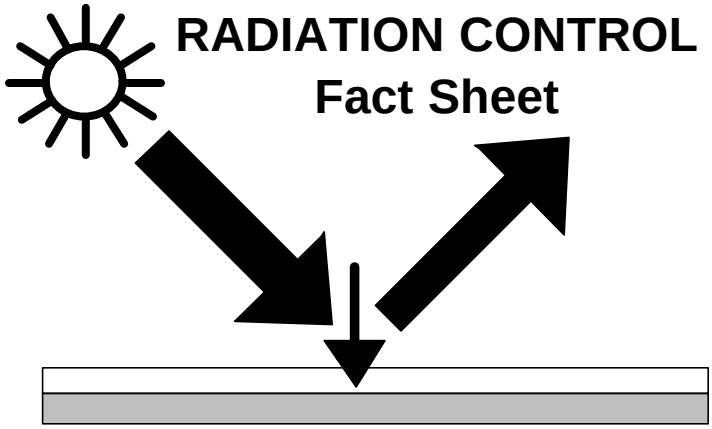

Introduction

How does solar radiation affect the temperature of a roof surface and heat flow through the roof?

This radiation control fact sheet focuses on low-slope roofs for commercial buildings. The membranes or weatherproofing materials used for these roofs are opaque to solar radiation. When opaque roof surfaces are exposed to solar radiation, no solar radiation is directly transmitted through the roof. The sketch in the heading for this fact sheet is an opaque low-slope roof interacting with solar radiation. It illustrates that some of the sunlight is reflected away by the surface and the rest is absorbed. The fraction reflected is given by the solar reflectance of the surface, a number between 0 and 1 which applies to the solar part of the electromagnetic spectrum. Solar radiation includes the wavelength range from near ultraviolet to near infrared, spanning what is visible to the human eye. The sketch assumes a solar reflectance of about 0.85.

The solar radiation that is absorbed heats the surface. The absorbed energy is no longer solar energy. It is characterized by the temperature of the surface material, which is much lower than the equivalent solar temperature. Consequently, the surface emits radiation in the far infrared part of the spectrum. This infrared radiation is not to be confused with the reflected solar radiation. The amount emitted is in direct proportion to the surface's infrared emittance, a number between 0 and 1 which is generally different from the solar reflectance. A roof surface also exchanges energy by convection with the air above the roof and by conduction with the layer of the roof directly below the surface. Moisture effects, mainly evaporation and condensation of liquid water on the surface, are occasionally important for low-slope roofs.

The temperature of the roof surface is determined by a balance among energy gains and losses, including energy stored in the roof. The peak surface temperature strongly depends on the peak solar radiation and the solar reflectance of the surface. On a sunny day in late June, all of July or early August, a black roof surface (solar reflectance less than 0.1) may reach peak temperatures exceeding 170˚F (77˚C). At the same time, a highly reflective white surface (solar reflectance greater than 0.8) could be less than 110˚F (43˚C).

For steady conditions, heat flow per unit area through a roof is given by the quotient of the temperature difference across the roof and the total thermal resistance of the roof. On a cloud-free

day in the middle of summer for typical inside surface temperatures of 80˚F (27˚C), radiation control causes a decrease in the temperature difference across the roof from about 90˚F to 30˚F (from about 50˚C to 17˚C). If the total thermal resistance (R-value) of the materials present in the roof is small, a significant decrease in steady heat flux through the roof will occur. If the roof has significant thermal capacitance (thermal mass), absorbed energy will be stored in the roof and heat fluxes through the roof will be delayed and diminished, lessening the effect of radiation control. Cloudiness and other non-steady conditions also decrease the heat flux through the roof relative to the maximum steady value.

What affects the values of the solar reflectance and the infrared emittance?
The solar reflectance and infrared emittance of a surface are both dependent upon the kind of material that forms the surface and the condition of the surface. The effect of weathering is significant for solar reflectance. A typical white coating with initial solar reflectance exceeding 0.8 will likely have solar reflectance below 0.55 after a few years of exposure, if the surface is unprotected from airborne dust and contaminants. Typical white coatings seem to retain infrared emittances greater than 0.8 despite changes in solar reflectance. A typical aluminum coating with initial solar reflectance of about 0.6 will likely have solar reflectance about 0.4 after a few years of exposure. Typical aluminum coatings have infrared emittances from 0.3 to 0.5 when new and the infrared emittances increase to values from 0.5 to 0.7 due to weathering. These values of solar reflectance and infrared emittance are averages over the variations in surface temperature that roof surfaces undergo due to daily and seasonal climate changes.

Surface contamination and alterations cause the changes in radiation properties. Together they comprise what is called weathering. Contamination occurs over time due to atmospheric pollution and biological growth. Alterations occur due to many factors including ultraviolet radiation, temperature cycling due to sunlight, sudden temperature swings due to rain, moisture penetration, condensation and evaporation of dew, wind, freezing and thawing and effects of sleet, snow and hail. Rain and deliberate washing may temporarily help restore high solar reflectance but not to initial levels. Our experience with the entire range of commercially available coating materials in a three-year outdoor test in East Tennessee indicates that thorough washing of fully-weathered white coatings restores about 40% of the average 0.27 decrease in solar reflectance due to weathering. Thorough washing of fully-weathered aluminum coatings restores about 55% of the average 0.20 decrease in solar reflectance due to weathering. Washing did not affect infrared emittance of white coatings but appeared to restore the initial infrared emittance of aluminum coatings.

