Cool Roof Q & A (draft)

Ronnen Levinson
Lawrence Berkeley National Laboratory
RML27@cornell.edu

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The following information is intended for use in cool-roof brochures issued by the California Air Resources Board and/or the Cool Roof Rating Council.

See also http://CoolColors.LBL.gov and http://HeatIsland.LBL.gov .

Q: *What is a cool roof?*
A: The ideal "cool" roof is one whose surface is minimally heated by the sun, such as a bright white roof. However, sometimes the term "cool" is applied to a roofing product whose surface is warmer than that of a bright white material, but still cooler than that of a comparable standard product. For example, the afternoon surface temperature of a specially designed "cool" red roof is higher than that of a bright white roof, but lower than that of a standard red roof.

An example of a "hot" roof is one with a standard black surface, which grows very warm in the sun.

Q: *What makes a roof cool?*
A: The most important feature of an ideal cool roof is that its surface strongly reflects sunlight. The surface of an ideal cool roof should also efficiently cool itself by emitting thermal radiation. Thus, a cool roof should have both high "solar reflectance" (ability to reflect sunlight, measured on a scale of 0 to 1) and high "thermal emittance" (ability to emit thermal radiation, also measured on a scale of 0 to 1). The solar reflectance and thermal emittance of a surface are called its "radiative" properties because they describe its abilities to reflect solar radiation and emit thermal radiation.

An easy way to judge the coolness of a roof is to compare its surface temperature on a sunny afternoon to that of a reference black roof and that of a reference white roof. The "solar reflectance index" (SRI) assigns a coolness of 0 to the reference black roof (solar reflectance $R = 0.05$, thermal emittance $E = 0.90$) and a coolness of 100 to the reference white roof ($R = 0.80$, $E = 0.90$). Most roofing materials have an SRI (coolness rating) between 0 and 100, though values can be below 0 (hotter than reference black) or above 100 (cooler than reference white). The higher the SRI, the cooler the surface.

Q: *What happens to sunlight reflected from a cool roof?*
A: On a clear day about 80% of sunlight reflected from a horizontal roof will pass into space without warming the atmosphere or returning to Earth.

Q: *What are some examples of a cool roof?*

A: A roof with a clean, smooth bright white surface can reflect about 85% of incident sunlight (R = 0.85) and emit thermal radiation with 90% efficiency (E = 0.90). This surface has an SRI of 107 and will be only 9°F [5 K] warmer than the outside air on a typical summer afternoon. For comparison, the surface of a standard gray roof that reflects only about 20% of incident sunlight (R = 0.20, E = 0.90) has an SRI of just 19, and a surface temperature elevation (surface temperature – outside air temperature) ΔT of 69°F [38 K].

A roof with a clean, smooth "cool color" surface, such as a cool red tile, can reflect about 35% of incident sunlight (R = 0.35) and emit thermal radiation with 90% efficiency (E = 0.90). This surface has an SRI of 38 and a ΔT of 56°F [31 K]. The cool red tile is much warmer than the bright white roof, but still cooler than a standard red tile (R = 0.10, E = 0.90, SRI = 6, ΔT = 78°F [44 K]).

A roof with a clean, bare zincalume steel surface can reflect about 75% of incident sunlight (R = 0.75) but emits thermal radiation with only 5% efficiency (E = 0.05). This surface has an SRI of 68 and a ΔT of 36°F [20 K]. The surface of the bare zincalume steel is warmer than that of the bright white roof (SRI = 107), but still cooler than that of the cool red tile (SRI = 38) and the standard red tile (SRI = 6).

Figure 1 shows the initial solar reflectance, solar reflectance index, and surface temperature elevation (surface temperature minus outside air temperature on a summer afternoon) of cool products for low-sloped roofs (pitch ≤ 2:12), such as single-ply membranes, field applied coatings, and modified bitumen. Figure 2 does the same for cool materials for steep-sloped roofs (pitch > 2:12), including white and cool color tile, shingle, and metal products.

