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Jeremiah M. Steuterman
Pomona College

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Cool Roofs at Pomona College

Jeremiah Maloney Steuterman

In partial fulfillment of a Bachelor of Arts Degree in Environmental Analysis,
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Readers:
Char Miller
Richard Elderkin

Introduction

Energy efficiency is a hot topic as our society faces rising energy costs and dwindling resources in a system built on consumption. Buildings are some of the most notable consumers of energy, accounting for 40% of energy consumption in the US. In order to improve the energy efficiency of buildings there are a multitude of different products and designs that promise substantial improvements over traditional designs. An option to save energy is the application of a cool roof, which seeks to improve the reflection of solar radiation and minimize heat transfer into the building. The intention of this report is to investigate potential applications of cool roofs at Pomona College and the possible reduction in energy use due to increased solar reflectivity.

Cool roofs are used to address two prevalent environmental concerns: high cooling loads and Urban Heat Islands. These two problems are linked and exhibit the potential micro and mesoscale benefits of reducing roof surface temperature. By decreasing heat transfer across the building envelope cool roofs can limit strain on air conditioning units and reduce cooling costs. If applied on a large enough scale cool roofs can decrease the ambient air temperature and energy consumption of whole cities.

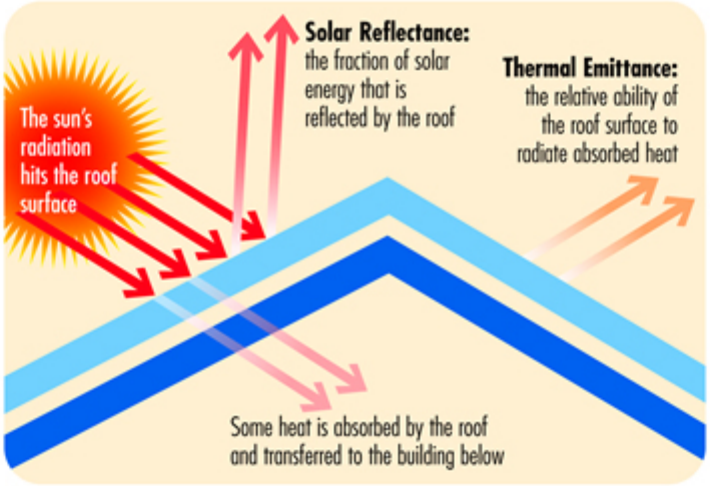
First in this report is a discussion of how a cool roof modifies the building envelope in order to improve energy efficiency. This includes information on the properties of cool roofs and on the relative merits of the available cool roofing products. It is important to recognize that cool roofs modify a small feature of the roof and that energy efficiency depends on much more than just the reflectivity of a roof. It is for this reason that a discussion of the relative energy efficiencies of different roofing materials is considered. Cool roofs are part of a larger set of strategies to improve energy efficiency and lower urban temperature, and so a synopsis of other possible solutions is provided. In order to understand the larger implications of cool roofs beyond individual energy savings the Urban Heat Island is briefly discussed. A central tenet of environmentalism is that solutions need to account for variations in local environments, and so this report addresses how cool roofs function in the arid Southern California climate and what large-scale application could mean for LA. Finally this report relates this issue of roof reflectivity back to Pomona College and discusses the current effect of roof reflectivity on building energy use and how this could be affected by reflective coatings.

The roofs of Pomona College are already fairly energy efficient due to the natural thermal properties of clay tile (which covers most college roofs). However there are a few flat roofs on campus that could be improved with the addition of a reflective coating. Energy cost reductions from reflective coatings are not so large that roof resurfacing should happen ahead of regular maintenance schedules, but as roof surfaces are replaced energy benefits could be gained from applying reflective coatings. College buildings that could gain the most from reflective coatings are Oldenborg, Thatcher Music Building, and Frary Dining Hall. These three buildings have standard low reflectivity flat roofs and could see significant reduction in cooling loads from being retrofitted with a cool roof.

Properties of Cool Roofs

The two factors that most affect the performance of a cool roof are solar reflectivity and thermal emissivity (Fig 1). Reflectivity affects how much radiation is absorbed by a surface, and so the amount of heat that is released. Reflectivity is the fraction of incident radiation reflected by a surface and is a function of the incident direction, reflected direction, and the incident wavelength. The difference between reflectivity and reflectance is that reflectivity refers to thick objects, whereas reflectance is used when referring to interactions across a thin surface. Reflectivity is the limit of reflectance as the surface thickens and the affect of the underlying layer is minimized. Reflectivity is inherent to a particular material and varies across different materials. When discussing reflectivity of a surface the concept of albedo is used to describe the diffuse reflectivity or reflecting power of a surface. It is a numeric value between 0 for a black surface that reflects no light and 1 for a perfectly reflecting white surface. The albedo of a surface typically depends on the frequency of the radiation, and generally is calculated across the spectrum of visible light.

The thermal emissivity of a material is also important when considering the effect of solar radiation on cooling loads. It is defined as the spectrum-dependent tendency of a material to release absorbed heat back into the atmosphere. For example a reflective metal roof reflects a lot of radiation, but has low thermal emissivity and builds up absorbed heat energy as opposed to releasing it into the atmosphere. Thermal emittance is calculated in watts per square meter from emissivity and temperature. Both reflectance and thermal emissivity must be considered when trying to affect the cooling load of a building. These two measurements have been combined by the Solar Reflectance Index, which quantifies both values relative to standard black at 0 and standard white at 1.



(Fig 1) Both solar reflectance and thermal emittance must be considered when designing a cool roof system.[1]

Extensive research has been done demonstrating the potential energy savings of cool roofs. In order to fully document the effect of high albedo roofing on a building, scientists with the Heat Island Project monitored peak power and cooling energy use for three buildings in Sacramento, California that had been treated with high albedo coatings (increase to albedo of .77 from .18).[2] The researchers made measurements of the microclimate and energy use of three sample buildings (one house and two school bungalows). They found a seasonal energy savings of 2.2 kWh/d (80% of base case use)

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[1] http://www.coolroofs.org/images/Diagram_1_002.jpg

[2] Akbari, Hashem, Sarah Bretz, Dan M. Kurn, and James Hanford. "Peak Power and Cooling Energy Savings of High-albedo Roofs." *Energy and Buildings* 25.17 (1997). pg 121. Web.

for the house and 3.1 kWh/d (35%) for the school buildings. In both building types the peak power demand was reduced by 6 kW. This study tested the effect of a standard white high albedo covering, but there are other ways to improve roof albedo.

Different Roof Types

The roofing material used for a particular project can determine to a large extent the energy efficiency of the future building. Roofs are first subdivided into flat and sloped roofs. Flat roof coatings all involve layering of water protective membranes and asphalt to prevent leakage into the building. Sloped roofs vary much more widely in materials, including clay, concrete, slate, and wood to name a few. Cool coatings are not immediately applicable to all roof surfaces, though many roofing products have high reflectivity options.

A flat roof is typically laid over a concrete deck and covered with a continuous membrane. There are three main types of flat roof and all are seen on Pomona's campus. A flat roof is typically covered with either: alternating layers of bitumen and felt which is then covered with loose gravel (a built up roof), a liquid applied membrane (spray-on or roll-on flexible coatings), or a single ply membrane of modified bitumen or some other polymer. Built up roofs (asphalt layered with water protective membrane) account for 5% of residential roofs and 30% of commercial roof surfaces.[3] All of these have similar construction, but there is still variation that could affect relative gains from a reflective coating. Gravel roofs are common among the flat roofs at Pomona and research shows that improving the albedo of a typical flat gravel roof can decrease energy use by 15 %.[4] All of these roofing types have reflective options that can be considered when resurfacing. Asphalt roofs are the least energy efficient, and therefore have the most to gain from an increase in albedo.