Because of the dependence on surface condition, solar reflectance and infrared emittance are not properties of the surface material alone. Values for solar reflectance and infrared emittance need to be qualified by descriptions of the material and its condition. For example, a clean metal surface has a high solar reflectance and a low infrared emittance. An oxidized or rusty metal surface would likely have a lower solar reflectance and a higher infrared emittance. Various combinations of high to low solar reflectances and high to low infrared emittances are possible with different surface materials and conditions. The values are not related.

What is solar radiation control?
Solar radiation control for low-slope roofs follows from use of surface materials which have high reflectance in the solar part of the electromagnetic spectrum and high emittance in the infrared part of the spectrum. High means 0.75 or more on a scale from 0 to 1. Such materials are known as 'cool materials.' See http://EETD.LBL.gov/HeatIsland/CoolRoofs/ for a comprehensive discussion, by researchers in the Heat Island Group at Lawrence Berkeley National Laboratory, of the importance of both solar reflectance and infrared emittance and techniques to measure them. Since the amounts of solar energy absorbed and infrared energy reemitted by low-slope roofs are linearly proportional to solar reflectance and infrared emittance, respectively, materials with solar reflectances and infrared emittances less than 0.75 are able to do some radiation control.

The objective of solar radiation control is to decrease the cooling load on a building. For commercial buildings, the high intensity of summertime direct solar radiation on horizontal surfaces and the large area of low-slope roofs makes these roofs the primary target for solar radiation control. High solar reflectance for the roof surface causes much of the solar radiation to be reflected away before it can affect the energy balance for the roof. High infrared emittance enhances the ability of the roof to radiate some of the absorbed solar energy and energy from inside the building to the sky, which is helpful during the cooling season. Especially on clear nights, the equivalent sky temperature is much lower than the roof temperature. It is common for surfaces with high infrared emittances to be 5˚F to 10˚F (3˚C to 6˚C) cooler than the outside air temperature on clear nights. Surfaces with low infrared emittances can be that much warmer than the outside air temperature, which can help to decrease the heating load on a building during the heating season.

Is radiation control recommended for all low-slope roofs?
With current methods to achieve radiation control on low-slope roofs, radiation control is a passive technology. It works night and day, all year round, except during rainy periods or when the roof is covered by dew. A layer of water has high infrared emittance. This dominates the nighttime behavior of a dew-covered roof. Even if air temperatures are several degrees above freezing, thin layers of water exposed to the night sky will freeze on clear nights. Until solar energy evaporates ponds or dew from a roof, the roof temperature remains near the ambient air temperature. In effect, therefore, even though it complicates the energy effects, water on a roof enhances radiation control.

Since solar radiation control cuts down on the amount of solar radiation absorbed by a roof, there is less heat gain during sunny periods through a roof with radiation control than without it. This heat gain may be desirable during the heating season. The diminution of heat gain during the heating season by solar radiation control is commonly referred to as a heating penalty. Many commercial buildings are dominated by the internal loads due to equipment and people. Hence, radiation control is not necessarily undesirable even in climates with a large number of heating degree-days. Heating degree-days are a common measure of the potential for conduction heat losses through the building envelope. They do not indicate how large the heat gains from internal sources are relative to the heat losses through the building envelope. That needs to be determined on a case-by-case basis. Only heat losses through the building envelope are proportional to the heating degree-days.

How is solar radiation control achieved if it is desired?
Solar radiation control can be implemented during construction of a roof by selection of a membrane material with the desired characteristics of high solar reflectance and high infrared emittance. Since traditional built-up roofs are constructed by mopping down layers of roofing felts with asphaltic materials, they have radiation properties typical of asphaltic materials: very low solar reflectances (less than 0.1) and high infrared emittances (greater than 0.8). A layer of gravel on top of a built-up roof may have slightly higher solar reflectance and does add thermal mass, but it does not qualify the roof to be termed a roof with solar radiation control. Low-slope roof materials with composition like light-colored shingles for high-slope roofs (asphaltic materials with small light-colored granules embedded in the surface) have solar reflectance no higher than 0.25.

Single-ply roofing membranes are available with high solar reflectances and high infrared emittances. They can be installed with the same techniques as used for traditional black single-ply roofs made from ethylene propylene diene monomer (EPDM) or atactic polypropylene polymer (APP)-modified bitumen. Mechanical fasteners can be used to attach the roof insulation and the radiation control membrane to the roof deck in a sufficient number of spots to meet requirements for resistance to wind uplift and other structural requirements. Alternately, the insulation can be attached to the roof deck by fasteners or other means and the membrane can be adhered to the insulation with a suitable adhesive.