Q: *What is a "cool color"?*
A: About half of all sunlight arrives in the invisible "near-infrared" spectrum. Standard light-colored surfaces strongly reflect both visible and near-infrared sunlight, while standard dark colored surfaces reflect modestly in both spectra. Special dark and medium-colored surfaces that strongly reflect near-infrared sunlight are called "cool colors." The solar reflectance of a cool dark color can exceed that of a standard dark color by about 0.4.

Q: *Do cool roofs stay cool?*
A: Over time, the deposition of airborne particles, the growth of microorganisms, and/or the oxidation of bare metal can reduce the solar reflectance of a cool roof. These events can also increase the thermal emittance of certain materials, especially those with bare metal surfaces. Eventually an equilibrium is reached between processes that soil the surface, such as particle deposition, and processes that clean the surface, such as wind and rain. Since the solar reflectance and thermal emittance of a outdoor surface typically reach steady values within one to three years, the "aged" solar reflectance and thermal emittance of a roofing product are measured after three years of natural exposure.

Figure 3 shows the aged solar reflectance, solar reflectance index, and surface temperature elevation (surface temperature minus outside air temperature on a summer afternoon) of cool products for low-sloped roofs.

Three years of exposure reduces the solar reflectance of an initially bright-white low-sloped roof to 0.65 from 0.85, and leaves the thermal emittance unchanged at 0.90. This lowers its SRI to 79 from 107 and increases its ΔT to 28°F [16 K] from 9°F [5 K]. Exposure also reduces the solar reflectance of a bare zincalume steel roof to 0.50 from 0.75, and increases its thermal emittance to 0.20 from 0.05. This lowers its SRI to 26 from 68, and increases its ΔT to 65°F [36 K] from 36°F [20 K]. Exposure has no net effect on a standard gray roof, which retains R = 0.20, E = 0.90, SRI = 19 and ΔT = 69°F [38 K].

Because they are newer to market, these is less information currently available about the effects of exposure on the solar reflectances and thermal emittances of cool materials for steep-sloped roofs, such as white and cool color tile, shingle, and metal products, However, preliminary data indicate that the radiative properties of cool color products for steep-sloped roofs are minimally changed by exposure.

Q: *Are green roofs cool? What about thermally massive, super-insulated, and/or ventilated roofs?*
A: There are a variety of roofing assembly technologies that can reduce the flow of heat into a building, including but not limited to solar-reflective, thermally emissive surfaces; vegetative cover (green roofing); thermally massive construction; super-insulation; and ventilation. We reserve the term "cool roof" to refer to one that stays cool in the sun by virtue of high solar reflectance and (preferably) high thermal emittance.

Q: *When should I install a cool roof?*
A: We recommend selecting a cool product for new construction or when an old roof is scheduled to be retrofitted. It is rarely economical to replace a mechanically sound roof just to increase its solar reflectance.

Q: *Can I paint my roof white or a cool color?*
There are specialized white elastomeric coatings available for low-sloped products and cool color polymer coatings available for tiles that can be sprayed on existing roofs.

Q: *What does a cool roof cost?*
A: The price of a cool roof is typically comparable to that of a standard (hot) roof of the same type, because coloration is responsible for a very small portion of the total installed cost of any roofing product.

Q: *What are the benefits of a cool roof?*
A: Selecting a cool roof instead of a standard (hot) roof directly benefits the occupants of the building, and indirectly benefits the entire community. Installing a solar-reflective roof can also immediately slow global warming through a process called "global cooling."

DIRECT BENEFITS

Substituting a cool material for a standard (hot) material lowers the daytime surface of temperature of the roof, which in turn reduces the flow of heat into the occupied space. This conserves energy in an air-conditioned building and makes an unconditioned building more comfortable.

Reducing the need for cooling doesn't just save money—it also reduces the emission of pollutants from electric power plants, including carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and mercury (Hg).

Reducing the building peak cooling load with a cool roof can allow the installation of a smaller, less expensive air conditioner. This is referred to as a "cooling equipment" saving. Smaller air conditioners are also typically less expensive to run, because air conditioners are more efficient near full load than at part load.

