Additions and Corrections

This report includes additional information, and technical errors found between June 15, 2008, and January 18, 2012, in the inch-pound (I-P) editions of the 2008, 2009, 2010, and 2011 *ASHRAE Handbook* volumes. Occasional typographical errors and nonstandard symbol labels will be corrected in future volumes. The most current list of Handbook additions and corrections is on the ASHRAE Web site (www.ashrae.org).

The authors and editor encourage you to notify them if you find other technical errors. Please send corrections to: Handbook Editor, ASHRAE, 1791 Tullie Circle NE, Atlanta, GA 30329, or e-mail mowen@ashrae.org.

2008 HVAC Systems and Equipment

p. 6.4, Eqs. (9a) and (10). The equations should read as follows:

$$q_c = 0.02(t_p - t_a)^{0.25}(t_p - t_a) \qquad (9a)$$

$$q_c = 0.31|t_p - t_a|^{0.31}(t_p - t_a) \qquad (10)$$

p. 12.11, Eq. (18). Change the "D*h*" to "Δ*h*."

p. 12.21, 1st col., 2nd paragraph. The reference to Equation (23) should be to Equation (20).

p. 12.24, 2nd col., 1st full paragraph. The reference to Equation (23) should be to Equation (20).

p. 21.1, Fig. 1. Replace the figure with the one shown below.

p. 22.1, Fig. 1. Replace the figure with the one shown at right.

p. 22.8, Example 1. In the third equation in the solution, delete "1000 × 2.5 × 4.18."

p. 23.4, Fig. 7. Replace the figure with the one shown at right, bottom.

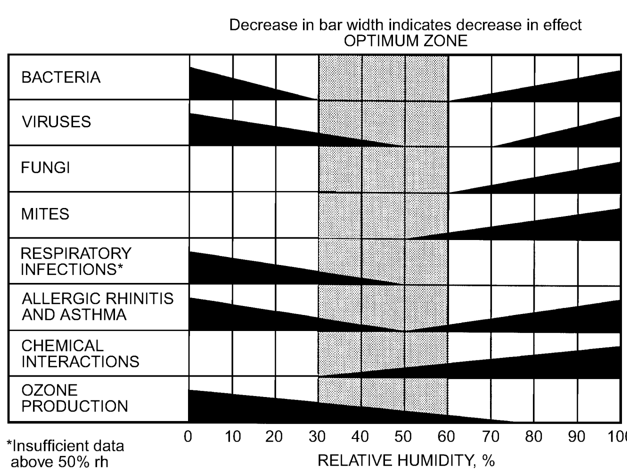

Fig. 1 Optimum Humidity Range for Human Comfort and Health
(Adapted from Sterling et al. 1985)
(2008 HVAC Systems and Equipment, Chapter 21, p. 1)

p. 23.10, Dry Air-Conditioning Systems, 4th paragraph. After the second sentence, add, "Dehumidified ventilation air that positively pressurizes the building may help counter moist air infiltration."

p. 25.4, 1st col. The second equation should solve for t_4.

p. 25.8, Paragraphs 7 to 11 repeat text earlier on the page; delete them. In Eq. (24), in both denominators, change $\dot{m}_e$ to $\dot{m}_s$.

p. 31.7, 2nd col., 7th line. Change "sue" to "use."

p. 34.10, 1st col. The unit for d_i should be inches.

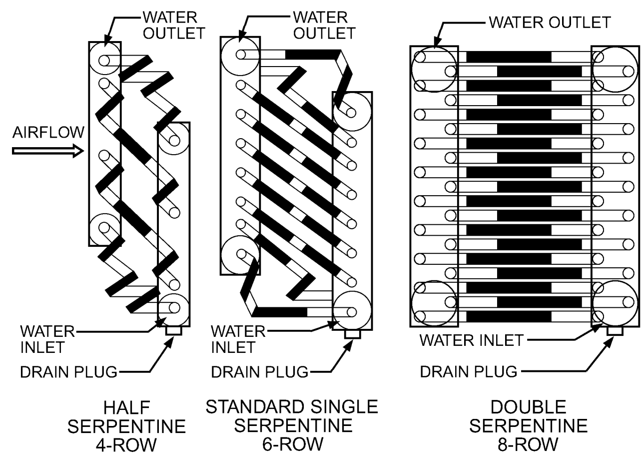

Fig. 1 Typical Water Circuit Arrangements
(2008 HVAC Systems and Equipment, Chapter 22, p. 1)

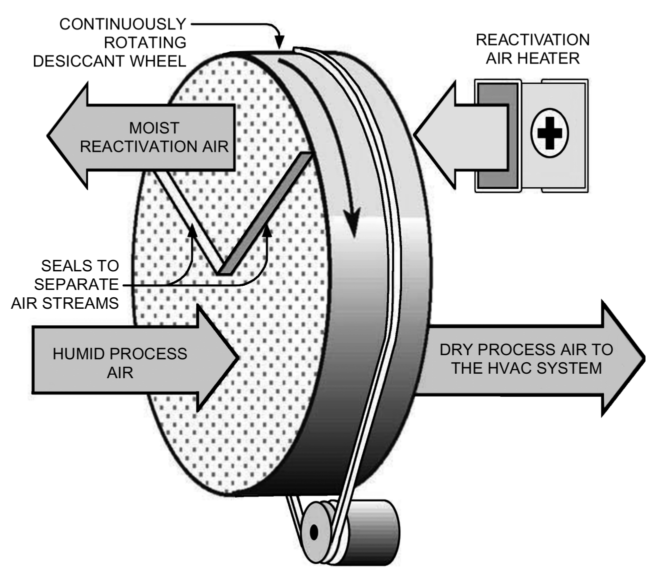

Fig. 7 Typical Rotary Dehumidification Wheel
(2008 HVAC Systems and Equipment, Chapter 23, p. 4)

p. 34.36, References. The Rutz (1992) resource is no longer available from the ASHRAE Handbook editor; instead, it is available from NTIS at http://www.ntis.gov/search/product.aspx?ABBR=PB92217504.

p. 45.12, Table 11, Notes. *L* is determined from Equation (5), not Equation (4).

p. 49.3, 1st col., 3rd line. The Energy Policy and Conservation Act of 2005 should be Public Law 109-58.

p. 50.28, Open Systems paragraph. Change "corrosion coon systems" to "corrosion coupon systems."

