Part 1: Opportunities in the Building Sector: Managing Climate Change

Part 2: Global Cooling: Effect of Urban Albedo on Global Temperature

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Faced with increasing concentrations of atmospheric carbon dioxide, many countries are aggressively implementing measures to reduce these emissions. Although the United States has not yet committed to reducing its carbon dioxide emissions, the State of California is moving forward with its efforts to reduce carbon emissions to 1990 levels by the year 2020. The specifics of how California will proceed are under development with full implementation expected in 2012 with some earlier measures prior to that date. In this paper, we will provide an overview of energy consumption in the United States and in California with particular emphasis on efforts that California has made to increase the efficiency of its energy use. Also, we will discuss and describe cost curves for carbon reduction and contend that much of the reduction needed to modulate global warming could be achieved at negative costs.

In 1974, the California Energy Commission was formed to develop and implement the first energy efficiency standards for buildings and appliances in the United States as well as assess supply and demand conditions, and site new thermal power stations. Over the years, the Commission also has developed capabilities and funding for research and development (R&D) efforts related to energy and environmental issues. Currently, funding in the R&D area amounts to $80 million dollars per year with about half of this focused on energy efficiency and demand response.

A common measure of energy efficiency is energy intensity, defined as the quantity of primary energy consumed per unit of gross domestic product (E/GDP). Energy intensity in the United States has declined at five times the historical rate since the 1973-74 oil crisis raised the price of energy, awareness of energy consumption, and also the profile of energy efficiency. Figure 1 provides details on how energy intensity in the United States has improved. The impact of this improvement on primary energy demand is illustrated in Figure 2. If, instead of the actual 2.1 percent decline per year experienced since 1973, the United State’s energy intensity had decreased by only the business-as-usual pre-1973 rate of 0.4 percent per year, energy use in the country would have risen by an additional 70 quadrillion Btus (quads) in 2005. Even with this improvement, primary energy use still climbed by 25 quads during these three decades.
Figure 1 -- Energy Intensity in the United States 1949 – 2005

Figure 2 -- Energy Consumption in the United States 1949 - 2005
The monetary savings associated with improvements in energy intensity in the United States amount to about $700 billion in 2005 as a result of reducing primary energy demand by about 70 quads, compared to what it could have been if pre-1973 energy intensity levels had remained unchanged through the subsequent three decades.

Improvements in energy intensity arise from many factors: improved technology, customers facing higher energy prices, customer awareness and others. These improvements occur throughout the economy. We estimate that the $700 billion in foregone energy expenditures in the United States (in 2005 compared to what we would have spent if the energy intensity of the U.S. economy had improved at only 0.4% per year) was 1/3 due to major structural changes in the economy (less heavy industry and more high tech); 1/3 due to improvements in transportation (CAFÉ standards); and 1/3 from improvements in buildings and industry (CFLs, better motors, building and appliance standards, etc.)

Next we address a comparison between California (34 million people) and the United States as a whole (300 million people, including California). But figures 1 and 2 included transportation fuel, which in turn depends on United States Federal policy and standards, which “pre-empt” California from adopting more stringent standards. Hence, we focus on electricity where California controls its own destiny.

Annual use of electricity in kWh per person from 1960 to 2005 with forecasts through 2008 in California and in the United States is illustrated in Figure 3. Use in California is currently about 40 percent less than in the United States, even though use was nearly the same in the 1960s. The lines start to diverge in the mid-1970s when we experienced our first energy crisis. At times, petroleum was rationed and energy prices increased rapidly. For example, the price of electricity to residential customers in California and throughout the United States nearly doubled (in nominal dollars) from the early 1970s to the later 1970s. In addition, California began its building and appliance efficiency standards which contributed to keeping per capita electricity use in California nearly flat since 1975. Of course, compared to the entire United States, other factors such as a different mix of industries and differences in climate also contribute. Although not depicted on this slide, other policies also have led to electricity savings in California. For example, California standards allow electric water heating in homes only when it is cost effective: which is seldom the case. This has resulted in only limited electricity use for this purpose in California.

