Updates on Revision to ASHRAE Standard 90.2: Including Roof Reflectivity for Residential Buildings

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ABSTRACT

This paper discusses the results of a simulation effort in support of ASHRAE SSPC 90.2 for inclusion of reflective roofs in the proposed standard. Simulation results include the annual electricity and fuel use for a prototypical single-family one-story house. In order to maintain consistency with the other requirements of the draft standards, we used the 90.2 Envelope Sub-committee DOE-2 prototype building and operating schedules which were supplied to us. The parametric simulations were performed for the following scenarios and combinations thereof: 3 heating systems, 4 duct and duct insulation configurations, 5 levels of ceiling insulation, 4 levels of roof reflectivity, and 4 levels of attic air change rate. The simulations were performed for 32 climate regions.

The results are condensed into climate-dependent adjustment factors that give equivalent reductions in roof insulation levels corresponding to increased roof reflectivity. The equivalence is designed such that the net energy use (cooling plus heating) of the building stays constant when compared with energy use of a dark-colored roof. Results indicate that in hot climates, increasing the roof reflectivity from 20% to 60% is worth over half of the roof insulation.

Introduction

Most commercial and residential buildings have dark roofs. Dark roofs are heated by the summer sun and this raises the summertime cooling demand. For highly absorptive (low-solar reflectance) roofs, the difference between the surface and ambient air temperatures may be as high as 50°C (90°F), while for less absorptive (high-solar reflectance) roofs, such as white paint, the difference is only about 10°C (18°F). For this reason, "cool" roofs (which absorb little "insolation") are effective in reducing cooling energy use. Numerous experiments in several residential and small commercial buildings in California and Florida show that painting roofs white reduces air-conditioning energy use (compressor and condenser unit) between 10 and 50% (ranging from \$10 to \$100 per year per $100m^2$), depending on the amount of thermal resistance of insulation under the roof (Akbari *et al.* 1997, Parker *et al.* 1998). The savings, of course, are strong functions of the thermal integrity of a building and climate conditions.

The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) develops voluntary standards to improve energy efficiency in buildings. In many applications, the voluntary ASHRAE standards are modified by states, federal, and other governmental organizations and used as codes and standards. Two such standards address energy efficiency in new buildings: ASHRAE Standard 90.1 (Standards for Buildings Except Low-Rise Residential Buildings) and ASHRAE Standard 90.2 (Energy-Efficient Design of New Low-Rise Residential Buildings). In 1998, Standard 90.1

adopted modification to the existing standards (Akbari *et al.* 1998, ASHRAE 1999). Prior to adoption of the standards for inclusion of reflective roofs, ASHRAE sponsored a symposium to discuss present results from field application and modeling (ASHRAE 1998). The Envelope Subcommittee of ASHRAE Standard 90.2 also recognized the importance of roof reflectivity in residential buildings in reducing the net energy consumption of a given building, and it organized a task group to develop a proposal to modify the existing standards. In order to be consistent with other sections of the proposed standards, the task group planned a detailed simulation approach to study the impact of reflective roofs on heating and cooling energy use of of several prototypical buildings over a wide range of climates. This paper summarizes the results of the simulation effort in support of ASHRAE SSPC 90.2 for inclusion of reflective roofs in the proposed standard.

Methodology

Reflective roofs reduce the flow of heat into the building by reflecting most of the incident solar radiation during hot summer days. Having a well-insulated roof will also reduce the heat gains during the day. During those hours of the day when the ambient temperature is lower than the inside temperature, having high insulation in the roof would block the path of heat flow out of the building. During the winter when the days are short and cloudy and the sun angle is low, a reflective roof may add a heating penalty. Therefore, we analyzed the impact of the roof reflectance in terms of a trade-off with roof insulation. On that basis, the Envelope Subcommittee directed us to perform comprehensive simulations to analyze cooling energy savings and heating energy penalties of several prototypical buildings over a wide spectrum of climatic conditions. The DOE-2.1E building energy simulation program was selected as the tool to perform this analysis.