After construction of a traditional black roof, solar radiation control can still be achieved. Liquid coatings can be sprayed, brushed or rolled on to the membrane. They dry to form a surface with radiation properties independent of those of the substrate. True radiation control coatings, with initial out-of-the-can solar reflectances greater than 0.75 and infrared emittances greater than 0.75, are generally white, water-based latex or acrylic products with titanium dioxide added to achieve high solar reflectance. The membrane needs to weather several weeks and/or special base coats must be applied to form a good bond between the coating and the roof.

Other coating materials and capsheets are available with initial solar reflectances generally less than 0.75 and infrared emittances anywhere from low to high values depending upon the material. Many have aluminum particles added to enhance the solar reflectance. A good bond between the coating and the substrate is also very important for these coatings and some weathering of the substrate and/or special base coats are needed to achieve it. Capsheets are a layer of bare or coated metal which is factory-applied to a substrate of asphaltic single-ply membrane material. The substrate with capsheet attached can be torch-adhered or adhesive-adhered to a fresh or weathered asphaltic roof membrane.

Effect of Solar Radiation Control on Energy Costs

This section presents an interactive tool to assist commercial building owners and/or operators in estimating the maximum effect of solar radiation control on energy needs for a building under a low-slope roof. To generate data for the equations used in the estimating tool, a computer model was run over a wide range of climates for various roofs. No other part of the building envelope was modeled. The climates were represented by typical meteorological year data from the Renewable Resource Data Center, with web site http://rredc.nrel.gov/solar/old_data/nsrdb/tmy2/. The following locations were used and their climates go from cooling-dominated to heating-dominated: Phoenix, Arizona; Miami, Florida; Tampa, Florida; Dallas/Fort Worth, Texas; Knoxville, Tennessee; Boulder, Colorado; Minneapolis, Minnesota and Anchorage, Alaska. The low-slope roofs had light weight decks and insulation levels of R-4.8, R-12.6, R-25.2 and R-31.5 $h \cdot ft^2 \cdot {}^\circ F/Btu$ (R-0.9, R-2.2, R-4.4 and R-5.5 $m^2 \cdot K/W$).

Seven combinations of solar spectrum reflectance R and infrared emittance E were modeled. They corresponded to measured values after two years in a comprehensive study of the thermal performance of twenty-four different coatings and four uncoated specimens. See the article http://www.ornl.gov/roofs+walls/research/reflective.htm on this web site. The combinations RxxEyy, where xx is the percentage solar reflectance and yy is the percentage infrared emittance, were R70E90 and R48E82, for the highest and lowest reflectance white latex coatings, respectively; R50E52 and R26E68, for the highest and lowest reflectance aluminum coatings, respectively; R33E90 for an aluminized asphalt emulsion, R64E11 for an aluminum capsheet; and R05E90 for an uncoated roof membrane.

Cooling load per unit area of the roof on the building cooling equipment was defined as the annual sum of heat flow through the roof deck when outside air temperature exceeded 75˚F (24˚C). Heating load per unit area of the roof on the building heating equipment was defined as the annual sum of heat flow through the roof deck when outside air temperature was below 60˚F (16˚C). Inside air temperature below the roofs was held at 72.5˚F (22.5˚C) and no thermostat setup or setback was modeled. Judging from results with a warehouse in an annual energy use estimate for the whole building, including severe thermostat setup and setback during unoccupied hours, the loads used for the estimating tool show the maximum amount of energy savings from radiation control on roofs of buildings with small internal loads.

In the estimating tool, polynomials are used to fit the results from the roof-only model. This permits the user to input parameters of interest that are not exactly the values used in the model. The cooling loads are fit as a function of solar reflectance and infrared emittance of the roof surface, roof thermal resistance, and cooling degree days and average daily solar irradiation of the location. The heating loads are fit as a function of solar reflectance and infrared emittance of the roof surface, roof thermal resistance, and heating degree days for the location.

Assuming a constant price for electricity and a constant efficiency of the air conditioning equipment, cooling savings are calculated relative to the cost to cool a building with an uncoated roof. The difference between the cooling load for the uncoated roof and the roof with radiation control is multiplied by average cost per kWh of electricity and divided by the average coefficient of performance of the air conditioner.

Assuming a constant price for natural gas or other heating fuel, including a separate heating season price if electricity is used for both heating and cooling, and a constant efficiency of the heating equipment, heating savings are calculated relative to the cost to heat a building with an uncoated roof. The difference between the heating load for the uncoated roof and the roof with radiation control is multiplied by average cost per Therm of natural gas or other fuel and divided by the average efficiency of the heating system. A negative difference means there is a heating penalty with radiation control. The sum of cooling savings and heating savings gives the net savings in U.S.$/ft² of roof area per year. For U.S.$/m² of roof area per year, multiply by 10.76.