Thus, for a variety of reasons -- some policy and others due to climate or economic variables, electricity use per capita has been flat in California and should decrease slightly as California expands programs aimed at efficiency improvements.

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1 For a thorough discussion of these factors, see Deconstructing the ‘Rosenfeld Curve’, Anant Sudarshan and James Sweeney, Stanford University, to be published in the Energy Journal.
In combination with technological improvement due to “naturally occurring” innovation, California beginning in the late 1970s introduced efficiency standards for some new appliances and buildings. In Figure 4, we provide examples of initially state and later United States federal standards for three appliances: gas furnaces, central air conditioning, and refrigerators. The trends are similar but the magnitude of improvement in efficiency differs.

The amount of energy consumed in a year by the average new appliance sold in California from 1972 to 2006 (estimated) is illustrated in this slide. For each appliance, use is indexed to the year 1972, i.e., scaled to a value of 100. Arrows indicate when new standards took effect or will take effect. White arrows indicate state standards that were first put in place in 1976, in response to the first oil crisis and generally rising fuel costs. United States Federal government standards are shown as black arrows. These did not begin until the early 1990s.

By the early 2000s,
- Gas furnace use has declined by 25 percent (100% - 75%)
- Central air conditioners by 50 percent
- Refrigerators have shown the most improvement, with >75 percent reduction in use.

Theses are just three examples. Many other appliances as well as building characteristics, such as insulation and windows, are regulated and these regulations are upgraded every few years as technological advancements continue to improve appliance
efficiency\textsuperscript{2}. During development of these new regulations, industry representatives play an active and important role.

Figure 4 - The impact of efficiency standards for three appliances

The most effective path toward energy efficiency has been standards for autos, buildings, appliances, equipment, etc. Figure 5 shows the remarkable gains in refrigerators. The red smoothly rising line is the increase in size, and the unit energy use is not corrected for increasing this, nor for the fact that we have also eliminated the use of CFCs. Since 1975, refrigeration labels and standards have improved efficiency 5 percent per year for 25 straight years. In the United States, we have now saved 40, 1-GW power plants, from improvements in refrigerators. Through all of this, the price for refrigerators has declined when viewed in constant dollars even as efficiency has improved and the size of refrigerators in the United States has increased.

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\textsuperscript{2} - see Experience with Energy Efficiency Regulations for Electrical Equipment, Mark Ellis, IEA, March 2007
Continuing with the impressive gains in refrigerator efficiency, we now compare the quantity of energy saved due to these improvements with various sources of electrical generation in the United States. The refrigerator data assume that all refrigerators in use meet the current standard (which of course they do not yet, but eventually will as old units are replaced with new units). In **Figure 6**, the comparison is based on electricity saved or generated. Using this as a basis of comparison, refrigerators save about one-third of the amount of energy that the entire nuclear fleet in the United States generates. The data are for the year 2005.
In the next image, Figure 7, present a similar comparison as in Figure 6, but here we value the electricity at the wholesale price (3 cents/kWh – for conventional hydro, renewables, and nuclear) but at the retail price (8.5 cents/kWh – for energy saved and PV systems. Using the value of the power as the metric, energy saved due to refrigerator standards has a value of nearly twice all the hydropower in the United States and about 75 percent of all electricity generated by the United States nuclear power stations. Again, we assume all refrigerators operate at the current standards for efficiency.

California’s efforts to encourage efficiency through building and appliance standards provide an interesting example that is directly applicable to the issue of reducing greenhouse gas emissions. In the mid-1970s in response to a rise in fuel prices, at times limitations in fuel supply, concerns regarding environmental impacts of electricity production and other factors, California began to set building and appliance standards, and initiated utility programs aimed at reducing electricity use. We estimate that the current impact of these programs reduces electricity demand in California by about 40 TWh or 15 percent. Figure 8, provides an illustration of these savings. This works out to a reduction of about 1,000 kWh per person currently.