We used a residential building prototype that ASHRAE has used extensively in support of developing criteria for Standard 90.2. The details of the prototypical building are summarized in **Table 1**. The building was simulated with electric cooling, electric heat pump, electric resistance heating, and gas heating systems.

Our simulations included prototypes with and without attics. These building were simulated for a variety of roof insulation and roof reflectances. The roof insulations included ceiling insulation levels: R-1, R-11, R-19, R-30, R-49. Parametric for roof reflectivity included reflectance of 0.10, 0.25, 0.50, and 0.75. In addition we modeled distribution system configurations with ducts in the attics with three levels of duct insulation (R-2, R-4, and R-6) and ducts in the conditioned space. For the prototypical buildings with an attic, a fractional leakage area of 1:300 for the attic was assumed.

The simulations were performed for a wide range of climatic conditions from very hot to very cold. A total of 36 climates were considered for these simulations; weather data for five of these locations were not available. Also, for the Los Angeles area, simulations were performed for both LAX, and Long Beach. Hence, in total, the simulations were performed for 32 climates. These climate conditions are shown in **Table 2**.

The locations of the distribution ducts have a significant impact on the energy performance of cooling systems. Leaky ducts in attics with a low level of duct insulation can significantly reduce the efficiency of duct systems. Jump and Modera (1994) have measured the duct efficiency and reported a reduced efficiency of as much as 50% in some residences. The higher the temperature of the attic, the higher the inefficiencies of the

Table 1. Prototypical construction, equipment, and operation characteristics for a single-family one-story ranch house.

Construction	
zones	interior: conditioned
	attic: unconditioned and naturally ventilated
floor area	$1540ft^2$
perimeter	166ft
aspect ratio	1:1
wall height	8ft
roof	1/4" asphalt shingle over 3/4" plywood decking (4/12 slope)
	solar absorptance: 0.90, 0.75, 0.50, or 0.25
	infrared emittance: 0.9
overhang	2ft around entire perimeter
ceiling	frame (15%) and R-1, 11, 19, 30, or 49 fiberglass insulation (85%) over 1/2" drywall
exterior wall	stucco over frame (15%) and R-11 fiberglass insulation over 1/2" drywall
windows	$185ft^2$ (14% of exterior wall area) double clear with operable shades, U-IP 0.57, and shading coefficient 0.88
foundation	slab-on-grade with carpet and pad
Equipment	
sizing	based on peak cooling and heating loads
sizing ratio	1.25
cooling	direct expansion: SEER 10
heating	(1) gas furnace: AFUE 78%
	(2) electric heat pump: HSPF 6.8
	(3) electric resistance
distribution	constant-volume forced air system
	10% duct leakage
	duct insulation R-value: 2, 4, 6 (attic), or 0 (interior)
	supply duct area $370ft^2$
	return duct area $69ft^2$
Operation	
cooling thermostat	78°F
heating thermostat	68°F
natural ventilation	enthalphic controlled window operation: 68°F min and 5 ACH max
infiltration	Sherman-Grimsrud: fla 1:2000 (interior) and fla 1:300 (attic)
peak internal heat gain	$0.68 W/ft^2$

Table 2. Selected locations, TMY2 weather file availability and degree-days.

