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Quantification of Climate Benefits of California's "Cool Roof" Regulations

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Summary: Cool roof technology reduces the air conditioning load on a building by reflecting, rather than absorbing, solar radiation. Much of that reflected energy goes back into space, so that the cool roof also mitigates the additional heat trapping in the atmosphere due to accumulation of anthropogenic greenhouse gases. As an example of this benefit, the California Air Resources Board (ARB) calculates that, averaged Statewide, new cool roof area added to California buildings under State energy efficiency regulations will counteract the effects of atmospheric CO_2 at a rate of about 26 kg for each square meter of roof. This translates to 2.4 metric tons of CO_2 per 1000 ft^2 of horizontal roof area. Aggregated over the estimated 10,625 acres (4300 hectares) expected to be added in the first decade after adoption of the State regulations, this is comparable to removing about 1.13 million metric tons of CO_2 from the atmosphere. Total benefits in the State would scale with wider application of cool roofs.

Background: The reflectivity of Earth's surface, its albedo, influences climate by controlling the fraction of sunlight that is reflected back to space and the balance that warms the planet. Very large changes in albedo over large areas, such as the waxing and waning of continental ice sheets, have long been recognized as significant factors in climate change. Small area albedo changes are known to influence microclimates ("heat islands") in both rural and urban settings. Small area albedo changes also contribute incrementally to the whole planet's energy balance, thus many small changes can create a cumulative climate effect.

California's energy efficiency standards for nonresidential buildings (Title 24, Part 6, of the California Code of Regulations) use cool roofing specifications to reduce air conditioning energy use. In addition to the energy conservation goal of the regulations, cool roofing also has a cooling effect on the climate in general (a "negative radiative forcing") due to the fact that increased roof albedo can reject more of the sun's energy back into space.

In order to enhance understanding of the climate benefits of cool roofs, ARB has computed an estimate of the climate forcing associated with California's cool roof program for newly built roofs on non-residential buildings. This analysis focuses on a known increment of new cool roof area that is already integrated into the State's construction industry, as a concrete example of the additional benefits available. Total benefits in the State would scale proportionally with wider application of cool roofs.

The Climate Mitigation Potential of Cool Roofs: The potential climate effect of cool roofs is backed up by both empirical and theoretical research. At the local scale, Campra *et al.* (2008) reported that widespread adoption of white-roofed greenhouse farming has resulted in local climate cooling in southeastern Spain. At the global scale, Akbari, Menon and Rosenfeld (2009) have calculated that widespread adoption of high albedo structural surfaces ("cool roofs" and "cool pavements") in low- and mid-latitude cities world-wide would generate a significant negative radiative forcing at a global scale, and they estimate that this could potentially offset the equivalent of 44 Gt of CO_2 emissions.

The combination of the known cooling effects of increased albedo with the adoption of building standards that insure large roof areas will be converted to or sustained as "cool" surfaces in California suggests that the State should formally recognize the climate benefits (negative radiative forcing) deriving from this program or any other application of "cool" surfaces as an external benefit, distinct from the energy savings incurred in the underlying structures.

Estimating the California Benefit: Computing the climate benefit of the Title 24 standards involves bringing together estimates of the of the total roof area affected by these regulations with estimates of the energy reflected by cool roofing in the state. Data on the location and area of roof affected by the regulations has been compiled by researchers at Lawrence Berkeley Laboratory (LBL) (Levinson *et al*., 2005). Sunlight data is available from the network of instruments operated by the California Irrigation Management Information System (CIMIS). These are combined here to estimate the climate benefit accruing from the Title 24 regulations after 10 years in effect.

When adopting the Title 24 rules, the California Energy Commission estimated that Statewide new construction of non-residential roofing averaged (2001- 2010) about 1470 ha (hectares), or roughly 3600 acres per year. The LBL group examined data on a sample of 990 non-residential buildings around the state to estimate that about 430 ha (1063 acres) of that would be converted to cool roof as a result of the regulations (the rest either would get cool roofs anyway, or were not subject to the rule for structural or other reasons). Also relying on the sample data, they apportioned that estimate across the State's 16 climate zones (Figure 1).

Thus, after 10 years in force, the Title 24 cool roof regulation is expected to add 4300 ha (10,625 acres) of new cool roof statewide. Using the CIMIS solar radiation data for the years 2002-2008 for representative sites for 15 of the 16 zones (CIMIC has no sites in Zone 1 – the forested and sparsely populated north coast), and the expected albedo increment of 0.35 for cool roofing (Levinson *et al*., 2005), we calculated the expected negative radiative forcing (W/m^2) added per unit area of roof (m^2) for reflected sunlight. Applying those results across the roof area distribution derived from the LBL sample set, we calculated the expected area-weighted statewide negative radiative forcing per unit area of added cool roof. The results are reported in Table 1.

Applying this effective forcing to the 4300 ha of new cool roof resulting from ten years' construction gives a total annual average negative forcing of about 1.22 GW.

Cool Roofs in Perspective: To put this radiative forcing in perspective relative to other climate initiatives, it can be compared to the effects of an equivalent amount of CO_2 in the atmosphere. Based on the present day unit climate impact (positive radiative forcing) of CO_2 as determined from published estimates derived from experiments with a climate model (Hansen *et al*., 2005; Shindell *et al.*, 2009), this is equivalent to removing about 1.13 GT of CO_2 from the Earth's atmosphere.