Each year, the cost of conservation programs, public interest R&D, and standards adds ~1 percent to electric bills, but cuts one-half percent off the bill. So an investment of $1 in say 1990 saves $0.50 per year for 10 to 20 years. The simple payback time is 2 years. We arrive at this by comparing the initial investment ($1) to a savings in each year of ($0.50). So in 2 years we have paid off the initial investment, but savings continue for many more years.
However, to implement this extensive effort for utility efficiency programs, California had to put in place a number of policies. In Figure 9, we provide annual funding levels for investment in energy efficiency by California’s investor owned utilities. As the graph indicates, funding levels have fluctuated considerably since 1976. The state has now placed energy efficiency as its most preferred resource and has committed to aggressively fund these efforts for the next few years, as the figure illustrates. The figure also highlights a number of important policy decisions that the state made over this time period. These include:

1982 -- Decoupling utility profits from sales to eliminate the negative incentives associated with reduced sales
1990 -- Providing performance incentives to utilities that meet or exceed efficiency savings
2001 -- Including efficiency as a part of Integrated Resource Planning (IRP) and directly comparing savings to other options of meeting future load and load growth, including other policy considerations.

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3 These utilities provide service to about 75% of the state’s population. The remainder is served by municipal utilities and other public agencies.
Figure 8 showed that to increase energy efficiency in the electric sector in California currently saves about 40,000 GWh per year. We estimate that this results in an annual reduction of carbon dioxide emissions in California by 20 million metric tonnes, based on marginal generation from natural gas plants with emission rates of one-half tonne of CO2 per MWH. California currently produces about 500 million metric tonnes of CO2 per year.

Various estimates of the costs and methods to reduce greenhouse gas emissions are currently under discussion. Concerns abound regarding how costly it may be to reduce CO2 emissions to acceptable levels to reduce the impact of global warming. In Figure 10, we reproduce a copy of a cost curve for greenhouse gas reductions prepared by McKinsey & Company (Per-Anders Enkvist, Tomas Naclér, and Jerker Rosander4) in collaboration with the Swedish utility Valtenfall. Note that in such plots, area is proportional to net annual euros saved (if area is below the x-axis) or expended (if above the x-axis). In more detail, the y-axis measures net cost in euros/tonne, the x-axis in quantity in tonnes per year, and the product (area) is the euros per year. All data are for a single year – in this case the year is 2030. Total savings or costs per measure depend on the longevity of the measure. In Figure 10, considerable amount of emission abatement can be accomplished at a negative cost – that is at a savings compared to business as usual practices. Most of these involve improving the efficiency of energy use:

- Increased building insulation

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Improved fuel efficiency in vehicles
Improved air-conditioning system and water heating

Figure 10 -- Cost Curve of Greenhouse Gas Abatement

We have estimated the area below the x-axis in this figure at ~450 Billion Euros per year, mainly from efficiency measures. Interestingly, the area above the x-axis, mainly for renewable supply, is roughly of the same magnitude. If we can implement these at savings and costs illustrated above, there would be no net cost of getting to 450 ppm of CO2.

Many other examples of such costs curve can be found and, generally, they show that energy efficiency measures not only reduce greenhouse gas emissions but actually save money. However, just as California had to struggle to convince others that building and appliance standards were not only a good idea but highly cost-effective, we think the same problems will arise as we try to convince others that energy efficiency is an important tool in our effort to stem the ever rising tide of global warming.
Global Cooling: Effect of Urban Albedo on Global Temperature\(^1\)

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\textbf{ABSTRACT}

In many urban areas, pavements and roofs constitute over 60\% of urban surfaces (roof 20-25\%, pavements about 40\%). The roof and the pavement albedo can be increased by about 0.25 and 0.10, respectively, resulting in a net albedo increase for urban areas of about 0.1.

Many studies have demonstrated building cooling-energy savings in excess of 20\% upon raising roof reflectivity from an existing 10-20\% to about 60\%. We estimate U.S. potential savings in excess of $1 billion (B) per year in net annual energy bills. Increasing albedo of urban surfaces can reduce the summertime urban temperature and improve the urban air quality.

Increasing the urban albedo has the added benefit of reflecting more of the incoming global solar radiation and countering the effect of global warming. We estimate that increasing the albedo of urban roofs and paved surfaces will induce a negative radiative forcing on the earth equivalent to removing 22 Gt CO\(_2\) from atmosphere. Since, 52\% of emitted CO\(_2\) remains in the atmosphere, removal of 22 Gt CO\(_2\) from atmosphere is equivalent to reducing global CO\(_2\) emission by 42 Gt.