id	location	tmy2 weather file	cdd 65	hdd 65
1	Adak, AK	**not available**		
2	Albuquerque, NM	Albuquerque, NM	1211	4361
3	Brownsville, TX	Brownsville, TX	3563	659
4	Bangor, ME	**not available**		
5	Bismarck, ND	Bismarck, ND	408	8666
6	Bryce, UT	**not available**		
7	Charleston, SC	Charleston, SC	2010	2209
8	Denver, CO	**Boulder, CO**	623	6007
9	Dodge, KS	Dodge City, KS	1371	5353
10	El Paso, TX	El Paso, TX	2046	2597
11	Fort Worth, TX	Fort Worth, TX	2415	2304
12	Fairbanks, AK	Fairbanks, AK	29	14095
13	Fresno, CA	Fresno, CA	1884	2602
14	Fort Smith, AR	Fort Smith, AR	1895	3351
15	Honolulu, HI	Honolulu, HI	4329	0
16	Jacksonville, FL	Jacksonville, FL	2657	1437
17	Kwajalein, PI	St.Paul Island, AK	0	11126
18	Lake Charles, LA	Lake Charles, LA	2624	1683
19	Laredo, TX	**not available**		
20	Las Vegas, NV	Las Vegas, NV	3067	2293
21	**Los Angeles, CA**	**LAX**	470	1291
21	**Los Angeles, CA**	**Long Beach**	943	1309
22	Miami, FL	Miami, FL	4127	141
23	Madison, WI	Madison, WI	521	7495
24	North Omaha, NE	Omaha, NE	1051	6047
25	New York, NY	New York, NY	1002	5090
26	Phoenix, AZ	Phoenix, AZ	3815	1154
27	Redmond, OR	Redmond, OR	194	6732
28	Roswell, NM	**not available**		
29	Tucson, AZ	Tucson, AZ	2763	1554
30	Sacramento, CA	Sacramento, CA	1144	2794
31	San Diego, CA	San Diego, CA	766	1076
32	Seattle, WA	Seattle, WA	127	4867
33	San Francisco, CA	San Francisco, CA	69	3239
34	St. Louis, MO	St. Louis, MO	1437	5021
35	Washington, DC	**Sterling, VA**	1044	5233
36	Winnemucca, NV	Winnemucca, NV	604	6444

duct systems. Parker *et al.* (1998) have developed a model to account for the impact of attic temperature on the performance of the cooling systems. In our simulations, we augmented DOE-2 with the algorithm developed by Parker *et al.*

Upon completion of simulated heating and cooling energy use, we regressed the results into quadratic functions of roof absorptance (1 - reflectance), α, and u-value, U, of the roof system. The equation used is:

$$E_i = C_0 + C_1 U + C_2 U^2 + C_3 U\alpha \quad (1)$$

Where, E_i is either annual electricity use in kWh, annual gas energy use in therms, or net energy use in \$. To obtain the net energy-use cost, we used the 1998 national average of \$0.0826/kWh and \$0.691/therm for the price of electricity and gas, respectively (EIA 1998). This linear correlation proved to be adequate for our analysis; the 95% confidence accuracy is 2%, the 98% accuracy is 3%.

We used these correlations to estimate the equivalency of the u-values and roof absorptance. That is: given the energy use of a building with a dark roof (high absorptance = α_1) and an overall u-value of U_1, what will be the new overall u-value (U_2) if the roof had a higher reflectivity ($\alpha_2 < \alpha_1$), such that the annual energy use remains the same? Applying this equivalency condition, the level of roof insulation requirements in most hot cities could be reduced by a factor of 2.

To optimize the energy use of the building, Akbari *et al.* (1998) recommended using a square root correlation of

$$\left(\frac{U_2}{U_1}\right)_{Recom} = \left(\frac{U_2}{U_1}\right)^{1/2}_{Equivalent} \quad (2)$$

where, Recom is the recommended value and Equivalent is the equivalency of the roof absorptance and u-value obtained from the correlations.

Results

Table 3 shows the simulated annual energy expenditure for three climate regions: Phoenix (hot and dry), Sacramento (moderate and dry), and Madison (cold). The results are shown for heat pump, electric resistance, and gas heating systems. In Phoenix, for gas heating systems, savings in the range of 6-17% (for various level of roof insulation) are estimated by increasing the roof reflectance from 0.10 to 0.50, In Sacramento, the savings are in the range of 4-11%. Savings for Madison are nil. Since the price of gas per unit of delivered energy is smaller than that of electricity, the savings are smaller for electric heat pump and resistance heating.

The impact of roof reflectivity on the required level of roof insulation is shown in **Table 4.** In hot climates, a significant amount of roof insulation can be saved by increasing the roof reflectivity. For example in Phoenix, a roof system with a reflectivity of 10% and ceiling insulation of R-30 has an equivalent annual energy performance of a roof system with a reflectivity of 50% and ceiling insulation of R-14; over 50% savings in required R-value of the insulation. Lower levels of insulation savings are observed in moderate climates such as Sacramento. In cold climates, the saving in roof insulation is obviously nil.