2009 Fundamentals

Contributors List. For Ch. 15, add the following contributors: Hakim Elmahdy, National Research Council of Canada; Brian Crooks; John L. Wright, University of Waterloo; and William R. McCluney, SunPine Consulting.

p. 1.6, Table 2. Correct values for s_s for temperatures from 100 to 200°F are given below.

Table 2 Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 14.696 psia

(2009 Fundamentals, Chapter 1, p. 6; partial)

Temp., °F *t*	s_s	Temp., °F *t*	s_s
100	0.1376	150	0.4855
101	0.1408	151	0.4995
102	0.1442	152	0.5140
103	0.1476	153	0.5291
104	0.1511	154	0.5447
105	0.1547	155	0.5609
106	0.1584	156	0.5778
107	0.1622	157	0.5953
108	0.1661	158	0.6136
109	0.1701	159	0.6325
110	0.1742	160	0.6523
111	0.1784	161	0.6728
112	0.1828	162	0.6943
113	0.1872	163	0.7167
114	0.1918	164	0.7400
115	0.1965	165	0.7644
116	0.2013	166	0.7900
117	0.2062	167	0.8167
118	0.2113	168	0.8447
119	0.2165	169	0.8741
120	0.2219	170	0.9049
121	0.2274	171	0.9372
122	0.2331	172	0.9713
123	0.2389	173	1.0072
124	0.2449	174	1.0450
125	0.2510	175	1.0849
126	0.2574	176	1.1271
127	0.2639	177	1.1717
128	0.2706	178	1.2190
129	0.2776	179	1.2693
130	0.2847	180	1.3228
131	0.2920	181	1.3798
132	0.2996	182	1.4406
133	0.3074	183	1.5057
134	0.3154	184	1.5755
135	0.3236	185	1.6506
136	0.3322	186	1.7315
137	0.3410	187	1.8189
138	0.3500	188	1.9136
139	0.3594	189	2.0167
140	0.3691	190	2.1291
141	0.3790	191	2.2524
142	0.3894	192	2.3880
143	0.4000	193	2.5379
144	0.4110	194	2.7046
145	0.4224	195	2.8908
146	0.4341	196	3.1005
147	0.4463	197	3.3381
148	0.4589	198	3.6097
149	0.4720	199	3.9232
		200	4.2889

p. 1.8, Table 3. The horizontal line between the two rows for 32°F marks the transition from saturated solid to saturated liquid for the first subcolumns under Specific Volume, Specific Enthalpy, and Specific Entropy.

pp. 1.9-1.11, Table 3. In the column headings, change "Sat. Solid" to "Sat. Liquid."

p. 1.13, top of 1st col. The units for *p* should be psia.

p. 1.13, 1st col. The reference to Eq. (38) in Chapter 5 should be to Chapter 6.

p. 1.16, Example 3. The reference to Table 2 should be to Table 3. The value for h_{w2} should be 18.07, which makes the result using Eq. (45) 10,154 Btu/min, or 50.77 tons of refrigeration.

p. 3.2, 2nd col., last paragraph. Delete the second instance of the sentence: "The terms E_M and H_M (= E_M/g) are defined as positive, and represent energy added to the fluid by pumps or blowers."

p. 4.19, Table 8, Eq. (T8.12). Change 0.37 to 0.037.

p. 4.22, Table 10. Correct Eqs. (T10.1) and (T10.7) as follows:

$$\frac{1 - \exp[-N(1 + c_r)]}{1 + c_r} \tag{T10.1}$$

$$\frac{1 - \exp(-c_r \gamma)}{c_r} \tag{T10.7}$$

p. 4.24, Table 11. In the Muley and Manglik (1999) equation for Nu, the last line should read "$\times$ $Re^{0.728-0.0543 \sin\{[\pi(90-\beta)/45+3.7\}}$"

p. 9.19, Eq. (79). The equation should be $t_{oc} = 54.1 + 0.31 t_{out.}$

p. 9.17, between Eqs. (64) and (65). The reference to Equation (58) should be to Equation (60).

p. 13.14, 2nd col., 3rd full paragraph. The equation should read $\rho = P/(R_{air}T)$.

p. 14.1, 1st paragraph. The StationFinder utility is included only with the HandbookCD+ version of this chapter, not with the CD-ROM included with the print edition.

p. 14.7, Eq. (5). Add a closing parenthesis at the end of the equation.

p. 14.8, bottom of page. The first column should end with "the following equation provides sufficient accuracy." The line beginning "**Solution:**" should be the next-to-last line in the second column.

p. 14.9, Eq. (20). The first operator should be +, not –.