For example, using an average cooling coefficient of performance of 2.5 and average furnace efficiency of 0.85 along with year 2000 to date average commercial electricity cost ($0.0745/kWh) and year 1999 average commercial natural gas cost ($0.533/Therm), Table 1 shows results as a function of location and roof thermal resistance. For detailed information on the cost of electricity and natural gas, see the Energy Information Administration Form EIA-826 for monthly electric utility sales and Form EIA-176 for annual natural and supplemental gas supply and disposition. State-by-state prices from these forms are suggested in the estimator when a state is chosen. Links to the current data are provided for the user to consult if needed to make a decision on whether or not to change the suggested prices.

Table 1. **Example net savings in annual energy costs per square foot of coated low-slope roof and R-value for an uncoated roof with same annual energy costs as a coated low-slope roof** for $0.0745/KWh of electricity with air conditioner COP=2.5 and $0.533/Therm of natural gas with furnace efficiency=0.85. RxxEyy means solar reflectance of xx% and infrared emittance of yy%. The roof with an uncoated surface has R05E90. The R70E90 surface is the best white latex coating, the R50E52 surface is the best aluminum coating, and the R64E11 surface is an aluminum capsheet, with all RxxEyy values obtained after two years of weathering in the study described in http://www.ornl.gov/roof+walls/research/reflective.htm.

	Net Savings ($/ft²) vs. R05E90			**$R_{uncoated}$ for Net Savings = 0**		
Miami	**R70E90**	**R50E52**	**R64E11**	**R70E90**	**R50E52**	**R64E11**
R-5 h·ft²·°F/Btu	$0.166	$0.077	$0.074	R-13	R-8	R-8
R-13 h·ft²·°F/Btu	$0.070	$0.032	$0.029	R-32	R-17	R-16
R-25 h·ft²·°F/Btu	$0.038	$0.017	$0.016	R-35	R-32	R-32
R-32 h·ft²·°F/Btu	$0.030	$0.013	$0.012	R-36	R-34	R-34
Knoxville	**R70E90**	**R50E52**	**R64E11**	**R70E90**	**R50E52**	**R64E11**
R-5 h·ft²·°F/Btu	$0.067	$0.047	$0.062	R-7	R-7	R-7
R-13 h·ft²·°F/Btu	$0.028	$0.018	$0.024	R-16	R-15	R-16
R-25 h·ft²·°F/Btu	$0.016	$0.010	$0.013	R-32	R-31	R-32
R-32 h·ft²·°F/Btu	$0.012	$0.008	$0.010	R-34	R-34	R-34
Minneapolis	**R70E90**	**R50E52**	**R64E11**	**R70E90**	**R50E52**	**R64E11**
R-5 h·ft²·°F/Btu	$0.015	$0.022	$0.037	R-5	R-6	R-6
R-13 h·ft²·°F/Btu	$0.006	$0.008	$0.013	R-14	R-14	R-14
R-25 h·ft²·°F/Btu	$0.004	$0.004	$0.007	R-25	R-28	R-29
R-32 h·ft²·°F/Btu	$0.002	$0.003	$0.005	R-32	R-33	R-33

These example data show that annual energy cost savings due to solar radiation control can be significant in cooling-dominated climates with surfaces such as R70E90 on poorly insulated roofs. If, for example, a coating costs $0.50/ft² to purchase and install, energy savings would pay for it in less than four years in Miami. Subject to the assumptions inherent in Table 1, savings are positive even in heating-dominated climates. Note that the low infrared emittance of the R64E11 surface yields the most savings in heating-dominated climates because it prevents loss of infrared radiation to the night sky.

To estimate the maximum annual savings in your location and for your roof's insulation level and the type of radiation control you are investigating, choose an appropriate location and enter into the estimator values for the parameters R_{roof}, $\%R_{solar}$ and $\%E_{infrared}$. R_{roof} is in units of $h \cdot ft^2 \cdot {}^\circ F/Btu$ (divide R-values in $m^2 \cdot K/W$ by 0.176 to convert to $h \cdot ft^2 \cdot {}^\circ F/Btu$). In the examples in Table 1, the R-5 roof is minimally insulated with 1.5 in. (3.8 cm) of wood fiberboard. The R-13 roof is moderately insulated with 2 in. (5.1 cm) of polyisocyanurate foam. The R-25 and R-32 roofs are well insulated with 4 in. (10.2 cm) and 5 in. (12.7 cm), respectively, of polyisocyanurate foam. Table 2 repeats the seven surface descriptions and combinations of solar reflectance and infrared emittance that were obtained after two years of weathering and were used for the comprehensive modeling effort to produce the estimation tool. Values for the average white latex coating and the average aluminum coating are added. These data should help you decide appropriate solar reflectances and infrared emittances for the type of radiation control you are investigating. Table 3 contains a list of annual heating degree days based on 65°F (HDD_{65}), annual cooling degree days based on 65°F (CDD_{65}), and average daily solar irradiation in Btu/ft² (QS_{avg},). The list is from the TMY2 set of typical meteorological year climatic data for 235 locations in the United States, Pacific Islands and Puerto Rico listed alphabetically by two-letter postal abbreviation then location. The 235 locations should allow selection of one nearby or one with similar weather. The state and location are chosen in the estimator from pull-down menus and the data in Table 3 are entered automatically for each location.

