduction. They found that heat storage in vertical walls reduced the daytime UHI intensity, and increased the nighttime UHI intensity.

## Section 5: Large-Scale Impacts on the Environment

43. **What they said:** “However, a later simulation by Oleson et al. (2010) showed that reflective roofs increased winter interior heating more than they decreased summer air conditioning with respect to the global annual average.”

**What they got wrong:** *The authors omit key portions of the cited study’s conclusions.* Oleson et al. (2010) found that cool roofs yield a reduction in urban heat island nearly everywhere in nearly all seasons. It also identified a significant global cooling benefit by canceling the warming effect of atmospheric greenhouse gases.

Oleson et al. (2010) substantially underestimated global cooling energy savings and overestimated global heating energy penalties. First, they assumed that there was minimal use of air conditioning outside the United States by setting the cooling setpoint (the indoor air temperature above which air conditioning is activated) to 98 °F (37 °C) in the rest of the world. Second, they neglected internal heat sources, such as people, equipment, artificial lighting, and daylighting, and assumed that buildings are conditioned (heated or cooled) continuously (Oleson 2012). The result of the first assumption can be seen in Fig. 4 of Oleson et al. (2010), which shows no cool-roof cooling energy savings outside the US (no air conditioning means no cooling energy savings).

The second assumption substantially overestimates the cool-roof heating energy penalty, because (a) in the heating season, the daily accumulation of internally generated heat reduces, and often eliminates, heating demand in the afternoon; (b) cool roofs tend not to incur a heating penalty when the heating system is off, especially if the heating system will be off for many hours; and (c) nonresidential buildings, such as offices, are minimally heated at night, so a heating system turned off mid-day stays off until the following morning.

44. **What they said:** “Akbari et al. (2009) from LBNL investigated the possibility of offsetting global warming effect caused by CO<sub>2</sub> through large-scale deployment of reflective pavement materials. By increasing roof and pavement albedo respectively an additional 0.25 and 0.15 across all urban areas on the Earth, they estimated a change in global radiative forcing (RF) of about  $-4.0 \times 10^7$  kW using a conceptual Earth radiation balance model. Based on former studies and reports, Akbari et al. (2009) estimated an average RF change of 0.91 kW per tonne of CO<sub>2</sub> and adopted the European CO<sub>2</sub> price of \$25 per tonne for the economic calculation. Given these estimates, increasing the world wide urban albedo could offset about 44 Gt of CO<sub>2</sub> emissions annually, which is worth approximately \$1.1 trillion. Nevertheless, the fantastic savings demonstrated are dependent on unrealistic assumptions used in the study and are of great uncertainty.”

**What they got wrong:** As noted in [13] above, the authors incorrectly summarize Akbari 2009. To the point about unrealistic assumptions, Akbari 2009 includes an uncertainty analysis, concluding that the CO<sub>2</sub> offset could range from 30 to 100 Gt.

45. **What they said:** “First, shading effects by trees, adjacent buildings, and other sources are ignored. A limited analysis by Levinson et al. (2008) showed that shadows can reduce the annual incidence of sunlight on residential roofs by 10% to 25%. Although no similar studies were reported, this number is most likely to increase on pavement surfaces simply due to their lower elevations.”

**What they got wrong:** *Authors fail to cite research that contradicts their conclusion of pavement shading.* Levinson et al. (2008) is a conference paper presenting early results from the solar access study fully detailed in Levinson et al. (2009). Levinson et al. (2009) selected heavily treed residential neighborhoods in four California cities, and found that after at least 30 years of tree growth, rooftop light loss would be about 10% on a summer day, and about 25% on a winter day. (Shadows are longer in winter; also, to make the calculation of light availability conservative, the trees were assumed to keep their leaves in winter.)

A follow-up study by Rose and Levinson (2013) examining two of these four neighborhoods found that the solar access (i.e., the unshaded area) of roads was comparable to that of roofs. Since Levinson et al. (2009) and Rose and Levinson (2013) evaluated aggressive scenarios for shading, it is likely that roads are shaded well less than 10% in summer, and well less than 25% in winter.

46. **What they said:** “Moreover, the estimation of RF change by increasing urban albedo is inaccurate. Using the Earth radiation balance model, the increase in urban albedo is converted to equivalent global albedo change before calculation. This conversion



is not reliable as meteorological and geographical conditions are vastly different on the Earth's surface. Factors such as cloud cover, elevation, and especially aerosols over cities play an important role in determining RF change; these conditions need to be accounted for to ensure a better estimation. Third, complex mechanisms and various assumptions of atmospheric modeling lead to great uncertainties and potential errors in model results. Therefore the RF change of CO<sub>2</sub> per tonne used in this study is highly sensitive and varies within a wide range.”

**What they got wrong:** *Authors fail to cite studies that address this issue.* As noted above, Akbari 2009 included a sensitivity analysis. Further, a more recent [paper](#) addresses these issues.

47. **What they said:** “Millstein and Menon (2011) employed a regional atmospheric model (WRF) with a fully coupled representation of land-surface and atmospheric system to investigate the regional climate impact of large-scale cool roof deployment. They found that the adoption of cool roofs and pavements over the continental U.S. decreased afternoon summertime temperatures in urban locations but increased temperatures at some rural areas by up to 0.27°C. The increased temperature was associated with lower soil moisture, fewer or thinner clouds, and less precipitation.”