\textbf{1. INTRODUCTION}

For more than two decades, the Heat Island Group (HIG) at Lawrence Berkeley National Laboratory (LBNL) has performed research to quantify the effect of increasing urban albedo on reducing cooling energy use, cooling urban areas, and improving urban air quality. In many urban areas, pavements and roofs constitute over 60\% of urban surfaces (see Table 1; roof 20-25\%, pavements about 40\%) (Akbari et al., 2003, Rose et al., 2003, Akbari and Rose 2001a, Akbari and Rose 2001b).

<table>
<thead>
<tr>
<th>Metropolitan Areas</th>
<th>Vegetation</th>
<th>Roofs</th>
<th>Pavements</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt Lake City</td>
<td>33.3</td>
<td>21.9</td>
<td>36.4</td>
<td>8.5</td>
</tr>
<tr>
<td>Sacramento</td>
<td>20.3</td>
<td>19.7</td>
<td>44.5</td>
<td>15.4</td>
</tr>
<tr>
<td>Chicago</td>
<td>26.7</td>
<td>24.8</td>
<td>37.1</td>
<td>11.4</td>
</tr>
<tr>
<td>Houston</td>
<td>37.1</td>
<td>21.3</td>
<td>29.2</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Source: Rose et al., 2003.

\(^1\)This paper is an update to an earlier paper published in the second Passive And Low-Energy Cooling (PALENC) conference in Crete, Greece, September 27-29, 2007.
Many studies have demonstrated building cooling-energy savings in excess of 20% upon raising roof reflectivity from an existing 10-20% to about 60%. We estimate U.S. potential savings in excess of $1 billion (B) per year in net annual energy bills (cooling-energy savings minus heating-energy penalties). Increasing albedo of urban surfaces (roofs and pavements) can reduce the summertime urban temperature and improve the urban air quality (Taha 2002; Taha 2001; Taha et al. 2000; Rosenfeld et al. 1998; Akbari et al. 2001, Pomerantz et al. 1999). The energy and air quality savings resulting from increasing urban surface abedio in the U.S. can exceed $2B per year.

Increasing the urban albedo has the added benefit of reflecting more of the incoming global solar radiation and countering the effect of global warming (Kaarsberg and Akbari, 2006). Here we quantify the effect of increasing albedo of urban areas on the global temperature.

2. ESTIMATING GLOBAL URBAN AREAS

Figure 1 lists the area densities for the 100 largest metropolitan areas of the world (Wikipedia, 2006). The median area density is about 430 m² per urban dweller. The 100 largest metropolitan areas (with a total population of 670 M) comprise about 0.26% of the Earth land area. Assuming that about 3B people live in urban areas, total urban area of the globe is estimated at about 1.2% of land. In our calculations, we assume that urban areas are 1% of the land area.

3. POTENTIALS FOR URBAN ALBEDO CHANGE

Rose et al. (2003) have estimated that the fractions of the roof and paved surface areas in four U.S. cities. The fraction of roof areas in these four cities varies from 20% for less dense cities to 25% for more dense cities. The fraction of paved surface areas varies between 29% to 44%. Many metropolitan urban areas around the world are less vegetated than typical U.S. cities. For this analysis, we consider an average area fraction of 25% and 35% for roof and paved surfaces, respectively.

Akbari and Konopacki (2005) have reviewed the solar reflectance of typical roofing materials used on residential and commercial buildings in many U.S. regions. A solar-reflective roof is typically light in color and absorbs less sunlight than a conventional dark-colored roof. Less absorbed sun light means a lower surface temperature, directly reducing heat gain from the roof and air-conditioning demand. Typical albedo values for low- and high-albedo roofs can be obtained from the cool roofing materials database (CRMD, 2007) developed at LBNL.