It is important to recognize that this not a comparison with CO_2 emission rates; rather this is equivalent to counteracting the warming of this amount of CO_2 in the ambient atmosphere. This effect begins when the cool roof is built, will continue as long as the cool roof material is maintained in place, and would disappear if the cool roof were demolished or replaced with conventional roofing material.

Figure 1. Climate Zones of California (after Levinson *et al*., 2005).

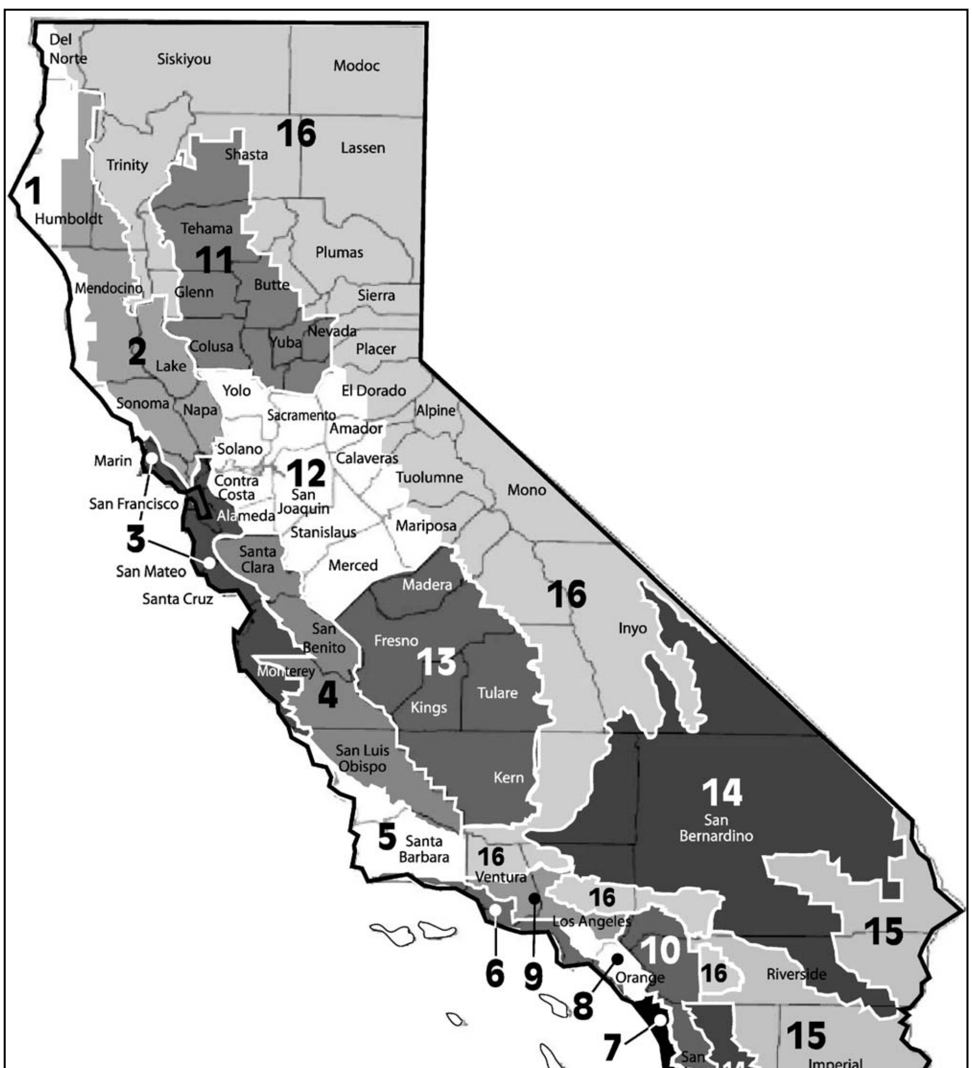

Table 1. Climate zone distribution of applicable roof area in 990 sample buildings (Levinson *et al*., 2005) and computed Negative Radiative Forcing for a Cool Roof in each zone. (This computation assumes a cool roof albedo increment of 0.35; dividing the numbers in the last column by 35 will yield the effective outgoing radiation for a unit albedo change of 0.01, for comparison with the generalize low latitude value of -1.27 used by Akbari *et al.* (2009).)

Zone	Fraction of Sample	Representative CIMIS Site	CIMIS Site Number	Average Negative Radiative Forcing W/m2 of "Cool Roof" Area	Equivalent Instantaneous Forcing of Ambient CO2, kg/m2 of "Cool Roof"
6	13.3%	Santa Monica	99	-30.0	-27.7
12	12.5%	Patterson	161	-23.9	-22.1
4	11.2%	Arroyo Seco	114	-26.8	-24.8
10	10.1%	U.C. Riverside	44	-29.2	-27.0
3	9.0%	Castroville	19	-22.4	-20.8
8	9.0%	Irvine	75	-30.1	-27.9
9	9.0%	Pomona	78	-27.7	-25.7
7	7.9%	Miramar	150	-30.5	-28.2
2	4.2%	Oakville	77	-25.3	-23.5
13	4.2%	Fresno State	80	-28.5	-26.4
14	3.7%	Barstow	134	-41.2	-38.1
11	2.2%	Gerber	8	-28.3	-26.2
15	2.2%	Blythe	135	-42.0	-38.9
5	1.3%	Santa Ynez	64	-25.9	-24.0
1	0.2%	None	n/a		
16	0.2%	Camino	13	-31.8	-29.5
	Statewide Weighted Average per Unit Area			-28.3	-26.2

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