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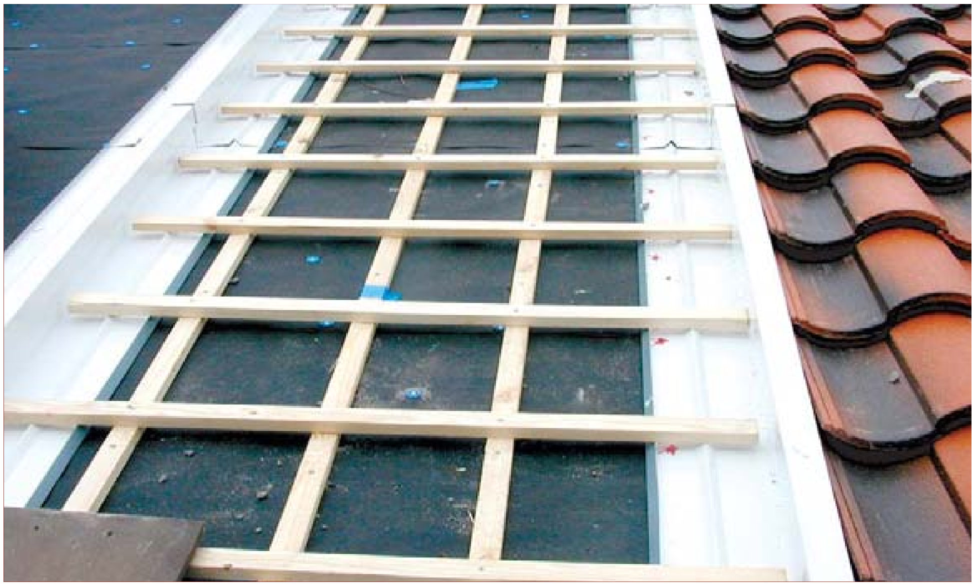
[3] Bretz, Sarah, Hashem Akbari, and Arthur Rosenfeld. "Practical Issues for Using Solar-Reflective Materials to Mitigate Urban Heat Islands" *Atmospheric Environment* 32.1 pg 95. Web.

[4] Rosenfeld, Arthur H, Hashem Akbari, Sarah Bretz, Beth L. Fishman, Dan M. Kurn, David Sailor, and Haider Taha. "Mitigation of Urban Heat Islands: Materials, Utility Programs, Updates" *Energy and Buildings* 22 (1995). pg 256. Web.

The energy efficiency of sloped roofs can also vary depending on the materials used. Concrete tile is a common roofing material and is often used because it is inexpensive, durable, and people like the look. The efficiency of concrete tile can be improved by increasing ventilation under tiles, installing a radiant barrier, and applying a reflective pigment coating. Ventilation can be improved by installing either a single batten or double batten system to elevate the tiles above the roof surface (Fig 2). This essentially supports the tiles on top of a lattice of 1" by 2" boards. The efficiency of tile can also be improved by installing a radiant barrier, which is a low emissivity metallic barrier (aluminum foil) that absorbs radiation in an open space. The radiative resistance of a building without a radiant barrier will be much lower and so the heat flux through the roof will be higher. A third common option is clay tile, which is present on most Pomona roofs. Clay has a fairly low thermal conductance of 0.52 WK/m and a high emissivity of 0.91.[5] These properties, along with the thickness of clay tiles, ensure the slow transfer of heat across the tiles. Figure 3 below compares the daily temperature profile for these three roofing materials, along with the relative effects of improved ventilation and a radiant barrier.



(Fig 2) This is an example of a batten and counter-batten system (also called a double batten system) used to improve ventilation under tiles. A single batten system would comprise of only the vertical members.

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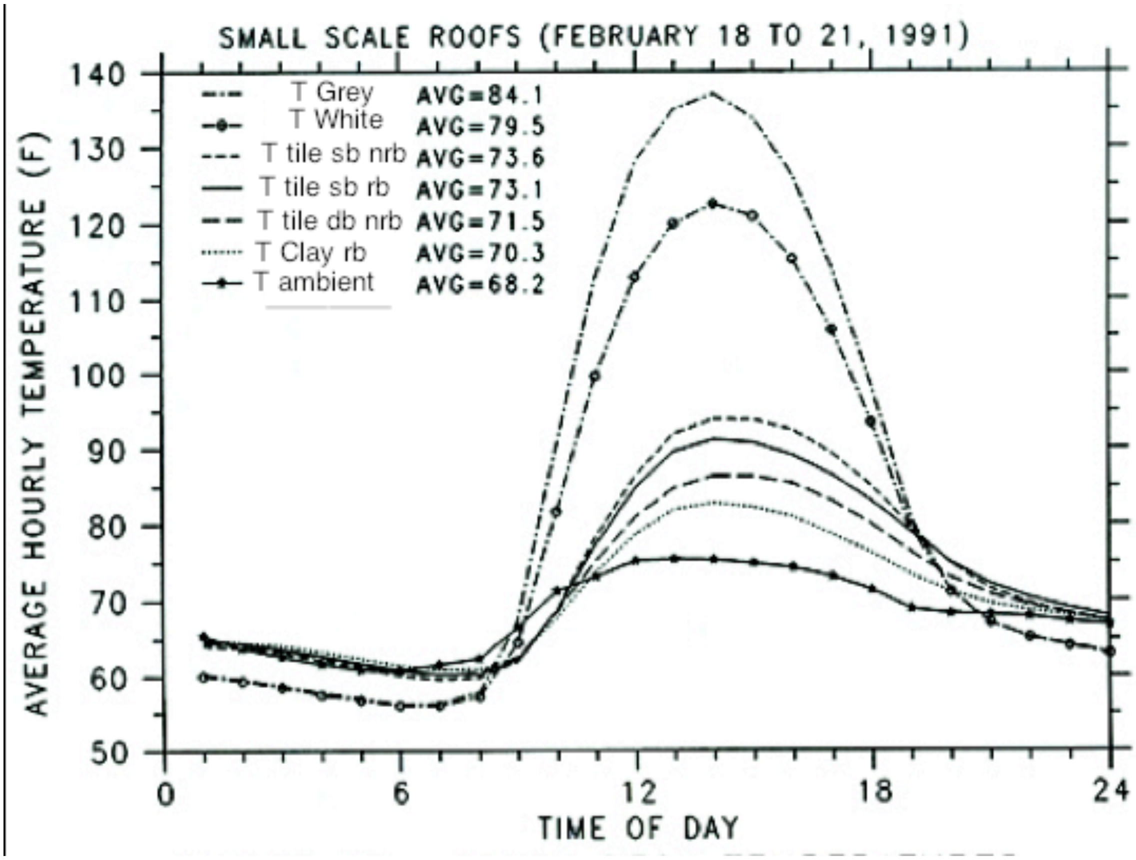
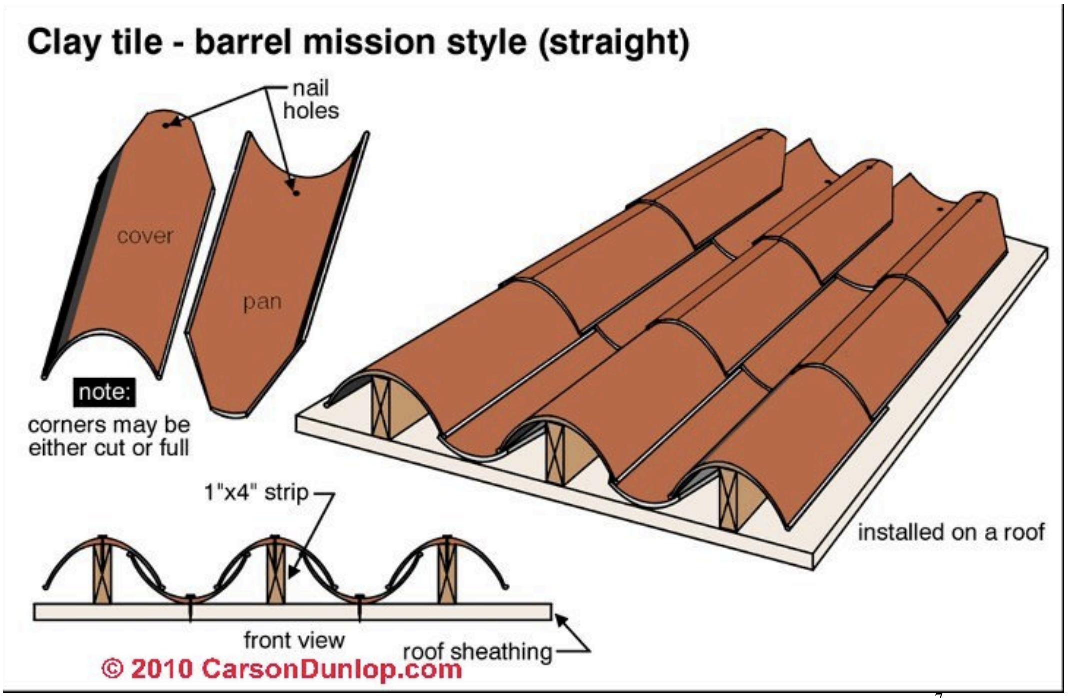
[5] http://www.engineering.com/Library/ArticlesPage/tabid/85/articleType/ArticleView/articleId/152/Thermal-Conductivity.aspx



(Fig 3) This image charts the surface temperature of different roofing materials over a 24 hour period. The two materials that reach the highest daily temperature were the grey and white shingles. The three lines in the middle (tile sb nrb, sb rb, db nrb) represent concrete tiles with varying degrees of ventilation and with or without a radiant barrier. Tile sb nrb is concrete tile on single battens without a radiant barrier, sb rb is with a radiant barrier on single battens, and db nrb is concrete tile on double battens without a radiant barrier. As can be seen the concrete tile on double battens is more efficient than either of the other two concrete tile set ups and results in a more significant change than the addition of the radiant barrier. This exhibits the considerable effect of airflow between tiles on surface temperature. The clay tile was laid without battens on a radiant barrier and as can be seen had the lowest surface temperature. It should be noted that this was without a batten system to improve ventalation, illustrating the effect of the termal properties of clay on heat transfer.