For the sloped-roof residential sector, available highly reflective materials are scarce. White asphalt shingles are available, but have a relatively low albedo of about 0.25. Although it can be argued that white coatings can be applied to shingles or tiles to obtain an aged albedo of about 0.5, this practice is not followed in the field. Some highly reflective white shingles are being developed, but are only in the
prototype stage. Recently, one U.S. manufacturer has developed and marketing cool-colored fiberglass asphalt shingles with a solar reflectance of 0.25. Some reflective tiles and metal roofing products with greater than 50% reflectivity are also available.

Conversely, highly reflective materials for the low-slope commercial sector are on the market. White acrylic, elastomeric and cementitious coatings, as well as white thermoplastic membranes, can now be applied to built-up roofs to achieve an aged solar reflectance of 0.6.

The albedo of typical standard roofing materials ranges from 0.10-0.25; one can conservatively assume that the average albedo of existing roofs does not exceed 0.20. The albedo of these surfaces can be increased to about 0.55 to 0.60.

Pomerantz et al. (2000a, 2000b, 1997) and Pomerantz and Akbari (1998) have documented the solar reflectance of many standard and reflective paved surfaces. They report that the solar reflectance of a freshly installed asphalt pavement is about 0.05. Aged asphalt pavements have a solar reflectance between 0.10-0.18, depending on the type of aggregate used in the asphalt mix. A light-color (low in carbon content) concrete can have an initial solar reflectance of 0.35-0.40 that will age to about 0.25-0.30. Pomerantz et al. also reviewed the solar reflectance of other paving materials such as chip seal, slurry coating, light-color coating.

Akbari et al. (2003) provide estimates for two scenarios for potential changes in the albedo of roofs and paved surfaces (See Table 2). Based on this data, we assume that roof albedo can increase by 0.25 for a net change of 0.25x0.25=0.06. The pavement albedo can increase by 0.15 for a net change of 0.35x0.15=0.04. Hence, the net potential change in albedo of urban area is estimated at 0.10. Increasing albedo of urban areas by 0.1 results in an increase of 3x10^-4 in Earth albedo.

<table>
<thead>
<tr>
<th>Surface-Type</th>
<th>Albedo Change</th>
<th>This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Roofs</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Commercial Roofs</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Pavements</td>
<td>0.25</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Source: Akbari et al., 2003.

4. THE EFFECT OF CHANGING URBAN ALBEDOS ON GLOBAL TEMPERATURE

We estimate the CO2 equivalency of cool urban surfaces using literature data (see Table 3).

Table 3: Radiative forcing and CO2 equivalence

<table>
<thead>
<tr>
<th>Row</th>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>2XCO2 radiation forcing (RF) on the surface of Earth a</td>
<td>4.19 W/m²</td>
</tr>
<tr>
<td>2.</td>
<td>Increase in atmospheric concentration by doubling CO2</td>
<td>275 ppm</td>
</tr>
<tr>
<td>3.</td>
<td>Increases in atmospheric concentration by adding 1Gt of CO2 b</td>
<td>0.128 ppm</td>
</tr>
<tr>
<td>4.</td>
<td>Increase in atmospheric CO2 by doubling concentration [Row 2/Row 3]</td>
<td>2.15 x 10^11 tonne</td>
</tr>
<tr>
<td>5.</td>
<td>Surface area of the Earth</td>
<td>5.08 x 10^14 m²</td>
</tr>
<tr>
<td>6.</td>
<td>Total radiation forcing on the Earth [Row 1 x Row 5]</td>
<td>2.13 x 10^13 W</td>
</tr>
<tr>
<td>7.</td>
<td>Earth surface radiation change per tonne of atmospheric CO2 [Row 6/Row 4]</td>
<td>1 kW / tonne CO2</td>
</tr>
</tbody>
</table>