We performed a detailed sensitivity analysis in looking at the impact of variation in duct R-value and attic leakage area fractions on the overall U2/U1. In general, in most

Table 3. Simulated annual cooling and heating total energy base use [$/1000ft^2] and the direct savings [%] from the use of high-albedo roofs for a typical single-family one-story ranch house with gas heat, R-4 attic ducts and 1:300 attic fractional leakage area.

	Phoenix					Sacramento					Madison				
Ceiling insulation→	R-1	R-11	R-19	R-30	R-49	R-1	R-11	R-19	R-30	R-49	R-1	R-11	R-19	R-30	R-49
Gas furnace															
base use, α=0.90	639	411	379	359	345	422	255	229	214	202	779	572	532	508	491
savings, α=0.75	6	4	3	3	2	4	2	2	2	1	0	0	0	0	0
savings, α=0.50	17	10	8	7	6	11	6	5	5	4	1	0	0	0	0
savings, α=0.25	28	17	14	12	10	17	10	8	7	7	1	-1	-1	-1	0
Electric heat pump															
base use, α=0.90	687	444	409	388	372	525	346	316	298	283	1166	997	953	925	904
savings, α=0.75	6	3	3	3	2	3	1	1	1	1	0	0	0	0	0
savings, α=0.50	16	9	8	7	6	8	4	3	3	2	1	-1	-1	-1	-1
savings, α=0.25	26	15	13	11	10	12	6	5	5	4	1	-1	-1	-1	-1
Electric resistance															
base use, α=0.90	804	513	468	442	423	856	557	504	473	449	1947	1522	1425	1367	1324
savings, α=0.75	5	3	2	2	2	1	1	0	0	0	0	0	0	0	0
savings, α=0.50	13	8	6	5	5	3	2	1	1	1	-1	-1	-1	-1	-1
savings, α=0.25	21	13	10	9	8	5	2	2	2	2	-2	-2	-2	-2	-1

Table 4. Estimated roof-composite U_factor (U2/U1) and equivalent cool-roof ceiling insulation R-value (shown in parentheses) as a function of roof solar absorptance (α) and roof-system conductance (U). Dark roof absorptance is 0.90. All results for R-4 attic ducts and 1:300 attic fractional leakage area.

	Phoenix				Sacramento				Madison			
ceiling insulation→	R-11	R-19	R-30	R-49	R-11	R-19	R-30	R-49	R-11	R-19	R-30	R-49
gas furnace												
$\alpha = 0.75$	1.14 (9)	1.16 (15)	1.17 (23)	1.18 (37)	1.07 (10)	1.08 (17)	1.08 (26)	1.08 (42)	1.00 (11)	1.00 (19)	1.00 (30)	1.00 (49)
$\alpha = 0.50$	1.48 (5)	1.54 (9)	1.59 (14)	1.64 (21)	1.21 (8)	1.23 (14)	1.24 (21)	1.25 (33)	1.01 (11)	1.01 (19)	1.01 (30)	1.01 (48)
$\alpha = 0.25$	1.97 (2)	2.16 (5)	2.33 (7)	2.50 (10)	1.39 (6)	1.42 (11)	1.45 (16)	1.47 (25)	1.01 (11)	1.01 (19)	1.01 (29)	1.01 (48)
electric heat pump												
$\alpha = 0.75$	1.13 (9)	1.14 (15)	1.15 (24)	1.16 (38)	1.05 (10)	1.06 (17)	1.06 (27)	1.06 (44)	1.00 (11)	1.00 (19)	1.00 (30)	1.00 (49)
$\alpha = 0.50$	1.42 (6)	1.47 (10)	1.51 (15)	1.55 (23)	1.16 (8)	1.17 (15)	1.17 (23)	1.17 (37)	1.00 (11)	1.00 (19)	1.00 (30)	1.00 (49)
$\alpha = 0.25$	1.85 (3)	2.00 (6)	2.12 (8)	2.25 (12)	1.29 (7)	1.30 (12)	1.31 (19)	1.31 (30)	1.00 (11)	1.00 (19)	1.00 (30)	1.00 (49)
electric resistance												
$\alpha = 0.75$	1.10 (9)	1.11 (16)	1.11 (25)	1.12 (40)	1.02 (11)	1.02 (18)	1.02 (29)	1.02 (47)	0.98 (11)	0.99 (19)	0.99 (31)	0.99 (50)
$\alpha = 0.50$	1.31 (7)	1.34 (12)	1.36 (18)	1.38 (28)	1.05 (10)	1.06 (17)	1.06 (27)	1.06 (44)	0.96 (12)	0.96 (20)	0.96 (32)	0.96 (53)
$\alpha = 0.25$	1.60 (4)	1.67 (8)	1.73 (12)	1.79 (18)	1.09 (9)	1.09 (16)	1.10 (26)	1.10 (41)	0.94 (12)	0.94 (21)	0.94 (33)	0.94 (55)