Most Pomona roofs are clay tile, which as mentioned, is already pretty energy efficient. The original missions were built using the locally available clay and adobe, and were designed to stay comfortable in this arid climate. Thick walls and clay tile slowly absorb heat during the day and slowly lose it over the course of the night to maintain a moderate temperature inside the building. Clay does not conduct heat very well and the airflow between the tiles keeps them cool and moves hot air away from the roof. Mission revival architecture typically employs a barrel mission style clay tile (Fig 4), which leaves considerable space for air to flow under the tile. The ease of airflow under the tiles is a significant factor in the energy efficiency of clay tile roofs. Pomona could apply a reflective coating to the clay tiles during roof upkeep and through this gain some energy benefits. However one of the most attractive qualities of clay tile is that it has a lifetime of 75 years and so a retrofit of college buildings would take a fairly longtime at standard rates of replacement. Research done on the effectiveness of these coatings in the Southern California climate indicate that there is still a net cost benefit to the building owner, though due to the efficiency of clay tile roofs this benefit is slow to arrive. [6] For homeowners in San Bernadino it can take 5-7 years to recover the costs of a cool pigment coating. However this study was done with a focus on homes, so the conclusions may not be directly transferable to college buildings. Pomona would probably stand to get similar gains, but as can be seen there are a multitude of factors that can affect a building's cooling load.



(Fig 4) As can be seen a barrel tile system allows for airflow between the tile and the roof deck.[7]

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[6] Levinson, Ronnen, Hashem Akbari, and Joseph C. Reilly. "Cooler Tile Roofed Buildings with Near Infared Non-White Coatings" *Building and Environment* 42 (2007) pg 176. Web.

[7] http://www.inspectapedia.com/roof/0040s.jpg

While white coatings remain the predominant method of improving roof albedo, a common objection to reflective roofs is the color, which building owners object to for aesthetic reasons. In order to improve the energy efficiency of colored roofs, pigmented reflective coatings have been developed. These coatings can be applied on top of or mixed in during production of a roofing surface. In clay tile the main methods of improving reflectivity are choosing high quality clay with low concentrations of light absorbing impurities (iron oxides and elemental carbon). Approximately 52% of solar energy arrives as near infrared radiation, and these coatings improve reflection of near infrared wavelengths without altering the appearance of the roof.[8] A study was done by the California Energy Commission to determine the effectiveness of these pigmented coatings on steep sloped clay and concrete tile roofs. Tile is already a fairly energy efficient roofing product due to clay's natural thermal emissivity and reflectivity, along with the venting airflow under tiles. However, it found that the application of a reflective coating can improve albedo by as much as 0.37 (for a black tile) (Fig 5). The reflective coating generally raises the albedo of a clay tile to between 0.4 and 0.5, though a white clay tile can have an albedo as high as 0.68.[9] The effectiveness of these coatings was tested on clay and concrete tile roofs at the Building Technologies Center by measuring heat flow under the tiles along with temperature, solar reflectivity and thermal emittance. The coated clay tile was found to be the most efficient with a 72% reduction in the heat transfer across the roof when compared to an asphalt shingle roof. The premium for a reflective pigment coating is .27 $\$/m^2$, which as mentioned above can typically be regained in cooling energy savings over 5-7 years.

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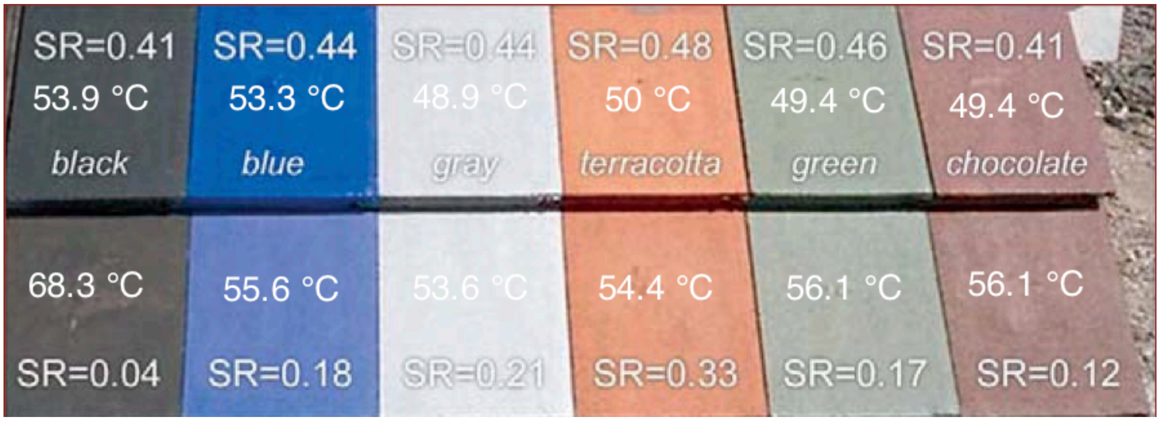
[8] Ibid 179.

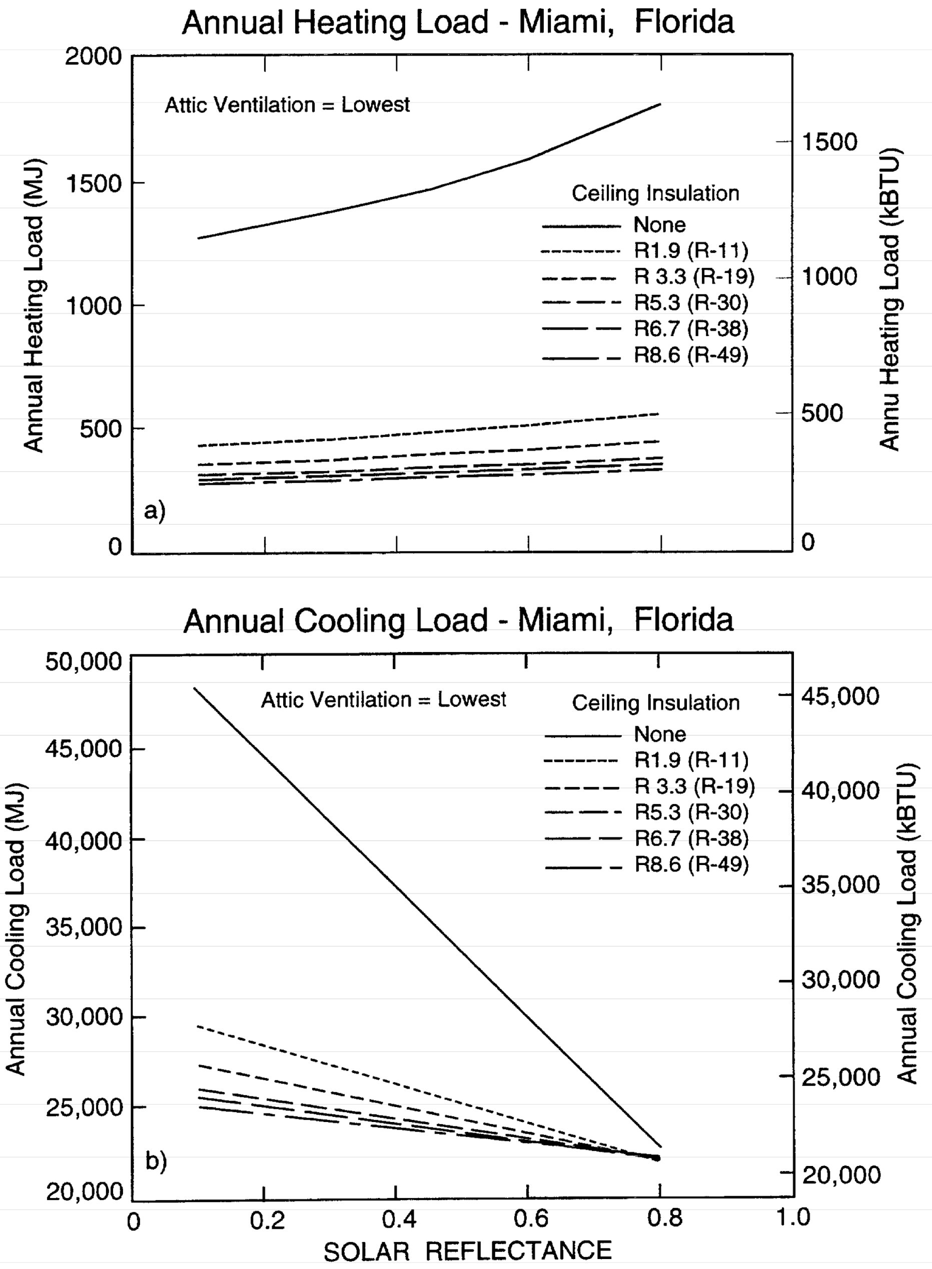
[9] Miller, William. "Steep Slope Assembly Testing of Clay and Concrete Tile Roofs: With and Without Cool Pigment" Claifornia Energy Commission. (2006). pg 13. Web.