Choosing a cool roof instead of a standard roof can slightly increase the need for heating energy in winter. However, winter penalties are often much smaller than summer savings even in cold climates because the northern mainland U.S. (latitude ≥ 40°N) receives about 3 to 5 times as much daily sunlight in summer as in winter.

The tables at the end of this document show in each California climate zone the present value of lifetime energy cost savings, the sum of the cooling equipment savings and the energy cost savings, and annual emission reductions for installation of a cool low-sloped roof on a nonresidential (office) building, and also for the installation of cool color shingle, tile and metal steep-sloped roofs on homes with and without attic radiant barriers.

Finally, lowering the peak daytime temperature of soft roofing products, such as single-ply membranes and asphalt shingles, may help them last longer by reducing the stress resulting from thermal expansion during the day and thermal contraction at night.

Indirect benefits

The citywide installation of cool roofs can lower the average surface temperature, which in turn cools the outside air. Cool roofs thereby help mitigate the "daytime urban heat island" by making cities cooler in summer. This makes the city more habitable, and saves energy by decreasing the need for air conditioning in buildings. For example, a program to install cool roofs, cool pavements, and trees over about 30% of the surface of the Los Angeles basin has been predicted to lower the outside air temperature by about 5°F [3 K]. Additional annual building energy savings expected from the cooler outside air are estimated to be about half those resulting from the cool roof itself.

Cooler outside air improves air quality by slowing the temperature-dependent formation of smog. Decreasing the outside air temperature in the Los Angeles basin by 5°F [3 K] is predicted to reduce smog (ozone) by about 10%, worth about $300M/yr in avoided emissions of smog precursors (e.g., NO_x).

Cool roofs decrease summer afternoon peak demand for electricity, reducing the strain on the electrical grid and thereby lessening the likelihood of brownouts and blackouts.

Global cooling

Replacing a hot roof with a cool roof immediately reduces the flow of thermal radiation into the troposphere ("negative radiative forcing"). Substituting 1000 ft^2 [100 m^2] of cool white roofing for standard gray roofing provides a *one-time* (not annual) offset of about 10 metric tons of CO_2, worth $250 at a price of $25/t CO_2. Similarly, substituting 1000 ft^2 [100 m^2] of cool color roofing for standard color roofing provides a *one-time* offset of about 5 metric tons of CO_2, worth $125. While the roof must be kept cool to retain this benefit, the offsets are based on aged, rather than initial, values of solar reflectance.