cases the impact was smaller than 10%. Hence, for the reminder of the analysis for the prototypes with an attic, we assumed a duct insulation of R-4 and a leakage area fraction of 1:300.

The results of the analysis for all climate regions are shown in **Table 5**, in an ascending ratio of heating-degree-days (base 65F) over cooling-degree-days (base 65). Our recommended U2/U1 values are significantly lower than those obtained from the correlations. Finally, we grouped the results into bins of similar modification based on the heating-degree-days.

ASHRAE Proposal

Based on this analysis, the ASHRAE Envelope Subcommittee of Standard 90.2 voted unanimously to adopt the following proposal as a modification to SSP 90.2.

"**Section 5.3.1.1: Single-Family Buildings (Ceiling with attics)**

Exception to 5.3.1.1: For roofs where the exterior surface has either: a) a minimum total solar reflectance of 0.65 when tested in accordance with ASTM E903 or E1918, and has a minimum thermal emittance of 0.75 when tested in accordance with ASTM E408 or C1371; or b) has a minimum solar reflectance index (SRI) of 75 calculated in accordance with ASTM E1980 for medium wind-speed conditions, the U-value of the proposed ceiling shall be permitted to be adjusted using Equation 5-3.1 for demonstrating compliance:

Uceiling_adj = Uceiling_proposed X Multiplier (5-3.1)

Where:
Uceiling_adj = the adjusted ceiling U-value for use in demonstrating compliance
Uceiling_proposed = the U-value of the proposed ceiling, as designed
Multiplier = the ceiling U-value multiplier from Table 5.3.1.

Section 5.3.1.2: Single-Family Buildings (Ceilings without attics)

Exception to 5.3.1.2: For roofs where the exterior surface has either: c) a minimum total solar reflectance of 0.65 when tested in accordance with ASTM E903 or E1918, and has a minimum thermal emittance of 0.75 when tested in accordance with ASTM E408 or C1371; or d) has a minimum solar reflectance index (SRI) of 75 calculated in accordance with ASTM E1980 for medium wind-speed conditions, the U-value of the proposed ceiling shall be permitted to be adjusted using Equation 5-3.1 for demonstrating compliance:

Uceiling_adj = Uceiling_proposed X Multiplier (5-3.1)

Where:
Uceiling_adj = the adjusted ceiling U-value for use in demonstrating compliance
Uceiling_proposed = the U-value of the proposed ceiling, as designed
Multiplier = the ceiling U-value multiplier from Table 5.3.1.