(Fig 5) Cool pigment coatings can increase albedo with minimal change to the appearance of the tile. This image shows the improvement in albedo for concrete tiles.

Weaknesses of Cool Roofs

High albedo coatings can be effective at reducing cooling loads but have certain weaknesses that can limit their impact. The first is that while reflective roofs reduce heat transfer across a roof during warm weather, they can also reduce the heat transfer during cold months (Fig 6). This reduction in solar heating can raise heating costs, and in cold climates offset the reduction in cooling costs during the summer.



(Fig 6) A study done by the National Institute of Standards and Technology verified that high albedo roofs do increase the heating load during the winter, but in warm climates this is offset by the reduction in the cooling load.[10]

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[10] Zarr, Robert R. "Analytical Study of Residential Buildings with Reflective Roofs" Building and Fire Research Laboratory, National Institute of Standards and Technology. Oct 1998. pg 7. Web.

The effectiveness of reflective coatings can also be undone by degradation due largely to dirt accumulation. In a report done for the Energy and Environment division of the Lawrence Berkley Laboratory researchers found this can result in a decrease in albedo of roughly 20% after the first year.[11] With cleaning, however, albedo can be restored to within 90% of the starting value. This same study found that 70% of the albedo loss happened in the first two months, and after the first year loss was consistent but minimal. The effects of temperature, moisture, and light can also decrease albedo. Studies of coating degradation show an increase in photo-oxidative degradation in high humidity and a correlation between increased light exposure and hydrolytic degradation. Albedo and roof temperature are related linearly, therefore by extending this linear relationship to albedo and cooling energy savings this study attempts to draw conclusions on the affect of dirt accumulation on cooling energy use. Using this method they approximate the savings lost due to dirt accumulation to be 20%. These costs could be minimized by regular cleaning, but it was concluded that in order to effectively combat albedo loss cleaning would need to be done fairly often and may not be worth the labor costs. The authors instead suggest the development of dirt resistant coatings. Roofing manufacturers recommend against walking on single ply roof surfaces due to the potential for tears. For this reason cleaning procedures must be undertaken with care to avoid puncturing the roof membrane, and incurring more costs than are being saved by the cleaning program.

Cool Roofs and Urban Heat Islands

Reflective roofs are not just energy efficient on the small scale, but research shows that large-scale application could reduce the Urban Heat Island Effect (UHI). This is when an urban area is significantly hotter than the surrounding rural areas due the tendency of building and paving materials to retain heat (Fig 7). The UHI can increase energy consumption, lengthen the growing season, and increase the monthly rainfall of

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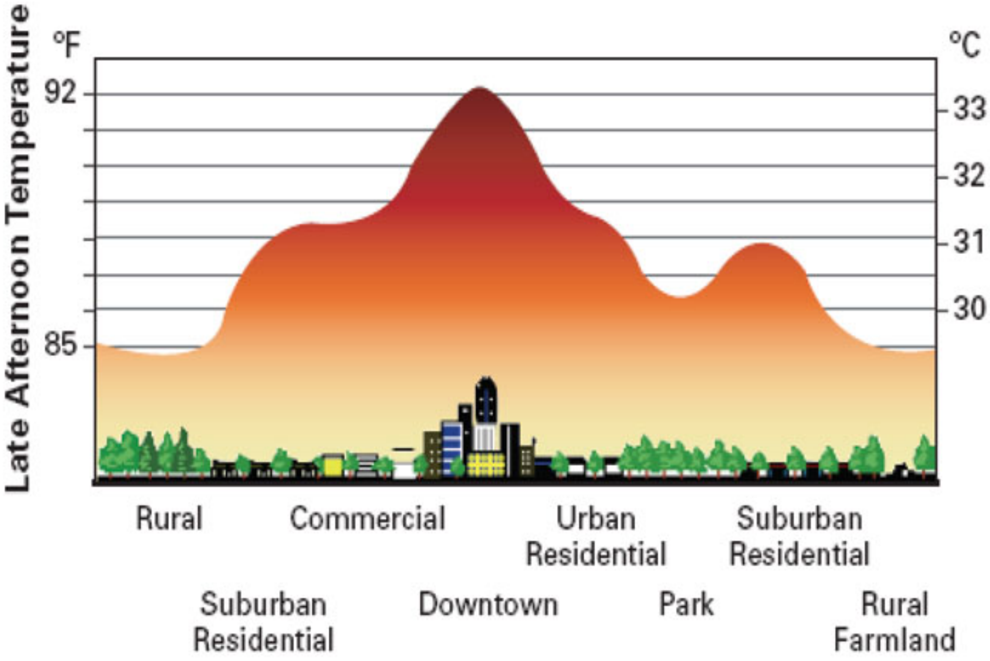
[11] Bretz, Sarah E, and Hashem Akbari. “Durability of High-Albedo Roof Coatings and Implications for Cooling Energy Savings” Energy & Environment Division, Lawrence Berkeley Laboratory, University of California Berkeley. pg 24.

areas downwind of an urban area. During summer months the UHI can increase the severity of smog and can lead to an increase in heat and pollution related illnesses. In urban areas the annual temperature can be 1.8 - 5.4 °F warmer than surrounding rural areas and in the evening, when the effect is most pronounced, the difference can reach 22 °F.[12] Cool roofs can reduce the severity of the UHI by decreasing surface temperature and decreasing emissions due to energy production.



(Fig 7) The Urban Heat Island (UHI) effect peaks over downtown areas with a high concentration of hard surfaces. The increase in trees and plants outside of city centers lessens the effect of the heat retained by the hard surfaces.[13]

A recent study published in *Energy Policy* attempts to quantify the effect of a large-scale increase in urban albedo on cooling energy use and emissions. [14] Using remote sensing, geographic information system (GIS), and building energy simulations over a sample area of Phoenix AZ the study determine the application of cool roofs where appropriate could reduce collective energy use by 4.3% annually. This study also

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[12] The Heat Island Effect http://www.epa.gov/hiri/about/index.htm

[13] http://www.emeraldcitiesproject.com/emeraldcities-initiative/images/stories/heat-island%2072dpi.jpg

[14] Jo, J.H., J. Carlson, J.S. Golden, and H. Bryan. "Sustainable Urban Energy: Development of a Mesoscale Assessment Model for Solar Reflective Roof Technologies" *Energy Policy* 38 (2010). pg 7954. Web.

calculated the reduction in GHG emissions to be 3823 tons of carbon dioxide, 5.29 tons of nitrogen oxide, and 3.52 tons of sulphur dioxide annually for the 4 square mile study area. If expanded to the whole Phoenix area the could result in a 3.4% decrease in land use CO_2 emissions.

Large-scale increases in albedo can reduce the effect of CO_2 by affecting the radiative forcing of the land area. Another study published in *Environmental Research Letters* attempts to quantify to what extent a large-scale increase urban albedo could offset the greenhouse effects of CO_2.[15] They estimate the global total outgoing radiation could increase by 0.5 W m^{-2} and surface temperature could decrease by 0.008 K due to an average increase in surface albedo of 0.003. These values may seem low but regional changes can be much larger. Figure 8 below shows the visual representation of these regional effects. The global values represent the effect of an average increase in urban albedo of 0.1 due to a 0.25 increase in roof reflectivity and a 0.15 increase in pavement reflectivity. If this improvement is made across all urban areas the potential CO_2 offset was found to be approximately 57 Gt. The global annual emissions of CO_2 total 23.9 Gt so a global increase in urban albedo would offset emissions for 2.4 years.