Ch. 14, Appendix: Design Conditions for Selected Locations. The 99% and 99.6% heating design dry-bulb temperatures for the following Alaska stations should be

	99.6% DB	99% DB
Anchorage/Elmendorf	–14.8	–9.3
Lake Hood Seaplane	–8.7	–4.1
Anchorage Intl AP	–8.9	–4.4
Anchorage Merrill Field	–11.0	–6.9

Ch. 14, Appendix: Design Conditions for Selected Locations, and Climatic Design Conditions Tables (on the CD-ROM). The main entry for Taiwan should read "Taiwan." In the Russian Federation, station UST-ISIM, WMO ID 283820, the longitude should be 71.18 E. Hong Kong International (WMO ID 450070) and Hong Kong Observatory (WMO ID 450050) should appear under Hong Kong rather than China. Correct the following latitudes and longitudes:

Station	WMO ID	Latitude	Longitude
Somerset, KY	724354	37.054N	84.601W
South St. Paul, MN	726603	44.857N	93.018W
Dyersburg, TN	723347	36.000 N	89.400W

p. 15.4, 1st col. In the definitions after Eq. (8), the unit for *L* should be inches.

p. 15.11, Example 2, Solution. The second reference to Table 4 should be to Table 1.

p. 15.16, 1st col., top. Add "when" before "greater accuracy is desired."

p. 15.29, Table 12. Change the title to read, "Solar Heat Gain Coefficients and U-Factors for Standard hollow Glass Block Wall Panels."

p. 15.60, Symbols. Add the following definition: "F_R = radiant fraction."

p. 15.62, References. Add the following source before LBL 2003:

Laoudi, A., A.D. Galasiu, M.R. Atif, and A. Haqqani. 2003. SkyVision: A software tool to calculate the optical characteristics and daylighting performance of skylights. *Building Simulation, 8th IBPSA Conference*, Eindhoven, Netherlands, pp. 705-712.

p. 16.7, Eq. (26). On the third line, change "[$C_p(3) - C_p(4)$]" to "[$C_p(3) + C_p(4)$]."

p. 16.23, Eq. (48). The equation should use the absolute value of Δt.

p. 17.7. For Eq. (11), the correct equation is as follows:

$$Q_v = 0.01A_{cf} + 7.5(N_{br} + 1) \quad \textbf{(11)}$$

In the definitions after Eq. (18), change $q_{vnt,l}$ to $q_{vi,l}$.

p. 17.8, Eq. (21). The closing parenthesis should be at the end of the equation.

p. 18.2, 2nd col., Cooling Load Calculations in Practice section. On the third line, change "filtration" to "infiltration."

pp. 18.8-18.11, Tables 5A to 5E. Items with an asterisk appear only in Swierzycna (2009); all others appear in both Swierzycna (2008) and (2009).

p. 18.31, Eq. (39). The denominator of the first fraction should be $\pi(z_2 - z_1)$.

p. 18.31, Eq. (40). The correct equation is as follows:

$$U_{avg,bf} = \frac{2k_{soil}}{\pi w_b} \times \left[\ln\left(\frac{w_b}{2} + \frac{z_f}{2} + \frac{k_{soil}R_{other}}{\pi}\right) - \ln\left(\frac{z_f}{2} + \frac{k_{soil}R_{other}}{\pi}\right)\right] \quad (40)$$

p. 18.33, 2nd col. In the list of variables under item 2, T_r = room or return air temperature, °F.

p. 18.41, Table 29. Correct the diffuse solar heat gain values for the following rows:

Local Std. Hour	Diff. Solar Heat Gain, Btu/h	Local Std. Hour	Diff. Solar Heat Gain, Btu/h
6	106	13	2436
7	569	14	2614
8	1002	15	2648
9	1371	16	2479
10	1665	17	2072
11	1887	18	1429
12	2177	19	599

p. 18.43, Table 31. For the convective and radiant columns, use the values shown above right.

Table 31 Window Component of Cooling Load (With Blinds, No Overhand)

(2009 Fundamentals, Chapter 18, p. 43; partial)

Convective 54%, Btu/h	Radiant 46%, Btu/h	Convective 54%, Btu/h	Radiant 46%, Btu/h
–29	–25	1615	1376
–48	–41	2293	1953
–65	–56	2853	2431
–80	–68	3093	2635
–90	–76	2847	2425
–35	–29	2102	1791
199	169	867	739
469	399	162	138
720	614	116	99
930	793	70	60
1100	937	31	27
1275	1086	0	0

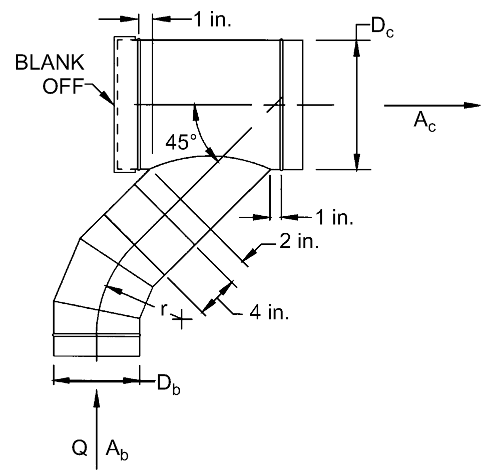

Figure for ED5-6

(2009 Fundamentals, Chapter 21, p. 44)

p. 19.18, Eqs. (55), (57), and (59). Multiply the right-hand side of the equation by the conversion factor 24 h/day. For Eq. (57), also change η_h to η_c.

p. 20.13, 2nd col., Air Diffusion Performance Index (ADPI), 1st paragraph. The reference should be to Eq. (15).

p. 20.14, 2nd col., Convective Flows Associated with Space Heat Sources, last paragraph. The reference should be to Eq. (12).

p. 21.6, Eq. (19). The correct equation is as follows:

$$\frac{1}{\sqrt{f}} = -2\log\left(\frac{12\varepsilon}{3.7D_h} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right) \quad (19)$$

p. 21.33, Table for ED5-1, Wye, 30°, Converging. In the expression centered over the table columns, change Q_b to Q_s.

pp. 21.42-44, Tables for ED5-3, D_c > 10 in., Converging. In the expressions centered over the table columns, change Q_b to Q_s (three places).

p. 21.44, Figures for ED5-6 and ED5-9. The correct figures are shown above and on page A.4.

pp. 21.45 (bottom table) and 21.46 (top table). Change "C_{b1} Values" to "C_{b2} Values."

p. 23.14, Fig. 7. The correct figure is shown on p. A.4.