Table 2. Solar reflectances and infrared emittances for surfaces weathered two years.

Surface	R_{solar} (%)	$E_{infrared}$ (%)
Highest R white latex coating	70	90
Average R white latex coating	56	90
Lowest R white latex coating	48	82
Highest R aluminum coating	50	52
Average R aluminum coating	39	56
Lowest R aluminum coating	26	68
Aluminized asphalt emulsion	33	90
Aluminum metal capsheet	64	11
Uncoated asphaltic surface	05	90

Once the location has been chosen and the reflective roof's insulation level and candidate reflective surface %R and %E have been entered, economic factors are needed. Required inputs are the price of electricity for cooling (in U.S.$ per kilowatt-hour), annual average coefficient of performance of the air conditioning system (seasonal energy efficiency ratio, SEER, in Btu/watt-hour, divided by 3.412), N or E to denote type of heating fuel, price of heating fuel if not electricity (in U.S.$ per Therm or 100,000 Btu of heating value) and seasonal average efficiency of the heating equipment (as a fraction). A capital N is required if the heating fuel is not electricity. Any other symbol can be used if it is electricity; a capital E is suggested. If the heating fuel is electricity, any value that is input for $/Therm is ignored and a value for electricity cost during the heating season is needed. If the heating system is electric resistance, its efficiency should be close to but not greater than 1.0. If it is a heat pump, its seasonal average efficiency (known as the heating coefficient of performance, HCOP) should be a number greater than one.

Table 3. Annual heating degree days based on 65˚F (HDD_{65}), annual cooling degree days based on 65˚F (CDD_{65}), and average daily solar irradiation in Btu/ft² (QS_{avg}) for locations in the United States, Pacific Islands and Puerto Rico listed alphabetically by two-letter postal abbreviation then location.

State	AK	AK	AK	AK	AK	AK	AK	AK
Location	Anchorage	Annette	Bethel	Big Delta	Cold Bay	Fairbanks	Gulkana	King Salmon
HDD65	10395	7215	13139.5	13465	9550	14170.5	13945.5	11466.5
CDD65	2	3	2	13.5	0	29	0	0.5
QSavg	772.7	855.6	760.9	812.6	682.4	810.5	849	771.9
State	AK	AK	AK	AK	AK	AK	AL	AL
Location	Kodiak	McGrath	Nome	StPaulIsland	Talkeetna	Yakutat	Birmingham	Huntsville
HDD65	8943.5	14284	13995.5	11125.5	11597.5	9798.5	2825	3543
CDD65	2	13.5	0	0	1.5	0	1671	1632
QSavg	791.9	793.6	783.3	699.5	793	741.1	1426	1405.2
State	AL	AL	AR	AR	AZ	AZ	AZ	AZ
Location	Mobile	Montgomery	Fort Smith	Little Rock	Flagstaff	Phoenix	Prescott	Tucson
HDD65	1709.5	2096	3350.5	3181	7433	1153.5	4404	1553.5
CDD65	2508	2104	1894.5	1928.5	106	3814.5	898	2762.5
QSavg	1404.3	1470.6	1455.5	1439.6	1624.1	1838.6	1706.5	1835.6
State	CA	CA	CA	CA	CA	CA	CA	CA
Location	Arcata	Bakersfield	Daggett	Fresno	Long Beach	Los Angeles	Sacramento	San Diego
HDD65	5195.5	2100	1739.5	2601.5	1308.5	1291	2793.5	1075.5
CDD65	3.5	2367	2983	1883.5	942.5	469.5	1144	766
QSavg	1245.4	1663	1856.8	1658.8	1578.8	1579.1	1557.5	1612.1
State	CA	CA	CO	CO	CO	CO	CO	CO
Location	SanFrancisco	Santa Maria	Alamosa	Boulder	Co. Springs	Eagle	Grand Junc.	Pueblo
HDD65	3238.5	3158.5	8774	6011.5	6519	8366.5	5675.5	5243.5
CDD65	68.5	59	53	622.5	408.5	71	1145	916
QSavg	1509.3	1644.4	1672.6	1466.7	1499.4	1489.2	1583.1	1588.9
State	CT	CT	DE	FL	FL	FL	FL	FL
Location	Bridgeport	Hartford	Wilmington	Daytona Bch	Jacksonville	Key West	Miami	Tallahassee
HDD65	5664	6266	5086.5	871	1436.5	62	141	1754.5
CDD65	797.5	744.5	1084.5	2735	2657	4756.5	4126.5	2360.5
QSavg	1213	1197.1	1295.1	1538.3	1460.4	1626.2	1556.8	1491.7
State	FL	FL	GA	GA	GA	GA	GA	GA
Location	Tampa	W.Palm Bch	Athens	Atlanta	Augusta	Columbus	Macon	Savannah
HDD65	697	236	2850	3089.5	2887	2312	2352.5	1951
CDD65	3311	3802	1639.5	1611	1778	2118	2090	2291.5
QSavg	1555.9	1501.9	1450	1477.5	1435.8	1458.3	1445.1	1474.7