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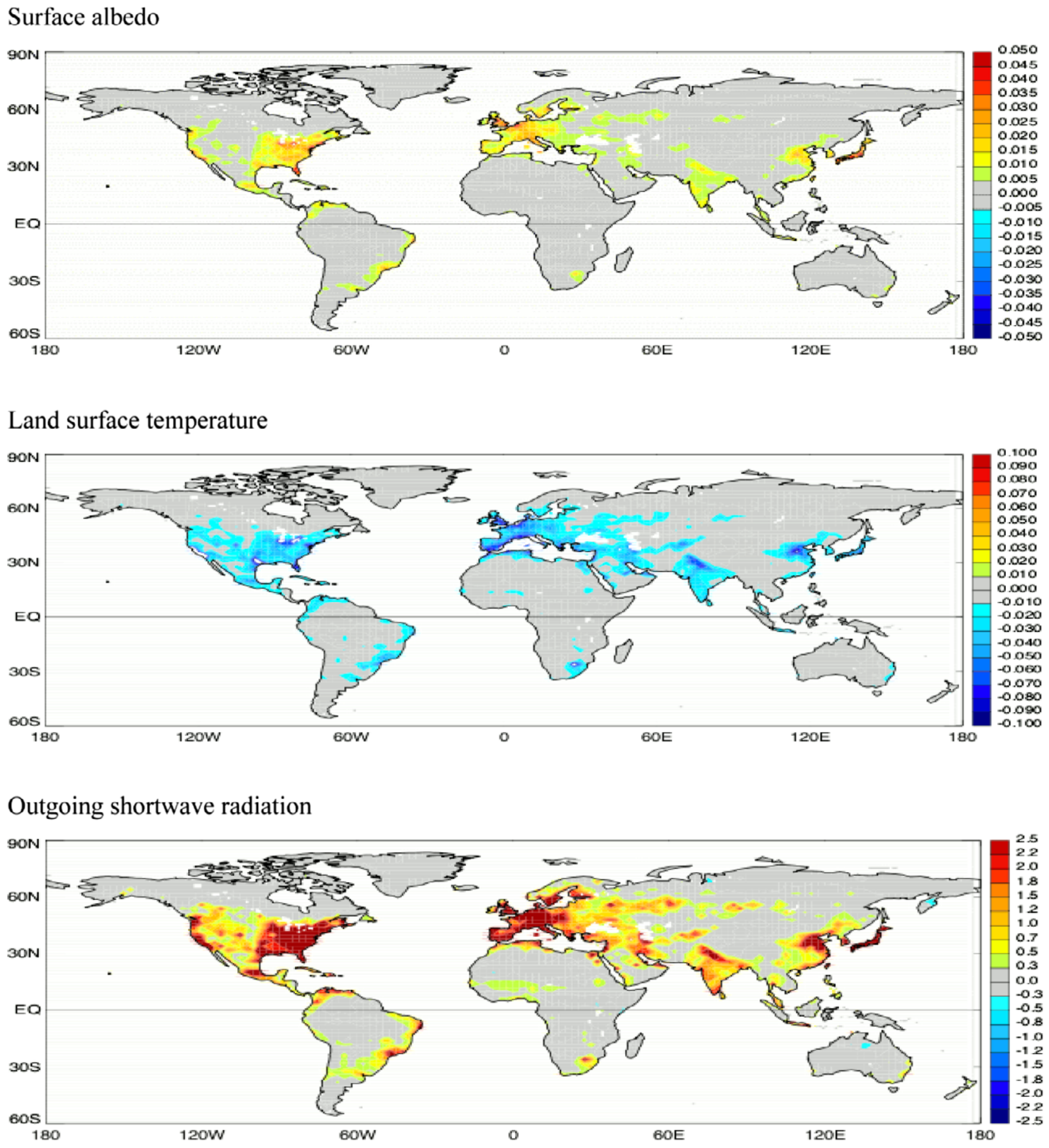
[15] Menon, Surabi, Hashem Akbari, Sarith Mahanama, Igor Sednev, and Ronnen Levinson. "Radiative Forcing and Temperature Response to Changes in Urban Albedos and Associated CO2 Offsets" *Environmental Research Letters* 21 (2010) pg 6. Web.



Surface albedo

Land surface temperature

Outgoing shortwave radiation

(Fig 8) This figure shows the regional changes in surface albedo, land surface temperature, and outgoing shortwave radiation due to a global increase in urban albedo. As is expected the significant improvements are concentrated in the urban areas, meaning a reduction in the UHI and its effect on surrounding rural areas.[16]

Other Strategies

Cool roofs are part of a larger cool communities strategy to reduce the UHI effect. The UHI like most other environmental issues comes from a variety of sources and so the

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[16] Ibid pg 4.

methods to reduce its effects cover a variety of sources. Some of the other main design alterations of individual building projects to combat UHI effects are cool pavements, green roofs, and trees shading buildings. Strategies also expand beyond individual building projects to include urban planning decisions (increasing airflow in cities by creating airflow channels), to lifestyle changes (decreasing pollution emissions). Cool roofs, green roofs, shade trees, and to a limited extent cool pavements, all attempt to alter the heat transfer across the building envelope to limit energy use in addition to decreasing air temperature. Each of these methods has advantages and drawbacks that make them suited to different environments.

As mentioned the amount of radiation absorbed by pavement can have an effect on the UHI and through this building energy consumption. The two main factors that affect the surface temperature of the pavement are emissivity and albedo.[17] An increase in albedo affects the pavement maximum temperature more than it affects the minimum and an increase in emissivity affects the minimum temperature more than the max. Cool pavements are expected to reduce UHI effects when applied over a large area, but can also moderate temperature in an area as small as a courtyard. By reducing outdoor temperature the theory is that cool pavements will also lower cooling energy use for buildings in the area. Though this intuitively makes sense there is debate over the actual effectiveness of cool pavements in mitigating the heat island effect. Howard Marks of the National Asphalt Pavement Association argues that the impact of pavement type on the Urban Heat Island has not be proven and though it probably has some effect, this effect has not been demonstrated relative to the effects of cool roofs, pollution, and shading.[18] However the study mentioned above (Menon), argues that pavement reflectivity can have a significant effect on UHI.

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[17] Gui, Jooseng, Patrick E. Phelan, Kamil E. Kaloush, and Jay S. Golden "Impact of Pavement Thermophysical Properties on Surface Temperatures" *Journal of Materials in Civil Engineering*, 19.8 (2007). pg 16. Web.

[18] http://www.buildings.com/ArticleDetails/tabid/3334/Default.aspx?ArticleID=10485#top#top

Most paving surfaces are either asphalt or concrete, which interact differently with solar radiation. The SRI of concrete is generally between 30 and 50, though values can be greater than 70 with white portland cement. In contrast the SRI of asphalt is zero. Age will affect the reflectivity of both surfaces but in different ways. Dirt accumulation on concrete can decrease albedo and lower SRI by as much as 25. Age can increase the SRI of asphalt by up to 20 over the course of several years due to the oxidation of the petroleum binder and exposure of the sand and stone aggregate. Albedo of concrete can be improved by the use of light colored cement or reflective surface treatments, and for asphalt the albedo can be increased with the application of a surface chip seal of light colored aggregate and use of a light colored binding agent.

Water permeable pavements also can be effective at reducing the UHI and reducing storm runoff. Originally designed to reduce runoff, permeable pavements tend to also have lower surface temperatures due to heat exchange with, and evaporation of, water percolating through the pavement. It has been found that while permeable pavements can have lower surface temperature, this effect is diminished with an increase in pore space or lack of water.[19] As pore space increases the amount of water retained by the pavement decreases and the cooling effects of evaporation are lost. Also when there is no rain for a while the pavement can dry out and have the same effect.

Increasing green space through green roofs and shade trees is shown to reduce outdoor air temperature as well as decreasing cooling needs. Trees that shade building surfaces naturally decrease surface temperature and heat transfer into the building. Also they lower air temperature through evapotranspiration. A study done by the Heat Island group found that planting trees in urban areas can reduce heating and cooling energy usage by up to 25%.[20] This same study found that the carbon offset of planting one tree in LA is 18kg even though a tree individually sequesters only 4.5-11kg growing in a forest. The other carbon offset benefits are due to the shade provided by trees and its

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[19] Asaedaa, Takashi, Vu Thanh Ca "Characteristics of Permeable Pavement During Hot Summer Weather and Impact on the Thermal Environment" *Building and Environment* 35 (2000) pg. 363 Web.

[20] Akbari, Hashem. "Shade Trees Reduce Building Energy Use and CO2 Emissions from Power Plants" *Environmental Pollution* 116 (2002). pg 4. Web.

affect on cooling energy use. Evapotranspiration and wind reduction can also have a positive effect on energy savings. Trees are a cost effective and attractive way of reducing energy use and the UHI effect, as well as being a generally positive addition to the urban environment.