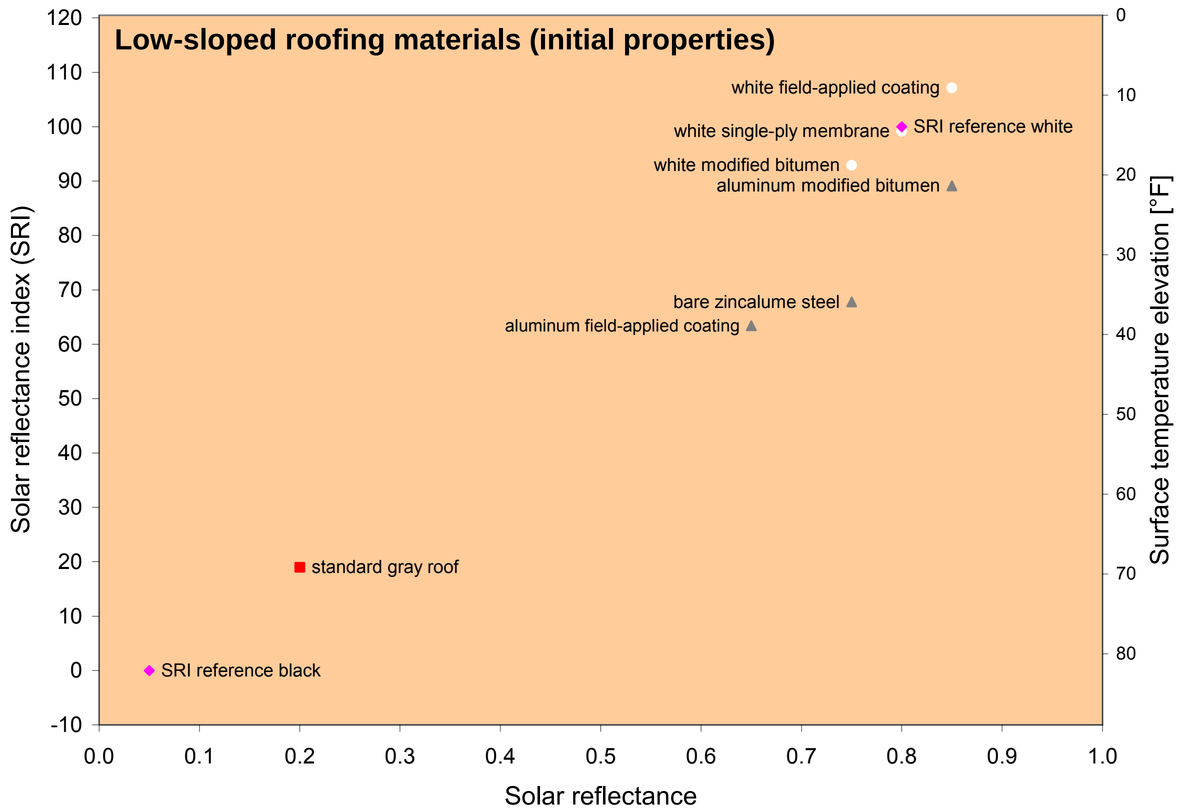

Figure 1. Initial solar reflectance, solar reflectance index (SRI), and surface temperature elevation (surface temperature – outside air temperature) of products for low-sloped roofs.