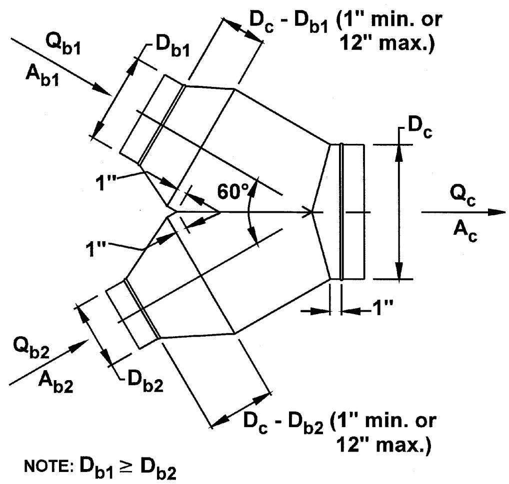

Figure for ED5-9
(2009 Fundamentals, Chapter 21, p. 44)

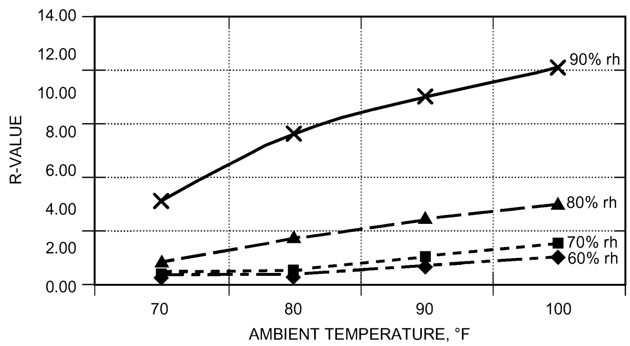

Fig. 7 R-Value Required to Prevent Condensation on Surface with Emittance ε = 0.9
(2009 Fundamentals, Chapter 23, p. 14)

p. 23.15, Eq. (7). Replace § with /.

p. 24.5, Fig. 7. The curves for L/W = 1/4 and L/W = 4 should be swapped. The correct figure is supplied above right.

pp. 26.5-9, Table 4. Please replace the table with the one that begins on page A.6. Cells with updated values are highlighted.

p. 26.19, References. Please add the following entry:

Cardenes, T.J. and G.T. Bible. 1987. *The thermal properties of wood—Data base*. American Society of Testing and Materials, West Conshohocken, PA.

pp. 27.3-4, Example 3. At the beginning of the Solution, change the first sentence to read, "If the R-values of building elements are not already specified," and delete "of the various building elements." For the table for the parallel-path method, for item #4, R for insulated cavity should be 13.0, and thus R_1 should equal 18.92. Immediately after that table, U_1 = 0.053 and U_2 = 0.097. Substituting these values into the equation for U_{av} gives a result of 0.064, and thus $R_{T(av)}$ should be 15.63. In the table for the isothermal-planes method, row 4, change the values to 13.0 and 8.70, making R_T = 14.62. On p. 27.4, R_{avs} = 8.70, RT = 14.62, and U_{av} = 0.068.

p. 27.9, Step 4, last line. The reference should be to Table 3 in Chapter 1. To convert table values from psia to in. Hg, multiply them by 2.036. Thus, 0.36334 psia × 2.036 = 0.7398 in. Hg.

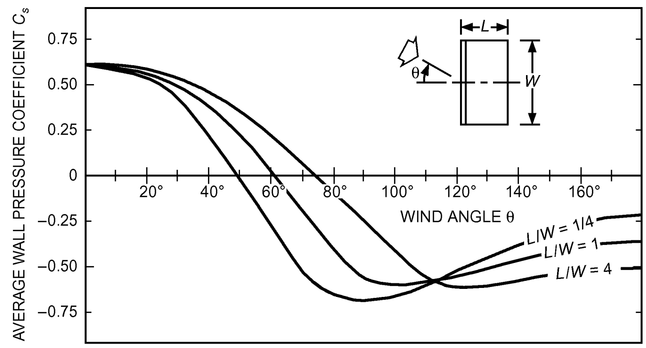

Fig. 7 Surface-Averaged Wall Pressure Coefficients for Tall Buildings
(Akins et al. 1979)
(2009 Fundamentals, Chapter 24, p. 5)

p. 31.6, 8, 10, and 11. Units for viscosity in Figures 12 and 16 and Tables 9 and 13 should be lb/ft·h.

p. 36.2, 1st col., Hydraulic diameter D_h. The second sentence should read "For a rectangular duct with dimensions W × H, the hydraulic diameter $D_h = 2WH/(W + H)$."