State	HI	HI	HI	HI	IA	IA	IA	IA
Location	Hilo	Honolulu	Kahului	Lihue	Des Moines	Mason City	Sioux City	Waterloo
HDD65	0	0	2.5	0	6513	8184	6700.5	7255.5
CDD65	3086.5	4329	3851	3846.5	908	505	841.5	586.5
QSavg	1466.4	1694.1	1740.8	1579	1313.6	1278	1312.1	1259.4

State	ID	ID	IL	IL	IL	IL	IL	IN
Location	Boise	Pocatello	Chicago	Moline	Peoria	Rockford	Springfield	Evansville
HDD65	5999.5	7280.5	6449.5	6307	6331.5	6939.5	5892	4804
CDD65	692	345.5	748.5	882	882	628	1170.5	1297.5
QSavg	1414.3	1380.8	1243.2	1265.2	1304.5	1247.9	1340.3	1328.2

State	IN	IN	IN	KS	KS	KS	KS	KY
Location	Fort Wayne	Indianapolis	South Bend	Dodge City	Goodland	Topeka	Wichita	Covington
HDD65	6393	5690	6292	5355	6274.5	5326	4902	5184
CDD65	656.5	910	777.5	1370.5	841.5	1280.5	1585	1007
QSavg	1239.9	1311.1	1204.5	1557.6	1506.8	1356.2	1460.1	1279.8

State	KY	KY	LA	LA	LA	LA	MA	MA
Location	Lexington	Louisville	Baton Rouge	Lake Charles	New Orleans	Shreveport	Boston	Worchester
HDD65	4994	4440.5	1653	1682.5	1464	2215.5	5840.5	6949
CDD65	1005	1300	2444	2623.5	2539	2286.5	646	388.5
QSavg	1300.1	1327.3	1434.4	1474.7	1459.6	1458.9	1243.4	1230.2

State	MD	ME	ME	MI	MI	MI	MI	MI
Location	Baltimore	Caribou	Portland	Alpena	Detroit	Flint	Grnd Rapids	Houghton
HDD65	4911.5	9536.5	7448.5	8464.5	6728.5	6984.5	7152.5	8552
CDD65	1133	113.5	315	214	566.5	444	507.5	233.5
QSavg	1287.1	1143.5	1251.5	1172.6	1199.5	1189.2	1215.9	1144.1

State	MI	MI	MI	MI	MN	MN	MN	MN
Location	Lansing	Muskegon	Slt St Marie	Traverse City	Duluth	Int. Falls	Minneapolis	Rochester
HDD65	7128	7038.5	9155	7794	10213	10466.5	8002	8261
CDD65	549.5	493.5	83	458	140	124.5	634	500
QSavg	1214	1239.4	1160.7	1181.4	1173.2	1139.7	1256.8	1230.6

State	MN	MO	MO	MO	MO	MS	MS	MT
Location	Saint Cloud	Columbia	Kansas City	Springfield	St. Louis	Jackson	Meridian	Billings
HDD65	8995	5128.5	5154.5	4692	5021	2500.5	2585	7091.5
CDD65	413.5	1227.5	1444.5	1346	1437	2233	1989.5	617.5
QSavg	1237.8	1388.3	1366.4	1393.7	1343	1457.2	1434.6	1310.2

State	MT	MT	MT	MT	MT	MT	MT	MT
Location	Cut Bank	Glasgow	Great Falls	Helena	Kalispell	Lewistown	Miles City	Missoula
HDD65	8675	8681	7752.5	7813.5	8319	8351.5	7799.5	7891.5
CDD65	67	468.5	362	328	105	208.5	598	274
QSavg	1251.7	1233.1	1268	1248.8	1169.4	1241	1299.4	1206.2

State	NC	NC	NC	NC	NC	NC	ND	ND
Location	Asheville	Cp Hatteras	Charlotte	Greensboro	Raleigh	Wilmington	Bismarck	Fargo
HDD65	4511.5	2639.5	3415.5	4090.5	3546.5	2657.5	8686.5	9092.5
CDD65	748	1474	1513	1222.5	1312.5	1868	408	546.5
QSavg	1363.2	1425.9	1420.1	1402.4	1412.4	1417.9	1292.2	1219.1

State	ND	NE	NE	NE	NE	NE	NH	NJ
Location	Minot	Grand Island	Norfolk	North Platte	Omaha	Scottsbluff	Concord	Atlantic City
HDD65	9116.5	6427.5	6885.5	6806	6051.5	6452	7674.5	5263.5
CDD65	308.5	925	998	773	1050.5	714	401.5	906.5
QSavg	1226.7	1412.4	1365.8	1421.8	1340.7	1425.3	1236.5	1290.8

State	NJ	NM	NM	NV	NV	NV	NV	NV
Location	Newark	Albuquerque	Tucumcari	Elko	Ely	Las Vegas	Reno	Tonopah
HDD65	5122.5	4361	3957.5	7240.5	8055	2293	5768.5	5371.5
CDD65	1061.5	1210.5	1450.5	289	144.5	3066.5	384	695
QSavg	1226.5	1778.3	1662.6	1457.2	1589.8	1804.7	1605.3	1660.7