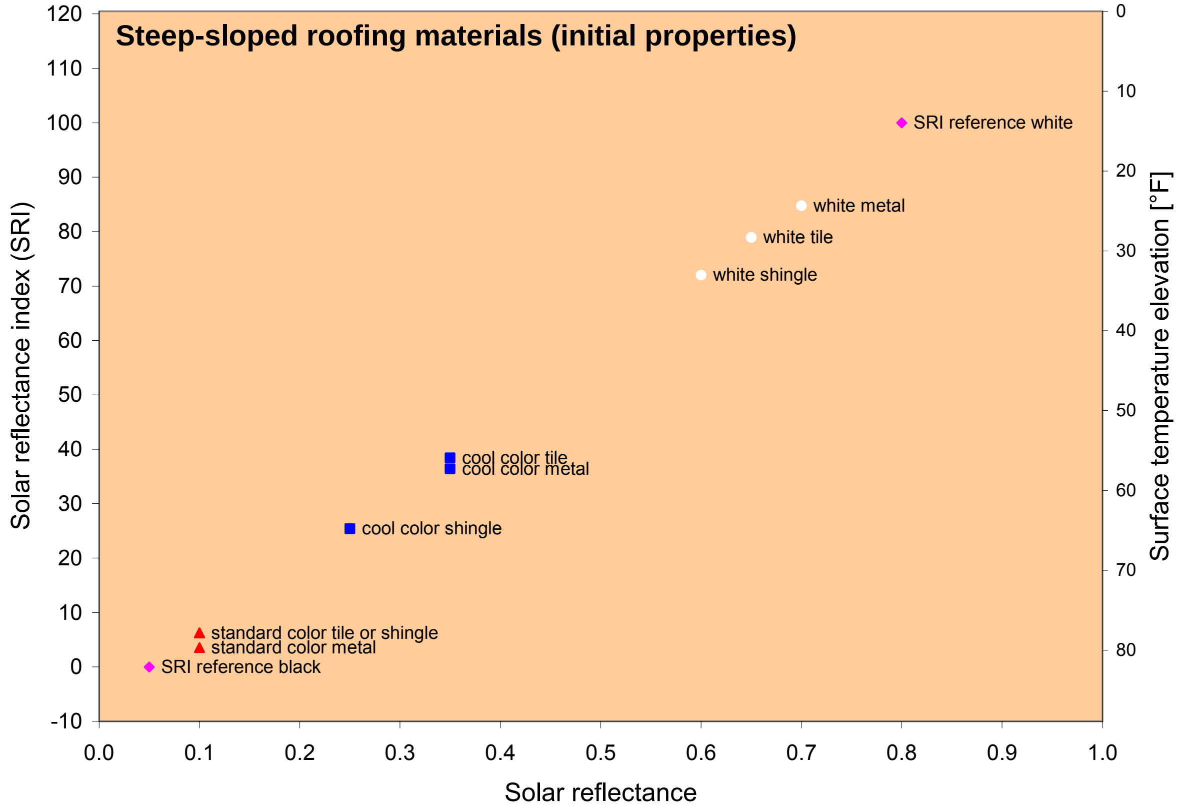

Figure 2. Initial solar reflectance, solar reflectance index (SRI), and surface temperature elevation (surface temperature – outside air temperature) of products for steep-sloped roofs.

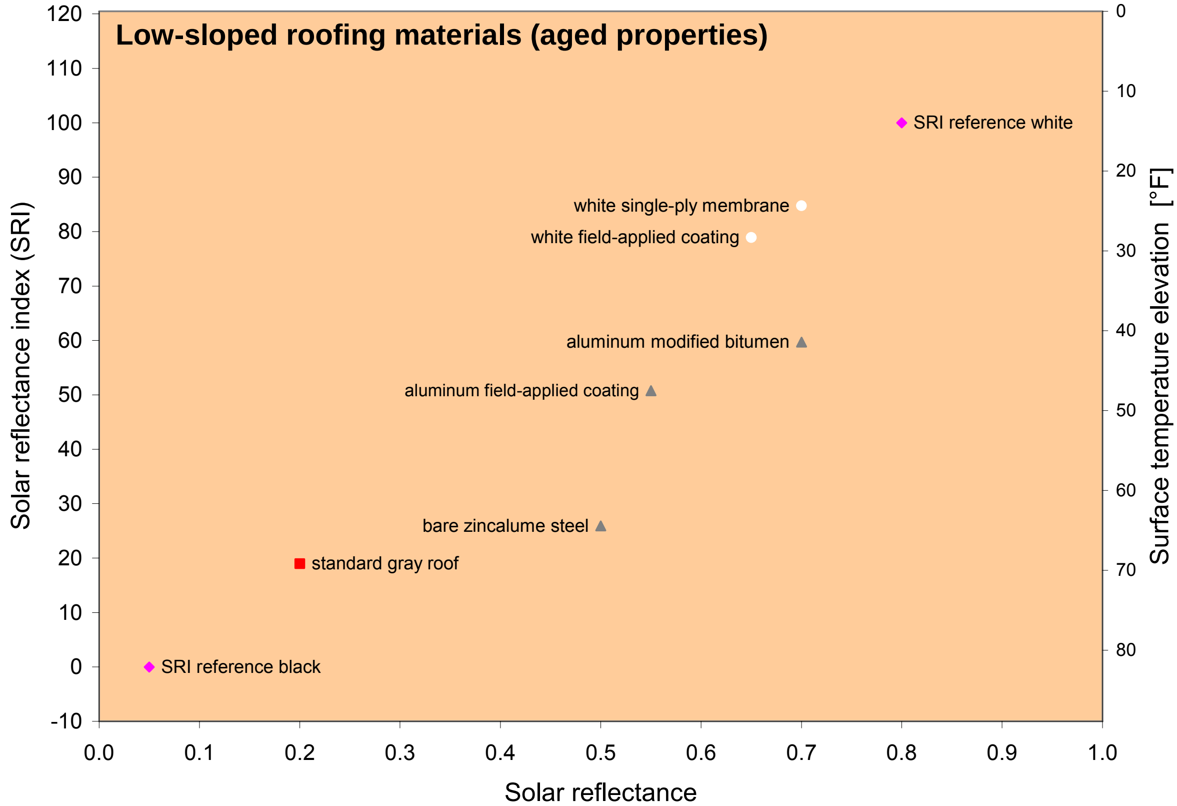

Figure 3. Aged solar reflectance, solar reflectance index (SRI), and surface temperature elevation (surface temperature – outside air temperature) of products for low-sloped roofs after three years of natural exposure.