Section 5.5.1.1: Multi-Family Buildings (Ceilings with attics)

Exception to 5.5.1.1: For roofs where the exterior surface has either: e) a minimum total solar reflectance of 0.65 when tested in accordance with ASTM E903 or E1918, and has a minimum thermal emittance of 0.75 when tested in accordance with ASTM E408 or C1371; or f) has a minimum solar reflectance index (SRI) of 75 calculated in accordance with

ASTM E1980 for medium wind-speed conditions, the U-value of the proposed ceiling shall be permitted to be adjusted using Equation 5-3.1 for demonstrating compliance:

Uceiling_adj = Uceiling_proposed X Multiplier (5-3.1)

Where:
Uceiling_adj = the adjusted ceiling U-value for use in demonstrating compliance
Uceiling_proposed = the U-value of the proposed ceiling, as designed
Multiplier = the ceiling U-value multiplier from Table 5.3.1.

Section 5.5.1.2: Multi-Family Buildings (Ceilings without attics)

Exception to 5.5.1.2: For roofs where the exterior surface has either: g) a minimum total solar reflectance of 0.65 when tested in accordance with ASTM E903 or E1918, and has a minimum thermal emittance of 0.75 when tested in accordance with ASTM E408 or C1371; or h) has a minimum solar reflectance index (SRI) of 75 calculated in accordance with ASTM E1980 for medium wind-speed conditions, the U-value of the proposed ceiling shall be permitted to be adjusted using Equation 5-3.1 for demonstrating compliance:

Uceiling_adj = Uceiling_proposed X Multiplier (5-3.1)

Where:
Uceiling_adj = the adjusted ceiling U-value for use in demonstrating compliance
Uceiling_proposed = the U-value of the proposed ceiling, as designed
Multiplier = the ceiling U-value multiplier from Table 5.3.1.

Table 5.3.1. Ceiling U-value Multiplier

HDD 65	(HDD18)	Ceilings with Attics	Ceilings without Attics
0-360	(0-200)	1.50	1.30
361-900	(201-500)	1.30	1.30
901-1800	(501-1000)	1.20	1.30
1801-2700	(1001-1500)	1.15	1.30
2701-3600	(1501-2000)	1.10	1.20
> 3600	(> 2000)	1.00	1.00

Section 8.8.3.1: Exterior Absorptivity

Since the colors are subject to change over the life of the building, the exterior absorptivity of all walls and roofs shall be 0.5 regardless of color, and the exterior absorptivity of roofs shall be 0.2 regardless of color. If unconditioned spaces so as garages are not modeled, walls between them and conditioned space shall be treated as exterior walls with an absorptivity of zero.

Note: For low absorptivity roofs, the reference house may employ Exceptions 5.3.1.1 or 5.3.1.2 or 5.5.1.1 or 5.5.1.2."

Conclusion

In this study, we have documented the result of a building energy simulation analysis to account for energy-saving benefits of reflective roofs in residential buildings.

Table 5. Estimated roof-composite U_factor (U2/U1) as a function of roof solar absorptance (α) and roof-system conductance (U). Dark roof absorptance is 0.90. All results for R-4 attic ducts and 1:300 attic fractional leakage area.