Table 47 Selection Guide for Vibration Isolation
(2011 HVAC Applications, Chapter 48, p. 45; partial)

		Floor Span		
Equipment Type	**Slab on Grade**	**Up to 20 ft**	**20 to 30 ft**	**30 to 40 ft**
Cooling Towers	0.25	3.5	3.5	3.5
	0.25	2.5	2.5	2.5
	0.25	0.75	0.75	1.5

p. 39.2, Table 2, Viscosity (absolute). In the fourth data row, change 0.0671955 to 0.671955.

2010 Refrigeration

Ch. 1. All existing references to Table 19 should be to Table 20. All existing references to Table 20 should be to Table 19.

pp. 1, 1st col., Hydraulic diameter D_h. The second sentence should read "For a rectangular duct with dimensions W × H, the hydraulic diameter $D_h = 2WH/(W + H)$."

p. 10.4, Table 3. Replace the table with the one on p. A.5.

p. 11.23, Table 2. Amend the table values as shown on p. A.5.

p. 19.2, Eq. (4). Change t_{wo} to x_{wo}.

p. 50.4, Horsepower entry. The value for horsepower should be 550 ft·lb_f/s^2, not 500.

2011 HVAC Applications

(CD only) Table of Contents, p. 2. Replace the second instance of "Building Operations and Management" with "General Applications."

Contributors List. For Chapter 4, add Dennis Wessel, Karpinski Engineering.

p. 28.8, 1st col. Under U.S. Evolutionary Power Reactor (USEPR), delete "(30 Pa)."

p. 36.9, Table 4. Replace the table with the one on p. A.11.

Table 3 Cellular Glass Insulation Thickness for Indoor Design Conditions

(90°F Ambient Temperature, 80% Relative Humidity, 0.9 Emittance, 0 mph Wind Velocity)

Nominal Pipe Size, in.	Pipe Operating Temperature, °F							
	40	20	0	–20	–40	–60	–80	–100
0.50	1.0	1.0	1.5	1.5	2.0	2.0	2.0	2.5
0.75	1.0	1.5	1.5	2.0	2.0	2.0	2.5	2.5
1.00	1.0	1.5	1.5	2.0	2.0	2.0	2.5	2.5
1.50	1.0	1.5	1.5	2.0	2.5	2.5	3.0	3.0
2.00	1.0	1.5	1.5	2.0	2.5	2.5	3.0	3.0
2.50	1.0	1.5	2.0	2.5	2.5	3.0	3.0	3.0
3.00	1.0	1.5	2.0	2.5	2.5	3.0	3.0	3.0
4.00	1.0	1.5	2.0	2.5	2.5	3.0	3.0	3.5
5.00	1.5	1.5	2.0	2.5	2.5	3.0	3.0	3.5
6.00	1.5	2.0	2.0	2.5	3.0	3.0	3.5	3.5
8.00	1.5	2.0	2.0	2.5	3.0	3.0	3.5	3.5
10.00	1.5	2.0	2.0	2.5	3.0	3.5	3.5	4.0
12.00	1.5	2.0	2.0	2.5	3.0	3.5	3.5	4.0
14.00	1.5	2.0	2.5	3.0	3.0	3.5	4.0	4.0
16.00	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
18.00	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
20.00	1.5	2.0	2.5	3.0	3.5	3.5	4.0	4.5
24.00	1.5	2.0	2.5	3.0	3.5	4.0	4.0	4.5
28.00	1.5	2.0	2.5	3.0	3.5	4.0	4.0	4.5
30.00	1.5	2.0	2.5	3.0	3.5	4.0	4.0	4.5
36.00	1.5	2.0	2.5	3.0	3.5	4.0	4.5	4.5

Notes:

1. Insulation thickness is chosen either to prevent or minimize condensation on outside jacket surface or to limit heat gain to 8 Btu/h·ft^2, whichever thickness is greater.
2. All thicknesses are in inches.
3. Values do not include safety or aging factor. Actual operating conditions may vary. Consult a design engineer for appropriate recommendation for your specific system.
4. Data calculated using NAIMA 3E Plus program.

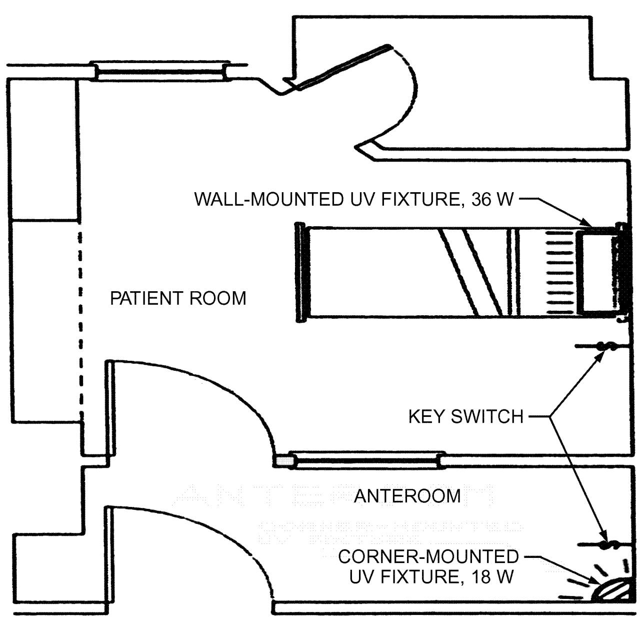

Fig. 9 Typical Layout of UVGI Fixtures for Patient Isolation Room

(First et al. 1999)

(2011 HVAC Applications, Ch. 60, p. 9)

Table 2 Values

(2010 Refrigeration, Chapter 11, p. 23)