**What they get wrong:** *The authors fail to mention important details of the cited paper to make their point.* Please see [7] for a detailed explanation.

48. **What they said:** “The reduction of cloud formation and precipitation has been observed by other researchers. Doughty et al. (2011) concluded that increased agricultural albedo over land interfered with and decreased cloud formation and precipitation at low latitudes from the Community Atmosphere Model (CAM 3.0) coupled with the Community Land Model (CLM 3.0).”

**What they got wrong:** *Authors incorrectly equate agricultural albedo and roof/pavement albedo.* Increasing agricultural albedo is not a useful analog to increasing urban albedo. First, there is much more land area devoted to agriculture than to cities. Second, while plant evapotranspiration varies with temperature, roofs and pavements are usually dry. Thus, cooling their surfaces does not significantly affect regional evaporation.

49. **What they said:** “Bala and Nag (2012) reported a significant decrease in global land-mean precipitation (13.38%), runoff (22.31%), and soil water content due to albedo increase over land using an atmospheric general circulation model (NCAR CAM 3.1) coupled with a slab ocean model.”



**What they got wrong:** A detailed description is included in [8] above.

**50. What they said:** “Georgescu et al. (2012) indicated that implementation of cool roofs reduced evapotranspiration throughout the calendar year and decreased accumulated precipitation by 4% in maximum Sun Corridor expansion scenario using WRF.”

**What they got wrong:** The Sun Corridor is a unique region and should not be taken as representative of the effects of cool roofs. For example, the Sun Corridor is drier, hotter, and has less vegetation than many other regions in the country; its annual pattern of precipitation is also unusual.

**51. What they said:** “Jacobson and Ten Hoeve (2012) concluded that there is localized cooling but overall global warming for reflective roofs.”

**What they get wrong:** *Authors fail to mention that cited study refers to global warming finding as “highly uncertain.”* Jacobson and Ten Hoeve’s findings indicate a tiny and highly uncertain increase in global warming as a result of higher reflectivity. Jacobson and Ten Hoeve also state that the uncertainty range associated with their results—that the urban heat island effect contributes 2-4% of gross global warming—may likely be larger than the model range presented.

The authors also neglect to mention the many studies that support the global cooling potential of reflective surfaces. The vast majority of research currently available on the global warming impacts of cool roofs, undertaken by scientists from around the world, indicates that reflected sunlight from cool roofs has a net global cooling effect. Even the studies that produce the most negative results for cool roofs global impact acknowledge their ability to reduce urban heat islands and note that global findings are highly uncertain.

Lawrence Berkeley National Lab published a [detailed response](#) to Jacobson and Ten Hoeve.

**52. What they said:** “With better simulation of interaction and feedbacks between land and atmosphere, these studies illustrate that large-scale installation of reflective roofs and pavements will lead to serious unintended consequences in local and regional hydroclimate.”

**What they got wrong:** *The papers presented do not indicate that reflective surfaces have serious consequences in local and regional hydroclimates.* The



statement “serious unintended consequences” is inadequately defined and misleading. For example, the potential changes to the land surface from cool roofs and pavements are negligible compared with land surface changes already incurred from the widespread conversion of undeveloped lands to agriculture and urban areas. The potential reductions in average temperatures in cities from the adoption of cool roofs and pavements ( $\sim 0.5^\circ\text{C}$ ) is the same magnitude of warming that has been observed globally from  $\sim 1950$  through today, and much smaller than the expected warming over this next century. When increasing urban albedo with cool roofs and pavements, the potential increases to temperature in isolated rural areas due to complex relationships between city surface characteristics and meteorological patterns are again even smaller ( $\sim 0.25^\circ\text{C}$ ). It is unclear how one would define these unanticipated changes as “serious.”

There is general agreement that cool roofs can reduce building energy use. There is general agreement that cool roofs and pavements can potentially provide local cooling to many urban areas. There is continuing research into the potential for global adoption of cool roofs and pavements to provide climate benefits, but it is likely that the marginal installation of a cool roof or pavement would increase the amount of solar radiation reflected to space thus providing some marginal climate benefit. One would be hard pressed to define any potential unintentional effect from brightening urban areas as “serious” when compared to meteorological changes that have already occurred due to agricultural and urban development (or when compared to global climate change).

## Section 6: Field Studies Indicate Reflective Pavements Have Little Impact on Air Temperatures

53. **What they said:** Authors summarize findings from their own field study of various pavement options. Findings indicate large differences in surface temperature but no small differences in air temperatures at a height of 5 feet.

**What they got wrong:** *The test methodology is insufficient to draw conclusions about air temperatures above cool pavements.* There are several problems with this work, which is not yet peer reviewed. The test beds, at 4 square meters each, are far too small to cause a temperature change at a height of 5 feet. Thus, the observation that the small plots did not affect air temperature at 5 feet is correct, but the conclusion that pavement does not affect air temperature at 5 feet is unfounded. Surface temperature readings did find that high albedo pavements were cooler than low albedo pavements.



It is also curious that the study's authors chose to present data gathered in December, rather than in summer when temperature differences between pavements would be greater.

Please contact Kurt Shickman ([kurt at globalcoolcities.org](mailto:kurt@globalcoolcities.org)) if you have any questions.