				Duct in Attics			Ducts in Conditioned Space			Roofs with no Attics		
Location	cdd_65	hdd_65	hdd/cdd	U2/U1	$(U2/U1)^{1/2}$	Recomm	U2/U1	$(U2/U1)^{1/2}$	Recomm	U2/U1	$(U2/U1)^{1/2}$	Recomm
Honolulu, HI	4329	0	0.00	2.62	1.62	1.5	2.62	1.62	1.5	1.69	1.30	1.3
Miami, FL	4127	141	0.03	2.19	1.48	1.5	2.19	1.48	1.5	1.67	1.29	1.3
Brownsville, TX	3563	659	0.18	1.6	1.26	1.25	1.6	1.26	1.25	1.61	1.27	1.3
Phoenix, AZ	3815	1154	0.30	1.53	1.24	1.2	1.53	1.24	1.2	2.39	1.55	1.3
Jacksonville, FL	2657	1437	0.54	1.52	1.23	1.2	1.52	1.23	1.2	1.59	1.26	1.3
Tucson, AZ	2763	1554	0.56	1.49	1.22	1.2	1.49	1.22	1.2	2.76	1.66	1.3
Lake Charles, LA	2624	1683	0.64	1.46	1.21	1.2	1.46	1.21	1.2	2.02	1.42	1.3
El Paso, TX	2046	2597	1.27	1.42	1.19	1.15	1.42	1.19	1.15	1.68	1.30	1.3
Los Angeles, CA	943	1309	1.39	1.38	1.17	1.2	1.38	1.17	1.2	1.64	1.28	1.3
San Diego, CA	766	1076	1.40	1.37	1.17	1.2	1.37	1.17	1.2	1.69	1.30	1.3
Las Vegas, NV	3067	2293	0.75	1.37	1.17	1.15	1.37	1.17	1.15	1.65	1.28	1.3
Fresno, CA	1884	2602	1.38	1.34	1.16	1.15	1.34	1.16	1.15	1.56	1.25	1.3
Charleston, SC	2010	2209	1.10	1.33	1.15	1.15	1.33	1.15	1.15	1.58	1.26	1.3
Fort Worth, TX	2415	2304	0.95	1.31	1.14	1.15	1.31	1.14	1.15	1.64	1.28	1.3
Fort Smith, AR	1895	3351	1.77	1.24	1.11	1.1	1.24	1.11	1.1	1.63	1.28	1.3
Sacramento, CA	1144	2794	2.44	1.22	1.10	1.1	1.22	1.10	1.1	1.61	1.27	1.2
Albuquerque, NM	1211	4361	3.60	1.19	1.09	1	1.19	1.09	1	1.4	1.18	1.2
Los_Angeles, CA	470	1291	2.75	1.16	1.08	1.2	1.16	1.08	1.2	1.55	1.24	1.2
St. Louis, MO	1437	5021	3.49	1.11	1.05	1	1.11	1.05	1	1.5	1.22	1.2
Washington, DC	1044	5233	5.01	1.09	1.04	1	1.09	1.04	1	1.23	1.11	1
Dodge, KS	1371	5353	3.90	1.09	1.04	1	1.09	1.04	1	1.34	1.16	1
North Omaha, NE	1051	6047	5.75	1.08	1.04	1	1.08	1.04	1	1.27	1.13	1
Denver, CO	623	6007	9.64	1.06	1.03	1	1.06	1.03	1	1.33	1.15	1
Winnemucca, NV	604	6444	10.67	1.06	1.03	1	1.06	1.03	1	1.28	1.13	1
New York, NY	1002	5090	5.08	1.05	1.02	1	1.05	1.02	1	1.28	1.13	1
Bismarck, ND	408	8666	21.24	1.02	1.01	1	1.02	1.01	1	1.25	1.12	1
Redmond, OR	194	6732	34.70	1.01	1.00	1	1.01	1.00	1	1.26	1.12	1
Madison, WI	521	7495	14.39	1.01	1.00	1	1.01	1.00	1	1.18	1.09	1
Seattle, WA	127	4867	38.32	0.97	0.98	1	0.97	0.98	1	1.12	1.06	1
Fairbanks, AK	29	14095	486.03	0.97	0.98	1	0.97	0.98	1	1.09	1.04	1
Kwajalein, PI	0	11126	∞	0.95	0.97	1	0.95	0.97	1	0.93	0.96	1
San Francisco, CA	69	3239	46.94	0.94	0.97	1	0.94	0.97	1	0.98	0.99	1

DOE-2 was used to calculate the annual electricity and fuel use for a prototypical single-family one-story house in 32 climate regions. Parametric simulations were performed for the following scenarios and combinations thereof: 3 heating systems, 4 duct and duct insulation configurations, 5 levels of ceiling insulation, 4 levels of roof reflectivity, and 4 levels of attic air change rate.

The results are condensed into climate-dependent adjustment factors that give equivalent reductions in roof insulation levels corresponding to increased roof reflectivity. The equivalence is designed such that the net energy use (cooling plus heating) of the building remains constant when compared with energy use of a dark-colored roof. Results indicate that in hot climates, by increasing the roof reflectivity from 20% to 60%, one can reduce the roof insulation by half and still have the same net annual energy use.

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