Refrigerant	*f*
On the low side of a limited-charge cascade system:	
R-13, R-13B1, R-503	2.0 (0.163)
R-14	2.5 (0.203)
R-23, R-170, R-508A, R-508B, R-744, R-1150	1.0 (0.082)
Other applications:	
R-11, R-32, R-113, R-123, R-142b, R-152a, R-290, R-600, R-600a, R-764	1.0 (0.082)
R-12, R-22, R-114, R-124, R-134a, R-401A, R-401B, R-401C, R-405A, R-406A, R-407C, R-407D, R-407E, R-409A, R-409B, R-411A, R-411B, R-411C, R-412A, R-414A, R-414B, R-500, R-1270	(0.131)
R-115, R-402A, R-403B, R-404A, R-407B, R-410A, R-410B, R-502, R-507A, R-509A	2.5 (0.203)
R-143a, R-402B, R-403A, R-407A, R-408A, R-413A	2.0 (0.163)
R-717	0.5 (0.041)
R-718	0.2 (0.016)

Notes:

1. Listed values of *f* do not apply if fuels are used within 20 ft of pressure vessel. In this case, use methods in API (2000, 2003) to size pressure-relief device.
2. When one pressure-relief device or fusible plug is used to protect more than one pressure vessel, required capacity is the sum of capacities required for each pressure vessel.
3. For refrigerants not listed, consult ASHRAE *Standard* 15.

p. 48.20, 2nd col. For frequency range #1, consult Table 13 for A_f. In definitions for Eq. (10), refer to Table 12 for α_a.

p. 48.45, Table 47. Deflection values for cooling towers should be as shown at top of this column.

p. 60.9, Fig. 9. Replace the figure with the one below.

Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values[a]

(2009 Fundamentals, Chapter 26, pp. 5-9)

Description		Density, lb/ft³	Conductivity[b] *k*, Btu·in/h·ft²·°F	Resistance *R*, h·ft²·°F/Btu	Specific Heat, Btu/lb·°F	Reference[n]
Building Board and Siding						
Board						
Asbestos/cement board		120	4	—	0.24	Nottage (1947)
Cement board		71	1.7	—	0.2	Kumaran (2002)
Fiber/cement board		86	1.7	—	0.2	Kumaran (2002)
		61	1.3	—	0.2	Kumaran (1996)
		26	0.5	—	0.45	Kumaran (1996)
		20	0.4	—	0.45	Kumaran (1996)
Gypsum or plaster board		40	1.1	—	0.21	Kumaran (2002)
Oriented strand board (OSB)	7/16 in.	41	—	0.62	0.45	Kumaran (2002)
	1/2 in.	41	—	0.68	0.45	Kumaran (2002)
Plywood (douglas fir)	1/2 in.	29	—	0.79	0.45	Kumaran (2002)
	5/8 in.	34	—	0.85	0.45	Kumaran (2002)
Plywood/wood panels	3/4 in.	28	—	1.08	0.45	Kumaran (2002)
Vegetable fiber board					—	
Sheathing, regular density[e]	1/2 in.	18	—	1.32	0.31	Lewis (1967)
intermediate density[e]	1/2 in.	22	—	1.09	0.31	Lewis (1967)
Nail-base sheathing[e]	1/2 in.	25	—	1.06	0.31	
Shingle backer	3/8 in.	18	—	0.94	0.3	
Sound-deadening board	1/2 in.	15	—	1.35	0.3	
Tile and lay-in panels, plain or acoustic		18	0.4	—	0.14	
Laminated paperboard		30	0.5	—	0.33	Lewis (1967)
Homogeneous board from repulped paper		30	0.5	—	0.28	
Hardboard[e]						
medium density		50	0.73	—	0.31	Lewis (1967)
high density, service-tempered and service grades		55	0.82	—	0.32	Lewis (1967)
high density, standard-tempered grade		63	1	—	0.32	Lewis (1967)
Particleboard[e]						
low density		37	0.71	—	0.31	Lewis (1967)
medium density		50	0.94	—	0.31	Lewis (1967)
high density		62	1.18	0.85	—	Lewis (1967)
underlayment	5/8 in.	40	—	0.82	0.29	Lewis (1967)
Waferboard		44	0.73	—	0.45	Kumaran (1996)
Shingles						
Asbestos/cement		120	—	0.21	—	
Wood, 16 in., 7 1/2 in. exposure		—	—	0.87	0.31	
Wood, double, 16 in., 12 in. exposure		—	—	1.19	0.28	
Wood, plus ins. backer board	5/16 in.	—	—	1.4	0.31	
Siding					—	
Asbestos/cement, lapped	1/4 in.	—	—	0.21	0.24	
Asphalt roll siding		—	—	0.15	0.35	
Siding						
Asbestos/cement, lapped	1/4 in.	—	—	0.21	0.24	
Asphalt roll		—	—	0.15	0.35	
Asphalt insulating siding (1/2 in. bed)		—	—	1.46	0.35	
Hardboard siding	7/16 in.	—	—	0.67	0.28	
Wood, drop, 8 in.	1 in.	—	—	0.79	0.28	
Wood, bevel						
8 in., lapped	1/2 in.	—	—	0.81	0.28	
10 in., lapped	3/4 in.	—	—	1.05	0.28	
Wood, plywood, 3/8 in., lapped		—	—	0.59	0.29	
Aluminum, steel, or vinyl,[j, k] over sheathing					—	
hollow-backed		—	—	0.62	0.29[k]	
insulating-board-backed					—	
	3/8 in.	—	—	1.82	0.32	
foil-backed	3/8 in.	—	—	2.96	—	
Architectural (soda-lime float) glass		158	6.9	—	0.21	
Building Membrane						
Vapor-permeable felt		—	—	0.06	—	
Vapor: seal, 2 layers of mopped 15 lb felt		—	—	0.12	—	

Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values[a] *(Continued)*

(2009 Fundamentals, Chapter 26, pp. 5-9)

Description	Density, lb/ft^3	Conductivity[b] *k*, $Btu\cdot in/h\cdot ft^2\cdot °F$	Resistance *R*, $h\cdot ft^2\cdot °F/Btu$	Specific Heat, $Btu/lb\cdot °F$	Reference[n]
Vapor: seal, plastic film	—	—	Negligible	—	
Finish Flooring Materials					
Carpet and rebounded urethane pad 3/4 in.	7	—	2.38	—	NIST (2000)
Carpet and rubber pad (one-piece) 3/8 in.	20	—	0.68	—	NIST (2000)
Pile carpet with rubber pad 3/8 to 1/2 in.	18	—	1.59	—	NIST (2000)
Linoleum/cork tile 1/4 in.	29	—	0.51	—	NIST (2000)
PVC/Rubber floor covering	—	2.8	—	—	CIBSE (2006)
Rubber tile 1.0 in.	119	—	0.34	—	NIST (2000)
Terrazzo 1.0 in.	—	—	0.08	0.19	
Insulating Materials					
Blanket and batt[c,d]					
Glass-fiber batts 3 to 3 1/2 in.	0.6 to 0.9	0.30	—	0.2	Kumaran (2002)
6 in.	0.5 to 0.8	0.31 to 0.33	—	0.2	Kumaran (2002)
Mineral fiber 5 1/2 in.	2	0.25	—	0.2	Kumaran (1996)
Mineral wool, felted	1 to 3	0.28	—	—	CIBSE (2006), NIST (2000)
	4 to 8	0.24	—	—	NIST (2000)
Slag wool	3 to 12	0.26	—	—	Raznjevic (1976)
	16	0.28	—	—	Raznjevic (1976)
	19	0.30	—	—	Raznjevic (1976)
	22	0.33	—	—	Raznjevic (1976)
	25	0.35	—	—	Raznjevic (1976)
Board and slabs					
Cellular glass	8	0.33	—	0.18	(Manufacturer)
Cement fiber slabs, shredded wood with Portland cement binder	25 to 27	0.50 to 0.53	—	—	
with magnesia oxysulfide binder	22	0.57	—	0.31	
Glass fiber board	10	0.22 to 0.28	—	0.2	Kumaran (1996)
Expanded rubber (rigid)	4	0.2	—	0.4	Nottage (1947)
Expanded polystyrene extruded (smooth skin)	1.6 to 2.4	0.15 to 0.21	—	0.35	Kumaran (1996)
Expanded polystyrene, molded beads	0.9 to 1.6	0.22 to 0.27	—	0.35	Kumaran (1996)
Mineral fiberboard, wet felted	10	0.26	—	0.2	Kumaran (1996)
core or roof insulation	16 to 17	0.34	—	—	
acoustical tile[g]	18	—	—	0.19	
	21	0.37	—	—	
wet-molded, acoustical tile[g]	23	0.42	—	0.14	
Perlite board	10	0.36	—	—	Kumaran (1996)
Polyisocyanurate, aged					
unfaced	1.6 to 2.3	0.14 to 0.19	—	—	Kumaran (2002)
with facers	4	0.13	—	0.35	Kumaran (1996)
Phenolic foam board with facers, aged	4	0.13	—	—	Kumaran (1996)
Loose fill					
Cellulosic (milled paper or wood pulp)	2 to 3.5	0.26 to 0.31	—	0.45	NIST (2000), Kumaran (1996)
fiberized	1.2 to 2.0				
Perlite, expanded	2 to 4	0.27 to 0.31	—	0.26	(Manufacturer)
	4 to 7.5	0.31 to 0.36	—	—	(Manufacturer)
	7.5 to 11	0.36 to 0.42	—	—	(Manufacturer)
Mineral fiber (rock, slag, or glass)[d]					
approx. 3 3/4 to 5 in.	0.6 to 2.0	—	11.0	0.17	
approx. 6 1/2 to 8 3/4 in.	0.6 to 2.0	—	19.0	—	
approx. 7 1/2 to 10 in.	0.6 to 2.0	—	22.0	—	
approx. 10 1/4 to 13 3/4 in.	0.6 to 2.0	—	30.0	—	
approx. 3 1/2 in. (closed sidewall application)	2.0 to 4.0	—	12.0 to 14.0	—	
Vermiculite, exfoliated	7.0 to 8.2	0.47	—	0.32	Sabine et al. (1975)
	4.0 to 6.0	0.44	—	—	(Manufacturer)
Spray-applied					
Cellulosic fiber	3.5 to 6.0	0.29 to 0.34	—	—	Yarbrough et al. (1987)
Glass fiber	3.5 to 4.5	0.26 to 0.27	—	—	Yarbrough et al. (1987)
Polyurethane foam (low density)	0.4 to 0.5	0.29	—	0.35	Kumaran (2002)
	2.4	0.18	—	0.35	Kumaran (2002)
aged and dry 1 1/2 in.	2.0	—	9.09	0.35	Kumaran (1996)
2 in.	3.5	—	10.9	0.35	Kumaran (1996)

Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values[a] *(Continued)*

(2009 Fundamentals, Chapter 26, pp. 5-9)