Green roofs are planting projects that cover a roof surface, and typically include grass planted in a soil layer (Fig 9). The mass of the roof covering reduces heat transfer across the roof membrane in summer and in winter, and so can be effective in reducing heating and cooling costs. Research has shown that green roofs can reduce energy use as effectively as cool roofs with an albedo of 0.7.[21] Green roofs can also offer storm water runoff benefits by using it to irrigate the roof. However in areas without consistent rainfall green roofs may have to rely on irrigation, and so lose some of the appeal as a sustainable roofing system. Green roofs recoup some of the initial costs in energy savings, but unlike cool roofs the savings do not fully offset the initial cost. Green roofs are shown to be 10-14% more expensive than standard roof systems over a 60 year lifetime.[22] Green roofs can also have higher maintenance costs due to occasional problems with water leaking through the protective membrane separating the green roof system from the roof surface. This is not common, however concerns about maintenance and increased initial costs may make building owners hesitant to install green roofs. Also green roofs are not as readily applicable to all surfaces due to limitations of building structure and climate. For these reasons green roofs are unlikely to be included in prescriptive legislation, though they do count for LEED credit.

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[21] Castleton H.F. "Green Roofs: Building Energy Savings and the potential for Retrofit." *Energy and Buildings.* 42.10 (2010). pg 16. Web.

[22] Ibid pg 19.

(Fig 9) Green roofs can reduce energy use, reduce air temperature, and reduce runoff. They can also be designed as usable roof top garden space and bring a lot of value through human enjoyment. A green roof is also a great place to keep your goats. [23]

In Los Angeles

The climate and geography of Los Angeles make it particularly prone to UHI and high cooling loads. Los Angeles (188° W, 34° N) is located in a coastal plain bounded by high mountains. LA is a fairly low density urban area (7544.6 people per sq. mile), but with prevalent pavement due to a deeply entrenched driving culture. Los Angeles has one of the most extensive freeway systems in the United States and a very high rate of car ownership with 1.8 cars per household. All this pavement naturally leads to the development of a heat island over the LA area. Los Angeles is shown to be warming at a rate of .8° F a decade, faster than most other places in the country (Fig 10). [24] This is thought to be largely the effects of urbanization and the resulting UHI. Energy use for cooling in LA ranges from approximately 11% for the industrial sector, to 15% for residential homes. Because of the mild temperatures and low humidity LA does not use very much energy for cooling and barely any for heating (Fig 11).

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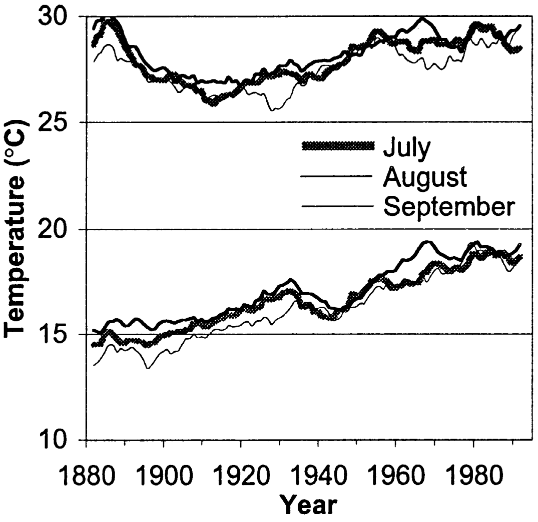
[23] Left: http://www.greenoptions.com/a/green-roofs Right: http://www.re-nest.com/re-nest/sales-and-events/events-green-roof-diy-workshop-in-nyc-087431

[24] Golden, Jay S. "The Built Environment Induced Urban Heat Island Effect in Rapidly Urbanizing Arid Regions – A Sustainable Urban Engineering Complexity" *Environmental Sciences* 40 2004 pg 143. Web.



(Fig 10) This is the running maximum and minimum temperatures in LA up until 1997. The graph shows the overall upward trend in local temperatures during summer months.[25]

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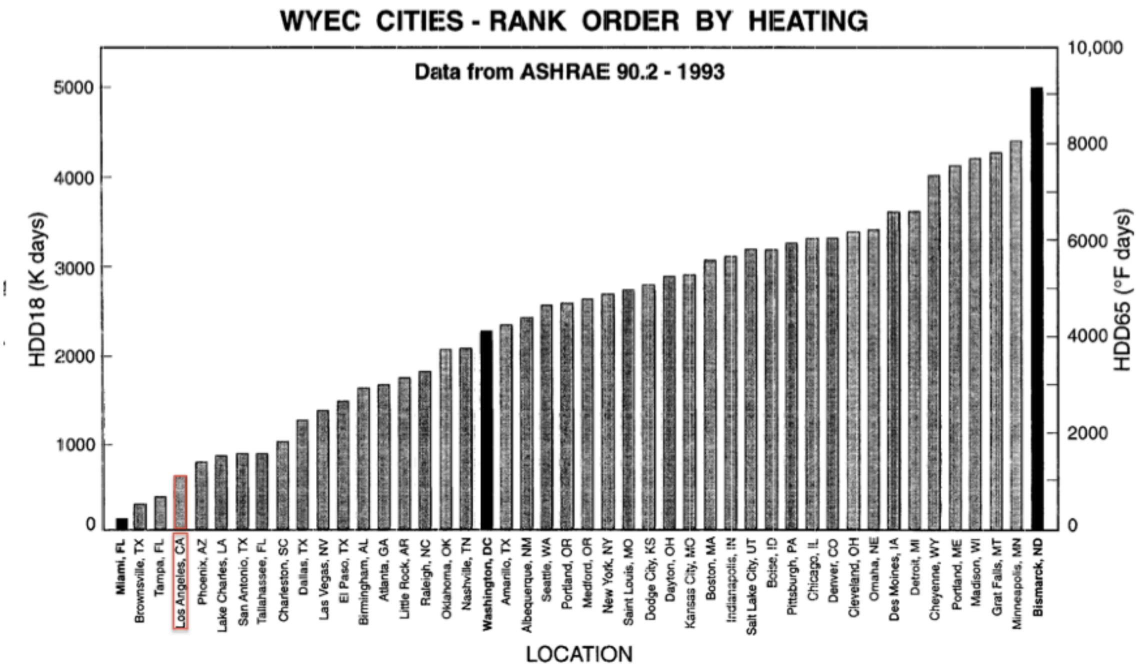
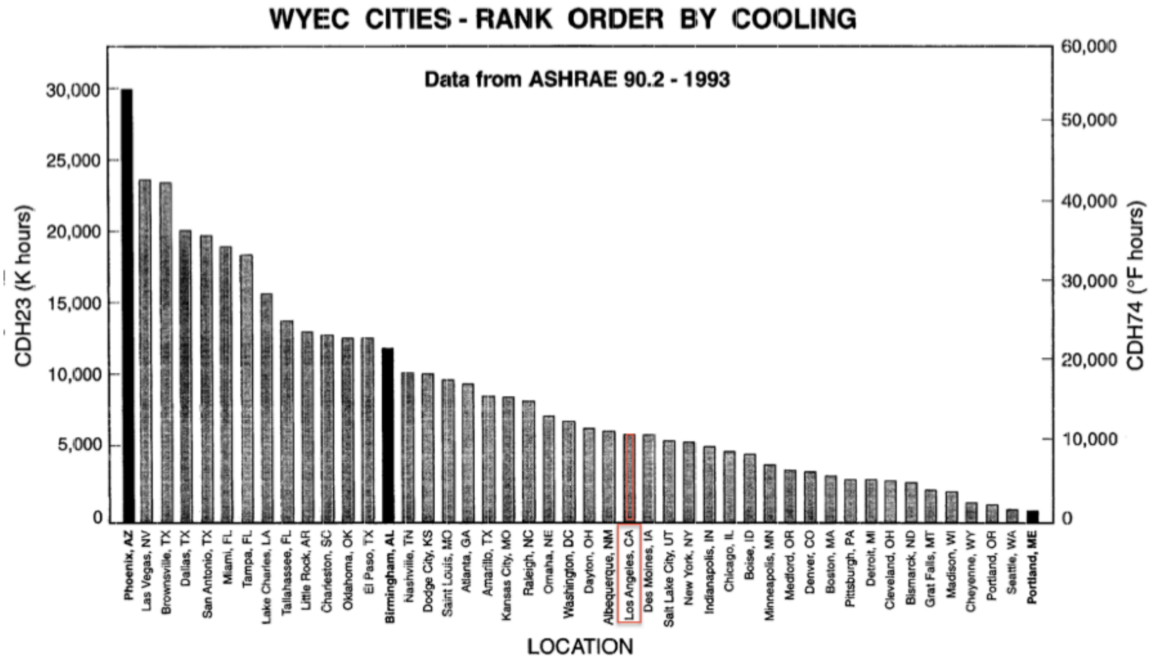
[25] Akbari, H, M Pomerantz, H Taha, "Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas" *Solar Energy* 70.3 pg. 296. Web.





