The case for cool roofs

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Solar reflective "cool" roofs save energy, money, and CO_2 when applied to air-conditioned buildings; improve comfort when applied to unconditioned buildings; and offset CO_2 via global cooling (negative radiative forcing) whether or not the building is conditioned. They also relieve strain on the electrical grid by reducing late-afternoon peak power demand. Widespread use of cool roofs can lower outdoor air temperatures, further reducing the need for cooling energy, as well as improving air quality and human health by slowing the formation of smog (Rosenfeld et al. 1998).

Over the 20 year service life typical of roofing, a national cool roof campaign could save 5.7 quad of net primary energy with a present value of $33B. Net energy conservation could reduce CO_2 emissions by 0.25 Gt, and global cooling would offset another 0.57 Gt CO_2. **The PV of the energy savings alone would represent a return on EERE R&D investment of over 1000:1.** The first three columns of Table 1 summarize the energy, energy cost and CO_2 saving benefits of high-performance white roofs applied to U.S. commercial buildings in all climates (Case 1); cool colored roofs applied to U.S. residential buildings in RECS climate zones 3-5 (Case 2); and the combination of Cases 1 and 2 (Case 3). The last three columns of Table 1 (Cases 4 - 6) are analogous to the first three columns, but apply cool roofs only in the two hottest climate zones (RECS CZ 4-5).

We recommend a no-cost upgrade program in which cool roofs are selected for new construction and for end-of-service-life roof replacement. Upgrading U.S. commercial and residential roofs at end of service life could over 20 years save 3.0 quad of net primary energy with a present value of $15.5B, at little to no extra cost. Conventional white roofs generally cost the same as otherwise identical conventional dark roofs, because (a) black and white pigments are both inexpensive, and (b) pigments account for a small fraction of roof cost. High-performance white roofs minimize soiling and biological growth via inexpensive modifications (e.g., better retention of plasticizers and incorporation of biocides) and, therefore, are expected to cost about the same as conventional white roofs. We are aware of at least one high performance white roll roofing system sold today (aged solar reflectance 0.78) that costs slightly *less* than a conventional white roll roofing system from the same manufacturer (aged solar reflectance 0.58).

Cool colored clay tile, concrete tile, and metal roofs that replace conventional (NIR absorptive) pigments with cool (NIR scattering or transparent) pigments cost about the same as their conventional (warm) counterparts, because the pigments are responsible for only a small fraction of the product cost. Only for high-performance cool colored asphalt shingles is extra cost potentially expected because the need to maintain a rough, granular appearance makes increasing the solar reflectance of asphalt shingles more challenging than increasing that of other roofing products. We are exploring this technology in our FY12 Next Generation Cool Roofing Materials project.

Table 1. Cool roof energy savings, energy cost savings, CO_2 emission reductions, and CO_2 offsets. Rows show lifetime benefits, then annual benefits, then roof area. Note that third digit in each value is not likely to be significant.

Case	**1: Commercial, CZ [a] 1-5 [b]**	**2: Residential, CZ 3-5 [c]**	**3: Combined (cases 1,2)**	**4: Commercial, CZ 4-5 [d]**	**5: Residential, CZ 4-5 [e]**	**6: Combined (cases 4,5)**
Cumulative net primary energy savings over 20 year service life (quad, or PBTU) [f]	2.89	2.84	5.73	1.66	2.49	4.14
PV of net energy cost savings over 20 year service life ($B) [g]	16.4 [h]	16.2	32.6	9.42	14.1	23.5
Cumulative CO_2 emission reduction from energy conservation over 20 year service life (Mt)	125	123	247	71.4	107	179
One-time CO_2 offset from negative radiative forcing (Mt) [i]	277	288	566	144	214	358
Annual cooling primary energy savings (TBTU) [j]	165 [h]	162 [k]	327	90.6 [l]	133 [m]	223
Annual heating primary energy penalty (TBTU) [j]	20.8 [h]	19.9 [k]	40.7	7.72 [l]	8.52 [m]	16.2
Annual net primary energy savings (TBTU)	145	142	287	82.9	124	207
Annual cooling primary energy savings / annual heating primary energy penalty	7.95	8.14	8.04	11.7	15.6	13.8
Annual net energy cost savings ($B) [n]	1.10 [h]	1.08	2.19	0.632	0.948	1.58
Annual CO_2 emission reduction from energy conservation (Mt) [n]	6.23	6.13	12.4	3.57	5.36	8.9
Conditioned roof area to be upgraded (billion ft^2)	22.2 [o]	40.4 [p]	62.6	11.5 [q]	30.0 [p]	41.5