a: Hansen et al., 1997.
b: Broecker (2007) estimates that for each 4 Gt of fossil carbon burned, the atmosphere's CO2 content rises about 1 ppm. Each tonne of carbon produces 3.67 tonne of CO2. Also, about 52% of the CO2 emitted stays in the atmosphere. Hence, we then estimate that each Gt of CO2 emitted increase the atmosphere’s CO2 by 0.128 ppm.
In summary, Hansen et al. (1997) estimate a 2xCO2 adjusted radiation forcing (RF) on the surface of 4.19 W/m². This checks with Myhre (1998) formula of RF [W/m²] = 5.35 * ln(1+ ΔC/C) = 5.35*ln2 = 3.71 W/m². Using the Hansen et al. (1997) estimate of radiation forcing, the total global radiation forcing is 2.13x10¹⁵ W. Doubling of CO2 relative to pre-industrial era increases the atmospheric CO2 by 275 ppm. It is estimated that 1 Gt of CO2 increases the atmospheric CO2 concentration by 0.128 ppm (Broecker 2007). Hence, doubling atmospheric CO2 concentration to 550 ppm is equal to increasing the atmospheric CO2 by 2010 Gt CO2. The radiation change per tonne of CO2 is then estimated as [2.1 x 10¹⁵ W] / [2010 Gt CO2] = 1 kW/tonne CO2 (airborne).

Hansen et al. (1997) also estimate adjusted RF for changing albedo of 'Tropicana' by 0.2 is -3.70 W/m². In our analysis, we estimate that Tropicana is 50% of the land area; or about 1/7 of globe surface. For the reflected surfaces, the radiation forcing per 0.01 unit change in albedo as estimated by Hansen et al. (1997) is -1.30 W per m² of Tropicana land. Using the 1 kW/tonne CO2, we estimate that a CO2 equivalency of -1.3 kg of CO2 per m² of Tropicana land for a unit change in albedo (see Table 4). For cool roofs with a proposed albedo change of 0.25, the CO2 equivalency is then estimated at -33 kg CO2 per m² of roof area. For cool pavements with a proposed albedo change of 0.15, the CO2 equivalency is equal to -20 kg CO2 per m² of pavement area.

Table 4: Radiation forcing of changing the roofs and pavements and their CO2 equivalency

<table>
<thead>
<tr>
<th>Row</th>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radiation forcing (RF) on the surface of Earth by changing albedo of</td>
<td>-3.70 W/m²</td>
</tr>
<tr>
<td></td>
<td>‘Tropicana’ by 0.20ª</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Assumed change in the albedo of ‘Tropicana’ª</td>
<td>0.20</td>
</tr>
<tr>
<td>3</td>
<td>Earth RF for a Δ albedo of 0.01 [Row 1 / Row 2]</td>
<td>-18.5 W/m² of Earth</td>
</tr>
<tr>
<td>4</td>
<td>Fraction of land to Earth surface area</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>Tropicana fraction of land areaª</td>
<td>0.50</td>
</tr>
<tr>
<td>6</td>
<td>Tropicana fraction of Earth surface area [Row 4 x Row 5]</td>
<td>0.145</td>
</tr>
<tr>
<td>7</td>
<td>Tropicana RF for a Δ albedo of 0.01 [Row 3 / Row 5]ª</td>
<td>-1.30 W/m² of Tropicana</td>
</tr>
<tr>
<td>8</td>
<td>Tropicana CO2 equivalency for a Δ albedo of 0.01 [Row 7 / Row 7 Table 3]</td>
<td>-1.3 kg CO2/m² of Tropicana</td>
</tr>
<tr>
<td>9</td>
<td>Proposed change in the solar reflectance of roofs</td>
<td>0.25</td>
</tr>
<tr>
<td>10</td>
<td>CO2 equivalency of cool roofs [Row 8 x Row 9]</td>
<td>-33 kg CO2/m² of roof area</td>
</tr>
<tr>
<td>11</td>
<td>Proposed change in the solar reflectance of pavements</td>
<td>0.15</td>
</tr>
<tr>
<td>12</td>
<td>CO2 equivalency of cool pavements [Row 8 x Row 11]</td>
<td>-20 kg CO2/m² of paved area</td>
</tr>
</tbody>
</table>

ª: Hansen et al., 1997.
ª: Estimated by the authors.
ª: As a check, the average solar radiation on the Earth is about 368 W/m². Correcting for the cloud cover (25% absorbed and 25% reflected), about 50% of the radiation reaches the Earth surface, i.e. 184 W/m². For a surface albedo change of 0.01, 25% of the reflected radiation is again absorbed by clouds, 50% escape the Earth, and 25% reflected back to Earth. Ultimately 0.01x(2/3)x184 W/m² = 1.23 W/m² short-wave radiation escapes the Earth atmosphere. This checks with Row 7.