(Fig 11) These two graphs show the energy used for cooling and heating in different cities across the US. Los Angeles spends a very limited amount on heating and also a limited amount on cooling when compared with cities like Phoenix and Las Vegas. The limited amount spent on heating means that the typical increase in heating costs associated with cool roofs does not lower savings.[26]

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[26] Zarr, Robert R. "Analytical Study of Residential Buildings with Reflective Roofs" Building and Fire Research Laboratory, National Institute of Standards and Technology. Oct 1998. pg 233.

Due to pollution from cars and industry LA is plagued by smog. The high mountains keep the smog from being blown out across the plains and a strong temperature inversion keeps it from escaping into the outer atmosphere. So all the pollution gets blown in and trapped against the mountains where the intense sunlight causes further photochemical reactions. A recent study has determined that LA ozone concentration (a product of the photochemical reactions in smog) begins to exceed the National Ambient Air Quality Standard of 120 parts per billion by volume when the daily maximum temperature reaches 22° C and by the time the temperature reaches about 32°C the ozone concentration can reach 240 ppbv. With every 1° K decrease in temperature there is an associated 5% decrease in the probability that ozone levels will exceed the California standard of 90 ppbv.[27] So in ten degrees of temperature change the air quality can change rapidly. The costs associated with medical problems due to LA air quality are thought to be 10 billion dollars a year.[28] Smog reduction has been the major environmental issue for LA since the industrial revolution.

Los Angeles has been identified as an area that could benefit highly from a cool communities strategy. A study published in *Energy and Buildings* attempts to quantify the potential savings from implementing a cool communities strategy in LA. They consider the results of increasing roof albedo by .35 and increasing the albedo of paved surfaces by .25 along with planting 11 million trees. It is estimated that this could reduce the average temperature during the day by as much as 3° C. The potential savings from these measures are calculated in three separate parts: the direct savings due the effect of these measures on building energy use, the indirect energy savings due to the decrease in ambient temperature, and the savings due to the reduction in smog. The total possible savings due to cooler roofs is $171 million per year, the total due to cool pavement is $91 million per year, and more trees can save a total of $273 million per year. Trees provide

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[27] Menon, Surabi, Hashem Akbari, Sarith Mahanama, Igor Sednev, and Ronnen Levinson. "Radiative Forcing and Temperature Response to Changes in Urban Albedos and Associated CO2 Offsets" *Environmental Research Letters* 21 (2010). pg 15. Web.

[28] Rosenfeld, Arthur H, Hashem Akbari, Joseph J. Romm, and Melvin Pomerantz. "Cool communities: Strategies for Heat Island Mitigation and Smog Reduction" *Energy and Buildings* 28 (1998) pg 51. Web.

such impressive savings due to the direct effect shade has on a building's air conditioning needs and the decrease in ambient temperature due to evapotranspiration. The way the total savings breaks down indicates that smog reduction would be the biggest benefit from this cooling strategy. The total direct savings are $104 million a year, the indirect savings are $71 million a year, and the smog reduction savings are estimated at $360 million a year for a total benefit of $535 million a year.[29] This study does not include the health benefits of heat wave mitigation or the effects of the UHI in LA on the surrounding areas, so the actual savings could be more.

Due to the proven benefits of large scale implementation of UHI reduction strategies cool roofs are beginning to be included in building codes. The individual energy savings of cool roofs have been shown to make up the slightly higher cost within 15 years.[30] However this is not always enough of an incentive for building owners to make the decision to pay the higher costs now. The prime time to install cool roofs is during new building construction or during resurfacing of existing roofs. If lawmakers would like to see the benefits of a cool communities strategy then building owners must be reached during the process of selecting a new roof. For this reason cool roofs have made their way in sustainability legislation and building codes around the country. Scientists from the Heat Island Group of the Lawrence Berkeley National Laboratory recommend that due to the cost savings cool roofs become a prescriptive requirement for non-residential low sloped buildings in the California building energy efficiency code (Title 24, Part 6 of California Code of Regulation). There is also considerable pressure from researchers and industry in California to include cool roofs in the NO_x trading program RECLAIM due to the proven impact of air temperature on smog intensity. Currently the program focuses on reducing emissions that cause smog and is notable for offering credits to companies that buy and dispose of old cars. However the inclusion of cool roofs is a departure from

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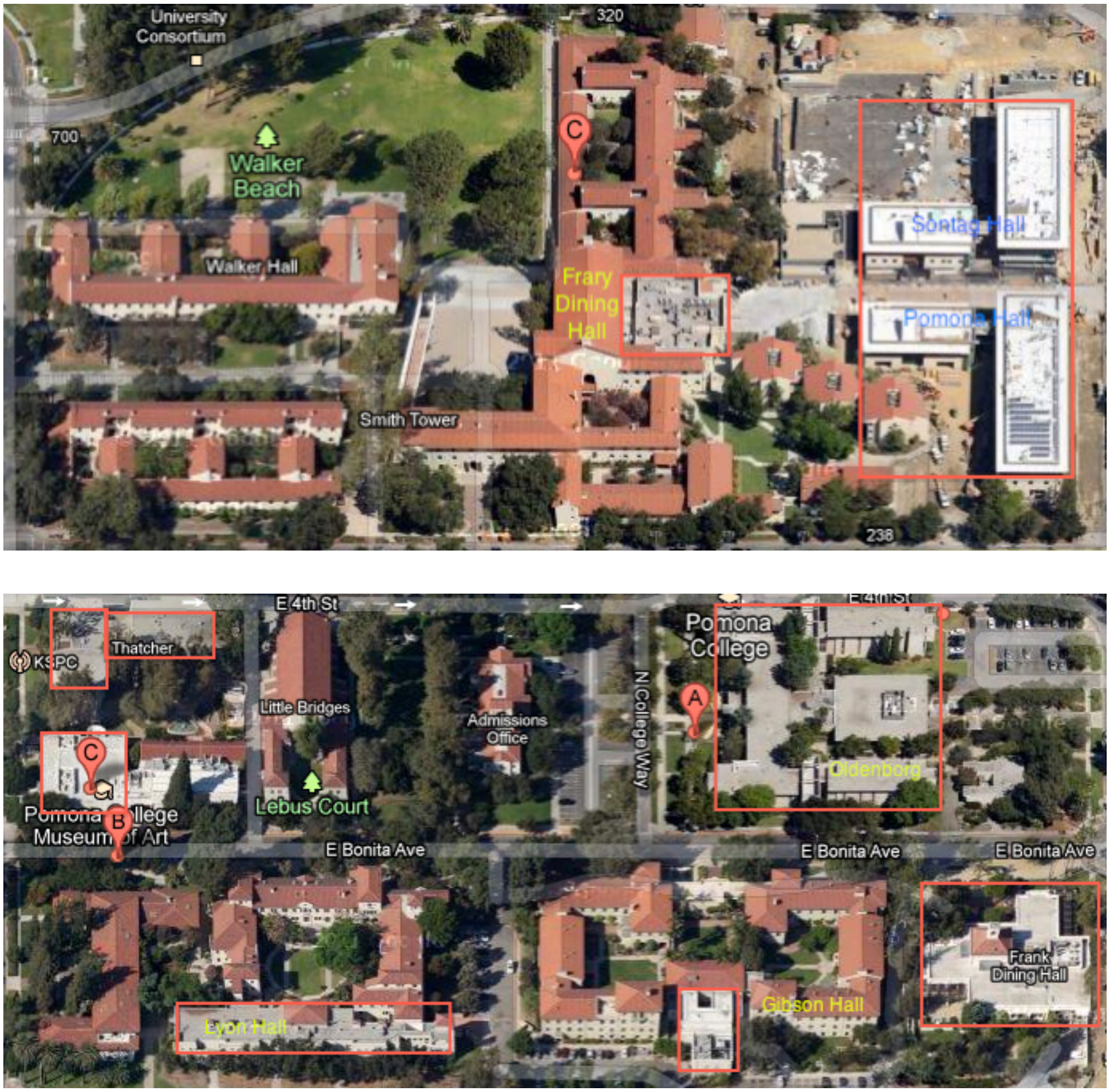
[29] Ibid pg. 55

[30] Levinson, Ronnen, Hashem Akbari, Steve Konopacki, Sarah Bretz. "Inclusion of Cool Roofs in Nonresidential Title 24 Prescriptive Requirements" *Energy Policy* 33 (2005) pg 157. Web.

the original scope of the program, and the requirements in Title 24 mean that many of the target industries may have already made roofing changes. Both of these measures target industry and there are significant gains to be made by increasing albedo of residential and commercial buildings as well. For this reason cool roofs are included in the LEED certification program and can also be worth an IRS tax credit of 30% of the cost of the roof. Through legislation like this governments are trying incentivize the measures to reduce the UHI effect.