a. CZ refers to RECS U.S. climate zone (EIA 2011). There are 5 climate zones, ordered from coolest (1) to hottest (5). The studies by Levinson & Akbari (2010) and Konopacki et al. (1997) considered cool roofs in CZ 1-5 (all U.S. climates) and CZ 3-5 (three hottest U.S. climates), respectively, while Farese focused on cool roofs in CZ 4-5 (two hottest U.S. climates).

b. Upgrading 80% of conditioned roof area on U.S. commercial buildings to high-performance white (aged SR 0.70-0.75) from dark gray (aged SR 0.20).

c. Upgrading 95% of conditioned roof area on U.S. homes to high-performance cool color (aged SR 0.35-0.40) from traditional dark color (aged SR 0.05-0.10).

d. Same as Case 1, but limited to the two hottest U.S. climate zones.

e. Same as Case 2, but limited to the two hottest U.S. climate zones.

f. Calculated by multiplying annual energy savings by 20. If linearly phasing in cool roofs over N years, multiply instead by $\sum_{i=1}^{N}(i/N)$ to obtain cumulative savings over these N years.

g. Calculated by multiplying annual energy cost savings by 14.9, based on a real annual rate of return r =3%; see Table 1 of Levinson & Akbari (2010). If linearly phasing in cool roofs over N years, multiply instead by $\sum_{i=1}^{N}\left(\frac{i}{N}\right)\left(\frac{1}{1+r}\right)^{i}$ to obtain present value of cumulative savings over these N years.

h. Multiplied savings and penalties reported by Levinson & Abkari (2010) by 1.5 since (a) aged SR gain here (0.50-0.55) is 1.5 times that modeled in study (0.35), and (b) cool roof savings and penalties scale with gain in aged SR (Konopacki et al. 1997).

i. Using one-time offset of 64 kg CO_2/m^2 per 0.25 increase in aged SR (Akbari et al. 2009). Offset scales linearly with gain in aged SR.

j. Using U.S. average primary/site energy ratios = 3.107 electricity, 1.043 gas.

k. Adjusted residential annual cooling site energy savings and annual heating site energy penalty for CZ 3-5 reported in Table E-1 of Konopacki et al. (1997) following method described in Appendix of Levinson & Akbari (2010), then multiplied by 95% (fraction of residential roof area to be upgraded).

l. Derived from Farese's allocations of cooling energy savings and penalties to two hottest U.S. climate zones (see worksheet 'Cool roof calc' in his Prioritization tool).

m. Adjusted residential annual cooling site energy savings and annual heating site energy penalty for CZ 4-5 reported in Table E-1 of Konopacki et al. (1997) following method described in Appendix of Levinson & Akbari (2010), then multiplied by 95% (fraction of residential roof area to be upgraded).

n. In Cases n=2, 3, 4 and 5, obtained by scaling Case 1 result by ratio of Case n annual net primary energy savings to Case 1 annual net primary energy savings.

o. From Levinson & Akbari (2010).

p. Derived from Tables C-3 and E-1 of Konopacki et al. (1997).

q. Calculated by summing for each U.S. census division the product of its commercial building conditioned roof area and Farese's "share hottest 2" (see worksheet 'Cool roof calc' in his Prioritization tool).

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