4. GLOBAL COOLING: CO2 EQUIVALENCE

In our calculations, we estimate that urban areas are at least 1% of the Earth’s land area about 1.5x10¹² m² (see Table 5). The roof area is 3.8x10¹¹ m². The paved surface area is 5.3x10¹¹ m². Hence, the global
atmospheric CO2 equivalency potentials for cool roofs are 12 Gt of CO2. The global atmospheric CO2 equivalency potentials for cool pavements are 10 Gt of CO2. The total global atmospheric CO2 equivalency potentials for cool roofs and cool pavements are 22 Gt of CO2. IPCC estimates that only 52% of the emitted CO2 stays in the atmosphere. Hence, the total global emitted CO2 equivalent potential for cool roofs and cool pavements is 42 Gt of CO2. This 42 Gt CO2 is over a year of the 2025 projected world-wide emission of 37 Gt CO2 per year (EIA 2003).

Currently, in Europe CO2 is traded at ~$25/tonne. A 42 Gt CO2 emission reduction for changing albedo of roofs and paved surfaces is worth over $1000 billion. The contribution of cooler roofs to this CO2 savings is worth $600B.

Table 5: CO2 equivalency of increasing the albedo of roofs and pavements in all major hot cities of the world.

<table>
<thead>
<tr>
<th>Row</th>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Area of the Earth</td>
<td>508x10^{12} m²</td>
</tr>
<tr>
<td>2.</td>
<td>Land Area (29% of Earth area)</td>
<td>147x10^{12} m²</td>
</tr>
<tr>
<td>3.</td>
<td>Dense and developed urban areas (1% of land area)</td>
<td>1.5x10^{12} m²</td>
</tr>
<tr>
<td>4.</td>
<td>Roof area (25% of urban area)</td>
<td>3.8x10^{11} m²</td>
</tr>
<tr>
<td>5.</td>
<td>Paved surface area (35% of urban area)</td>
<td>5.3x10^{11} m²</td>
</tr>
<tr>
<td>6.</td>
<td>Potential atmospheric CO2 reduction of cool roofs [Row 4 x Row 10 Table 4]</td>
<td>12 Gt CO2</td>
</tr>
<tr>
<td>7.</td>
<td>Potential atmospheric CO2 reduction of cool pavements [Row 5 x Row 12 Table 4]</td>
<td>10 Gt CO2</td>
</tr>
<tr>
<td>8.</td>
<td>Total potential atmospheric CO2 reduction of cool roofs and cool pavements [Row 6 + Row 7]</td>
<td>22 Gt CO2</td>
</tr>
<tr>
<td>9.</td>
<td>Fraction of emitted CO2 that remains in the atmosphere</td>
<td>0.52</td>
</tr>
<tr>
<td>10.</td>
<td>Total potential of CO2 emission reduction for cool roofs and cool pavements [Row 8 / Row 9]</td>
<td>42 Gt CO2</td>
</tr>
<tr>
<td>11.</td>
<td>Projected 2025 world CO2 emission(^a)</td>
<td>37 Gt CO2</td>
</tr>
</tbody>
</table>


5. CONCLUSIONS

Using cool roofs and cool pavements in urban areas, on the average, can increase the albedo of the urban areas by 0.1. We estimate that increasing the albedo of urban roofs and paved surfaces will induce a negative radiative forcing on the earth surface equivalent to removing 22 Gt CO2 from atmosphere. Removal of 22 Gt CO2 from atmosphere is equivalent to reducing global CO2 emission by 42 Gt. A 42 Gt CO2 emission reduction for changing albedo of roofs and paved surfaces is worth over $1000 billion. The contribution of cooler roofs to this CO2 savings is worth $600B.

Given these potential savings, we would like to recommend establishing an international organization where the developed countries offer financial support to large cities in developing countries, to trigger a cool roof/pavement program in those cities.

6. ACKNOWLEDGEMENT

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REFERENCES