Pomona Roofs

This section provides an overview of the flat roofs on Pomona's campus in order to inform the discussion of applications of reflective coatings. Most of the significant expanses of flat roof are located on South Campus and so this area receives the primary focus of this report (Fig 12). In order to consider new construction alongside potential retrofits Pomona and Sontag halls are also addressed.



(Fig 12) These images highlight in red the roofs discussed in this report. The buildings discussed are the Pomona College Museum of Art (Fig 13), Thatcher Music Building (Fig 14), Gibson Hall (Fig 16), Frary Dining Hall (Fig 17), Oldenborg Hall (Fig 18), Lyon Hall (Fig 19), Frank Dining Hall (Fig 20), and the new Pomona dorms Sontag and Pomona (Fig 21). Buildings with flat roofs not addressed in this report are Raines Athletic Center, Bridges Auditorium, Seaver Theater, Seaver Biology building, and Pendleton Dance Studios. However conclusions drawn in this report can be readily applied to those roofs as well. (adapted from Google Earth)

(Fig 13) The flat built up roof on top of the art museum is covered with a high albedo coating. This coating is comprised of reflective granules and as can be seen in this picture is sprayed over roof surfaces and can also cover ventilation ducts. This is also a foam roof, which according to the manufacturer provides additional energy benefits over a standard concrete roof. (11/30/11)

(Fig 14) This is the roof on top of the Thatcher music building. This is a very common inexpensive roof where asphalt, bitumen, and felt are laid over a concrete slab and then gravel is spread over the top. (12/6/11)

(Fig 15) This is an example of the most common roof type on campus (on Harwood). It is a double barrel clay tile roof similar to the one pictured in Figure 4. The difference is that is a single barrel set up and on much of the campus there is a second layer of cover tiles. This increases the thickness of the conducting surface and increases airflow between tiles. (11/30/11)

(Fig 16) This is the roof on top of Gibson dorm. It features a liquid applied reflective coating, though it has lost some of its brightness due to age and dirt accumulation. This effect can be seen in the difference in color between the walls and the deck. (11/30/11)

(Fig 17) This is the flat roof above the kitchen of Frary dining hall and it features a built up coating of layered asphalt and polymer sheets. The coating on this roof is not a reflective coating, but due to the evident age of this coating it could be due for resurfacing. At this point a reflective coating should be considered. (11/30/11)

(Fig 18) Oldenborg also sports a gravel roof, with a small area covered with a reflective coating. Oldenborg is a low profile building with one of the most expansive flat roofs on campus, and so is a location that should be considered for a reflective coating. (12/6/11)

(Fig 19) Frank dining hall has a single-ply reflective coating that as can be seen has aged significantly. This coating is laid down as a continuous sheet, and so even a small tear can cause leaks. This is the reason for the several light colored patches. (12/6/11)

(Fig 20) On Lyon Hall there is another gravel roof. (12/6/11)

(Fig 21) This is the new single ply reflective coating on top of Sontag Hall. It is similar to the coating on Frank, though it is much newer. (11/30/11)

Discussion & Conclusions

In the previous section several Pomona roofs were highlighted as potential locations for a cool roof. It is very difficult to estimate the potential energy savings from this policy due to the multitude of different buildings on campus. Construction and building modification have been near continuous since the founding of the college and so campus buildings feature technologies and techniques spanning the past hundred years, in addition to being in varying conditions. The college could pay to have a roof resurfaced, but if the windows still leak then the money will not have been applied to best affect energy use. If a building is being considered for a reflective coating then this solution must be considered within the energy weakness of a particular building. Part of the reasons it would be hard to estimate Pomona's possible gains from cool roofs is that there is variance even among the flat roofs. The three main types of flat roofs we see on Pomona's campus are gravel, built up, and single-ply continuous coatings. All of these have similar construction but there is still variation that could affect relative gains from a reflective coating. Each of these roof types has a reflective option, so for any flat roof reflectivity could be improved without affecting the functionality of the roof.

Most of the college buildings have double barrel clay tile roofs in the mission revival style. These roofs are already energy efficient due to the thermal properties of clay tile, airflow between tiles, and the double layer of cover tiles. In addition high albedo pigmented coatings are available for clay tiles and can improve reflection of near infrared radiation. However these coatings are not as easily applied as flat roof coatings and must be baked in or applied directly to the tile during production. For this reason if the college wished to pursue energy reduction through applications of reflective clay tile it would have to occur during scheduled roof replacements. Clay tile roofs are intended to last for 75 years, so reflective pigments could be a point of discussion as clay tile is replaced, but does not need to figure prominently in Pomona's dialogue on energy efficiency.

Cool roofs would have the greatest effect on older buildings with minimal insulation, and expansive low flat roofs. Older buildings may also have other energy issues that must be addressed, but applying a cool roof is a good way to improve the energy efficiency of an underperforming building without having to make significant changes or affect building function. It is for this reason that older buildings get special mention. Anyone who has worked with old buildings knows that fixing one problem often brings to light three more, and so a cool roof may be an attractive option to improve energy use without having to overhaul a building. Also college buildings receive a lot of use and so any building modification that does not affect building operation deserves special attention. Increasing insulation reduces gains from cool roofs and so buildings without insulation can see significant energy gains. Low flat buildings have a larger ratio of roof area to volume than multi story buildings. Therefore more heat transfer occurs through the roof than in a tall building which would lose more through the walls and windows.

Of the roofs reviewed in this report, those without high albedo coatings are Thatcher, Oldenborg, Lyon, and Frary. The college could see some energy use returns by applying reflective coatings to these buildings. Oldenborg could benefit significantly due to the wide area of flat roof exposed to direct sunlight. Oldenborg is also a low wide building, so most of the heat exchange with the outside environment is through the roof. Thatcher similarly has significant flat roof area that could be affecting cooling in the building. Thatcher and Oldenborg stand to make similar gains in cooling reduction, but an important difference between these buildings and Lyon is that Lyon does not have air conditioning. For this reason benefits in improving roof albedo would come in increased comfort to residents and not direct cost reduction. Lyon is a thin rectangular building and so the ratio of roof area to the volume of the building is smaller than we would find in Oldenborg. For this reason, while there may be some heat flux through the roof, it is possible that more heat is gained through the long south facing wall. Frary has an old built up roof above the kitchen, which could be replaced during the next maintenance cycle with a cool roof. Air conditioners servicing high traffic kitchens like Frary have to work especially hard to keep them cool, and so the benefits of a high albedo covering on this roof could be pronounced.

The roofs that already have some kind of high albedo coating are the art museum, Gibson Hall, Frank Dining Hall, Pomona and Sontag Halls. Of these coatings the ones on Pomona and Sontag are naturally the newest and the one on Frank is the oldest. The two coatings are similar, both being single-ply reflective coatings, but age has had an obvious effect on the coating on Frank (Fig 19). The coating has gotten much darker from what was once a presumably near white coating. The coatings on Pomona and Sontag serve as potential models for what could be applied to remaining flat roofs. Improvements have also been made in the durability of these coatings, meaning the coatings on the new dorms will be less prone to tearing. Therefore even though Frank already has a reflective coating it is one of the locations that could benefit from being resurfaced with a new coating. Gibson and the art museum both have foam roofs with applied liquid reflective coatings, which manufacturers claim can reduce energy costs by 20-70% over a typical built up roof (the amount of savings is drastically affected by the properties of the rest of the building).[31] A foam roof does not have to be applied to every flat roof to cut energy costs, but each of these roof types has a high albedo option that should be considered.

Due to Pomona's demonstrated interest in sustainability, roof reflectivity must be included in any discussion of college energy use. There is still plenty of research that can be done on how the design of Pomona's campus and buildings affect energy use. Future students could look into the energy impact of other building properties, use of tree planting, shaded and unshaded courtyards, and the conversion of parking lots to underground structures. Within this context it must be remembered that whether trying to address issues of Urban Heat Islands or individual building's energy use, cool roofs are part of a much larger set of solutions that must be considered all together to tackle a particular issue. When dealing with UHI effects cool roofs must be considered with the larger cool communities strategy and, when discussing energy use, one must consider the multitude of other factors that affect building climate. The college's commitment to trees and open greenspace has had the added benefit of controlling campus temperature and limiting UHI effects on campus, at least compared with most of LA. For this reason a policy of applying cool roofs to combat UHI effects would be unnecessary. Any individual's contribution to the UHI is very small and Pomona's only utility from employing this policy for this reason would be to reduce an already negligible contribution. The main benefit Pomona could derive from cool roofs is in energy savings, primarily on low flat roofed buildings.

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[31] http://www.dura-foam.com/resources/foam-roofing/foam-roofing-cost/

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