State	NV	NY	NY	NY	NY	NY	NY	NY
Location	Winnemucca	Albany	Binghamton	Buffalo	Massena	NY City	Rochester	Syracuse
HDD65	6445	7083	7535.5	6720.5	8481	5089.5	6735.5	7042.5
CDD65	604	542.5	317.5	510.5	350.5	1001.5	620	483
QSavg	1493.2	1215.4	1164.3	1165.5	1178.6	1268.3	1180.5	1200.3

State	OH	OH	OH	OH	OH	OH	OH	OK
Location	Akron	Cleveland	Columbus	Dayton	Mansfield	Toledo	Youngstown	Ok City
HDD65	6202	6107.5	5551	5929	6247.5	6757	6698	3799.5
CDD65	613.5	617	779	714.5	687.5	609.5	517.5	1810
QSavg	1204.7	1201.4	1218.3	1251.4	1207.6	1250.9	1144.6	1505.5

State	OK	OR	OR	OR	OR	OR	OR	OR
Location	Tulsa	Astoria	Burns	Eugene	Medford	North Bend	Pendleton	Portland
HDD65	3816.5	5291	7072	4627	4829	4632.5	5310.5	4461
CDD65	1869.5	13.5	284.5	227.5	671.5	1	686.5	278.5
QSavg	1431	1027.5	1377.1	1192.7	1400.5	1237.9	1316	1127.3

State	OR	OR	PA	PA	PA	PA	PA	PA
Location	Redmond	Salem	Allentown	Bradford	Erie	Harrisburg	Philadelphia	Pittsburgh
HDD65	6734.5	4968.5	5857.5	8251	6757	5478.5	5180.5	5986.5
CDD65	194	200	721.5	143	454	987	1053	683.5
QSavg	1406.3	1190	1232.3	1193.3	1211.1	1261.9	1263.6	1202.5

State	PA	PA	PI	PR	RI	SC	SC	SC
Location	Wilkes-Barre	Williamsport	Guam	San Juan	Providence	Charleston	Columbia	Greenville
HDD65	6685	6088	0	0	5986.5	2208.5	2765	3407.5
CDD65	547	672	5183.5	5332	608.5	2010	1897.5	1483
QSavg	1188	1182.4	1606.4	1684.8	1263.1	1462.4	1438.4	1425.4

State	SD	SD	SD	SD	TN	TN	TN	TN
Location	Huron	Pierre	Rapid City	Sioux Falls	Bristol	Chattanooga	Knoxville	Memphis
HDD65	8254.5	7234.5	7315	7858	4345.5	3534.5	3662	3107.5
CDD65	529.5	795	516.5	794	929	1585	1365.5	1998.5
QSavg	1308.8	1344.8	1358.3	1300.3	1301.7	1365.3	1333.6	1467.6

State	TN	TX	TX	TX	TX	TX	TX	TX
Location	Nashville	Abilene	Amarillo	Austin	Brownsville	C Christi	El Paso	Fort Worth
HDD65	4031.5	2597	4655.5	1630	658.5	884	2596.5	2304
CDD65	1672	2284	1294	2965	3562.5	3267	2045.5	2414.5
QSavg	1403.3	1622.1	1608.1	1548.8	1514.6	1449.6	1835.4	1558.8

State	TX	TX	TX	TX	TX	TX	TX	TX
Location	Houston	Lubbock	Lufkin	Midland	Port Arthur	San Antonio	Victoria	Waco
HDD65	1552	3450.5	1910.5	2772	1543	1678.5	1127	2088
CDD65	2810	1569	2493	2031.5	2692.5	2863	2966	2546.5
QSavg	1405.5	1620.8	1480.5	1698.3	1462.1	1576.5	1475.6	1551.3

State	TX	UT	UT	VA	VA	VA	VA	VA
Location	Wichita Falls	Cedar City	SaltLakeCity	Lynchburg	Norfolk	Richmond	Roanoke	Sterling
HDD65	3054.5	6054.5	5636	4448	3489	4097	4215	5232.5
CDD65	2385	651	1054	1070	1439	1297	1034.5	1044
QSavg	1566.3	1618.8	1474.9	1404.3	1338.8	1336.1	1347.8	1300.2

State	VT	WA	WA	WA	WA	WA	WI	WI
Location	Burlington	Olympia	Quillayute	Seattle	Spokane	Yakima	Eau Claire	Green Bay
HDD65	7903	5495	5898.5	4867	6887	6059.5	8504.5	8299
CDD65	407	140	7.5	127	404.5	417	513	413.5
QSavg	1193.6	1044	966.9	1061.3	1213.8	1304	1205.2	1205.2

State	WI	WI	WI	WV	WV	WV	WY	WY
Location	La Crosse	Madison	Milwaukee	Charleston	Elkins	Huntington	Casper	Cheyenne
HDD65	7673	7504	7521	4632	6292	4495.5	7713	7320
CDD65	617	520.5	472.5	903	345	998	327.5	258
QSavg	1233.7	1247.5	1249	1244.8	1193.4	1259.3	1408.5	1416.2