Nonresidential (office) building (based on LBNL's 2005 Title 24 CASE study)

Roofing product	built-up roof							
ΔR in T24 simulation	0.35							
ΔR for CARB table	0.35							
result scaling factor	1.00							
climate zone	15-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 15-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	109	176	115	8	2	5	29	20
2	442	542	295	6	87	76	74	228
3	294	370	184	5	48	42	46	128
4	380	470	246	4	76	66	61	198
5	300	383	193	5	52	46	48	139
6	596	707	388	4	133	115	97	341
7	489	614	313	3	111	96	78	283
8	647	772	413	4	145	125	103	371
9	618	719	402	5	137	118	100	351
10	521	610	340	4	117	101	85	299
11	411	486	268	5	81	71	67	212
12	438	533	286	5	86	75	71	226
13	547	643	351	5	113	98	88	293
14	536	641	352	5	116	100	88	298
15	583	665	380	2	143	122	95	361
16	309	399	233	11	37	35	58	112

Residential building, standard insulation, no radiant barrier (based on LBNL's 2008 Title 24 CASE study)

Roofing product	**shingle**								
ΔR in T24 simulation	0.15								
ΔR for CARB table	0.15								
result scaling factor	1.00								
climate zone	30-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 30-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	-97	-80	4	4.5	-22	-17	1	-48
2	179	206	98	6.2	6	8	24	27
3	-5	20	18	2.7	-7	-5	4	-13
4	58	86	45	3.9	-3	-1	11	1
5	12	34	23	2.7	-5	-3	6	-8
6	40	68	22	1.4	1	2	5	6
7	80	111	39	2.2	4	4	10	14
8	247	284	91	2.5	23	21	23	63
9	295	324	103	2.1	30	26	26	79
10	490	529	169	3.2	51	44	42	133
11	469	512	159	2.6	50	43	40	129
12	316	344	116	3.1	30	27	29	81
13	587	632	196	2.8	63	55	49	164
14	452	490	171	4.9	42	38	43	115
15	761	790	234	0.9	89	76	59	224
16	209	259	92	4.1	15	14	23	45

Roofing product	**tile**							
ΔR in T24 simulation	0.30							
ΔR for CARB table	0.25							
result scaling factor	0.83							
climate zone	30-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 30-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	-156	-133	3	6.9	-35	-28	1	-76
2	189	229	129	10.2	-2	2	32	13
3	-17	17	24	4.1	-12	-9	6	-22
4	46	88	56	5.9	-9	-5	14	-11
5	-10	18	28	4.3	-12	-8	7	-21
6	39	76	28	2.3	-1	0	7	2
7	95	129	51	3.2	4	4	13	15
8	300	351	117	3.8	27	24	29	74
9	374	415	136	3.3	37	32	34	98
10	633	690	226	5.2	63	56	56	167
11	626	681	215	3.8	65	57	54	171
12	414	453	157	4.7	38	34	39	104
13	797	863	269	4.3	84	74	67	220
14	588	645	232	7.8	51	46	58	142
15	1029	1068	319	1.6	119	102	80	301
16	274	348	126	6.3	17	17	31	55