State	WY	WY	WY
Location	Lander	Rock Springs	Sheridan
HDD65	7760	8375.5	7694.5
CDD65	371	185	382
QSavg	1471.6	1478.8	1330.3

Non-Energy Considerations

What besides energy savings justifies radiation control for low-slope roofs?
The savings in annual energy costs and other cost savings need to be weighed against the local cost to purchase and install the coating or membrane system. The focus in this fact sheet is on protective coatings with optional reflective pigments (such as aluminum or titanium dioxide) to save on energy needed to cool buildings under the protected roofs. The other cost savings associated with the protective nature of the coating or membrane system may be more significant than the savings in annual energy costs, especially outside a cooling-dominated climate.

Protective coatings have a long history of use before air-conditioned buildings with cooling energy requirements became commonplace. See the Internet web site of the Roof Coatings Manufacturers Association http://www.roofcoatings.org/ for a brief history of protective coatings and their evolution to the variety of products available today. These products range from low viscosity, non-fibered coatings for penetrating primers and damp proofing coatings to high viscosity, heavy-bodied cements for adhering waterproofing membranes and components and for patching and repairing leaks. In the middle of this range are medium viscosity, fibered and non-fibered products for interply adhesives and top coatings.

Radiation control coatings fall in this medium viscosity category. Protective coatings, in general, use resins ranging from bituminous (such as asphalt) to polymeric (such as acrylic) with reinforcing fillers and a carrier solvent or water emulsification. Reflective pigments are added for radiation control. The coating is left behind as a cured, water resistant film when the carrier solvent or water evaporates.

An important purpose of the coating is to protect the membrane it covers from effects of the ultraviolet (UV) radiation in sunlight. UV degrades asphaltic and some rubber materials, causing them to become brittle and unable to flex during thermal stressing. Ultimately this leads to cracks in the membrane itself or its failure to adhere to flashings. Coatings with optional reflective pigments also protect the membrane from high peak temperatures, lessening the thermal stresses.

As shown by the section on the effect of solar radiation control on energy costs, radiation control savings with moderate to high levels of thermal insulation are less attractive than those with little or no thermal insulation. Nonetheless, the cost of a roof, especially with moderate to high levels of thermal insulation, is a significant investment. Often the only cure for water leaks into the building interior is extensive repair or replacement of the membrane. Water held in many types of roof insulation makes them ineffective as thermal insulation. Complete replacement of a damaged roof and disposal of wet insulation is more expensive than a newly constructed roof with the same specifications. Even with minimal energy savings due to decreased cooling loads, protective coatings have the potential to prolong the life of the membrane and add barriers or repair existing barriers against water leakage into the roof system. In this context, energy cost savings can be viewed as a bonus in addition to the other benefits of radiation control.

Installation

How is solar radiation control installed?
If radiation control is achieved by replacing the existing roof membrane by a new membrane with radiation control characteristics, roofing industry-accepted low-slope roof installation procedures are followed. An excellent guide to specifications and construction details for low-slope roof installation is the NRCA Roofing and Waterproofing Manual, Fourth Edition, Volumes 1 and 2, published in 1996 by the National Roofing Contractors Association, Rosemont, Illinois. See also the NRCA website for low-slope roofing on the Internet: http://nrca.net/technical/lowslope/.

Cleanliness is a special concern during installation of new membranes with radiation control characteristics. These membranes are light-colored and they are easily and permanently soiled by asphaltic materials. Foot traffic that tracks such materials from other areas on the roof must be avoided. Materials used to adhere insulation before the new membrane is installed may also have the potential to stain the top of the new membrane. If so, they must dry thoroughly before the new membrane is laid out on the roof. Besides being unsightly on a light-colored roof, every spot of asphaltic material lowers the solar reflectance of the affected area to less than 0.1.

Coating an existing roof to achieve radiation control is a less complicated procedure. For any coating process, the key to success is thorough cleaning and drying of the substrate. Roof coatings are especially formulated to adhere to a variety of roof membranes. They are not the same as paint. The final coating thickness for white latex or acrylic coatings is usually about 0.015 in. (0.38 mm) and is less for many aluminum coatings. Only minor surface defects can be bridged without compromising the integrity of the coating. Defects in the coating are potential sites for cracking and peeling. Many coating products are intended to seal the area they cover against leaks in the original membrane. Coating defects compromise this function before cracking or peeling becomes apparent .

The large area of most low-slope roofs rules out brush-coating as a means to apply the coating. Even so, brushing is often used near flashings and edges to precoat for additional sealing. On large areas of a smooth-surfaced roof, roller application of coatings is possible. A typical roller application is shown in Figure 1. On a rough-surfaced roof or for the most uniform application on any substrate, spray application of coatings is done. See Figure 2 where an airless sprayer is being used to apply a white coating to a gravel-topped built-up roof.

Figure 1. Applying a white acrylic elastomeric coating with rollers.

Figure 2. Applying a white latex coating with an airless sprayer.