Roofing product	**metal**							
ΔR in T24 simulation	0.30							
ΔR for CARB table	0.25							
result scaling factor	0.83							
climate zone	30-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 30-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	-166	-135	7	8	-39	-30	1	-83
2	343	391	177	11	15	17	44	58
3	-3	40	32	5	-12	-8	8	-21
4	120	171	84	7	-2	1	21	7
5	26	67	41	5	-8	-5	10	-12
6	78	130	41	3	3	4	10	13
7	154	212	73	4	9	9	18	30
8	458	524	167	4	44	39	42	119
9	545	598	188	4	56	49	47	147
10	892	963	304	5	94	82	76	244
11	863	943	291	5	92	80	73	239
12	586	636	213	5	57	50	53	152
13	1068	1148	354	5	116	100	88	298
14	828	894	308	8	78	70	77	212
15	1388	1441	427	2	161	138	107	408
16	383	470	166	7	28	26	41	83

Residential building, standard insulation, radiant barrier (based on LBNL's 2008 Title 24 CASE study)

Roofing product	**shingle**							
ΔR in T24 simulation	0.15							
ΔR for CARB table	0.15							
result scaling factor	1.00							
climate zone	30-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 30-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	-70	-59	1	3.1	-16	-12	0	-34
2	102	122	56	3.5	4	4	14	16
3	-6	11	12	2.0	-6	-4	3	-11
4	27	49	27	2.7	-3	-2	7	-4
5	2	17	15	2.0	-5	-3	4	-8
6	23	42	14	1.1	0	0	4	2
7	44	61	24	1.5	2	2	6	7
8	142	167	54	1.7	13	11	14	35
9	185	207	66	1.4	19	17	16	50
10	292	321	101	1.9	30	26	25	79
11	303	328	104	1.9	32	28	26	83
12	204	224	76	2.1	19	17	19	52
13	357	385	120	1.9	38	33	30	98
14	279	304	106	3.1	26	23	26	70
15	502	524	154	0.6	58	50	39	147
16	113	144	55	2.9	7	7	14	22

Roofing product	**tile**								
ΔR in T24 simulation	0.30								
ΔR for CARB table	0.25								
result scaling factor	0.83								
climate zone	30-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 30-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	-109	-93	2	4.8	-25	-19	0	-53
2	136	167	80	5.4	3	5	20	18
3	-15	10	17	3.0	-9	-7	4	-17
4	33	68	39	4.1	-6	-4	10	-7
5	-11	10	19	3.1	-9	-6	5	-16
6	21	48	18	1.7	-2	-1	4	-1
7	56	79	34	2.4	1	2	8	6
8	190	228	75	2.6	16	15	19	46
9	255	288	92	2.2	25	22	23	67
10	413	455	145	3.0	42	37	36	110
11	437	471	151	2.8	45	39	38	118
12	288	318	110	3.3	27	24	27	72
13	526	570	179	2.9	56	49	45	145
14	401	438	154	4.8	36	32	38	99
15	729	761	226	1.0	85	73	56	214
16	155	204	79	4.5	8	8	20	27

Roofing product	**metal**							
ΔR in T24 simulation	0.30							
ΔR for CARB table	0.25							
result scaling factor	0.83							
climate zone	30-yr NPV of TDV energy savings ($/1000ft2)	cooling equipment savings + 30-yr NPV of TDV energy savings ($/1000ft2)	cooling energy savings (kWh/1000ft2/yr)	heating energy penalty (therm/1000ft2/yr)	CO2 emission reduction (kg/1000ft2/yr)	NOx emission reduction (g/1000ft2/yr)	SO2 emission reduction (g/1000ft2/yr)	Hg emission reduction (µg/1000ft2/yr)
1	-122	-103	3	6	-28	-22	1	-60
2	187	221	99	6	8	9	25	30
3	-8	22	22	3	-9	-7	5	-17
4	52	91	49	5	-5	-3	12	-4
5	5	33	26	3	-8	-5	6	-13
6	41	76	26	2	0	1	6	4
7	78	109	42	3	3	3	10	12
8	256	301	97	3	24	21	24	65
9	333	373	117	2	34	30	29	89
10	519	568	179	3	54	47	45	142
11	543	588	186	3	57	50	46	149
12	363	400	135	4	34	30	34	92
13	632	683	213	3	67	59	53	175
14	497	539	187	5	46	41	47	125
15	894	933	275	1	104	89	69	263
16	199	254	97	5	11	11	24	37