Description	Density, lb/ft³	Conductivity[b] k, Btu·in/h·ft²·°F	Resistance R, h·ft²·°F/Btu	Specific Heat, Btu/lb·°F	Reference[n]
.... 4 1/2 in.	2.0	—	20.95	—	Kumaran (1996)
Ureaformaldehyde foam, dry	0.5 to 1.2	0.21 to 0.22	—	—	CIBSE (2006)
Metals					
(See Chapter 33, Table 3)					
Roofing					
Asbestos/cement shingles	120	—	0.21	0.24	
Asphalt (bitumen with inert fill)	100	2.98	—	—	CIBSE (2006)
....	119	4.0	—	—	CIBSE (2006)
....	144	7.97	—	—	CIBSE (2006)
Asphalt roll roofing	70	—	0.15	0.36	
Asphalt shingles	70	—	0.44	0.3	
Built-up roofing .... 3/8 in.	70	—	0.33	0.35	
Mastic asphalt (heavy, 20% grit)	59	1.32	—	—	CIBSE (2006)
Reed thatch	17	0.62	—	—	CIBSE (2006)
Roofing felt	141	8.32	—	—	CIBSE (2006)
Slate .... 1/2 in.	—	—	0.05	0.3	
Straw thatch	15	0.49	—	—	CIBSE (2006)
Wood shingles, plain and plastic-film-faced	—	—	0.94	0.31	
Plastering Materials					
Cement plaster, sand aggregate	116	5.0	—	0.2	
Sand aggregate					
.... 3/8 in.	—	—	0.08	0.2	
.... 3/4 in.	—	—	0.15	0.2	
Gypsum plaster	70	2.63	—	—	CIBSE (2006)
....	80	3.19	—	—	CIBSE (2006)
Lightweight aggregate					
.... 1/2 in.	45	—	0.32	—	
.... 5/8 in.	45	—	0.39	—	
on metal lath .... 3/4 in.	—	—	0.47	—	
Perlite aggregate	45	1.5	—	0.32	
Sand aggregate	105	5.6	—	0.2	
on metal lath .... 3/4 in.	—	—	0.13	—	
Vermiculite aggregate	30	1	—	—	CIBSE (2006)
....	40	1.39	—	—	CIBSE (2006)
....	45	1.7	—	—	CIBSE (2006)
....	50	1.8	—	—	CIBSE (2006)
....	60	2.08	—	—	CIBSE (2006)
Perlite plaster	25	0.55	—	—	CIBSE (2006)
....	38	1.32	—	—	CIBSE (2006)
Pulpboard or paper plaster	38	0.48	—	—	CIBSE (2006)
Sand/cement plaster, conditioned	98	4.4	—	—	CIBSE (2006)
Sand/cement/lime plaster, conditioned	90	3.33	—	—	CIBSE (2006)
Sand/gypsum (3:1) plaster, conditioned	97	4.5	—	—	CIBSE (2006)
Masonry Materials					
Masonry units					
Brick, fired clay	150	8.4 to 10.2	—	—	Valore (1988)
....	140	7.4 to 9.0	—	—	Valore (1988)
....	130	6.4 to 7.8	—	—	Valore (1988)
....	120	5.6 to 6.8	—	0.19	Valore (1988)
....	110	4.9 to 5.9	—	—	Valore (1988)
....	100	4.2 to 5.1	—	—	Valore (1988)
....	90	3.6 to 4.3	—	—	Valore (1988)
....	80	3.0 to 3.7	—	—	Valore (1988)
....	70	2.5 to 3.1	—	—	Valore (1988)
Clay tile, hollow					
1 cell deep .... 3 in.	—	—	0.80	0.21	Rowley (1937)
.... 4 in.	—	—	1.11	—	Rowley (1937)
2 cells deep .... 6 in.	—	—	1.52	—	Rowley (1937)
.... 8 in.	—	—	1.85	—	Rowley (1937)
.... 10 in.	—	—	2.22	—	Rowley (1937)
3 cells deep .... 12 in.	—	—	2.50	—	Rowley (1937)
Lightweight brick	50	1.39	—	—	Kumaran (1996)
....	48	1.51	—	—	Kumaran (1996)

Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values[a] *(Continued)*

(2009 Fundamentals, Chapter 26, pp. 5-9)

Description	Density, lb/ft³	Conductivity[b] *k*, Btu·in/h·ft²·°F	Resistance *R*, h·ft²·°F/Btu	Specific Heat, Btu/lb·°F	Reference[n]
Concrete blocks[h, i]					
Limestone aggregate					
8 in., 36 lb, 138 lb/ft³ concrete, 2 cores	—	—	—	—	
with perlite-filled cores	—	—	2.1	—	Valore (1988)
12 in., 55 lb, 138 lb/ft³ concrete, 2 cores	—		—	—	
with perlite-filled cores	—	—	3.7	—	Valore (1988)
Normal-weight aggregate (sand and gravel)					
8 in., 33 to 36 lb, 126 to 136 lb/ft³ concrete, 2 or 3 cores	—	—	1.11 to 0.97	0.22	Van Geem (1985)
with perlite-filled cores	—	—	2.0	—	Van Geem (1985)
with vermiculite-filled cores	—	—	1.92 to 1.37	—	Valore (1988)
12 in., 50 lb, 125 lb/ft³ concrete, 2 cores	—	—	1.23	0.22	Valore (1988)
Medium-weight aggregate (combinations of normal and lightweight aggregate)					
8 in., 26 to 29 lb, 97 to 112 lb/ft³ concrete, 2 or 3 cores	—	—	1.71 to 1.28	—	Van Geem (1985)
with perlite-filled cores	—	—	3.7 to 2.3	—	Van Geem (1985)
with vermiculite-filled cores	—	—	3.3	—	Van Geem (1985)
with molded-EPS-filled (beads) cores	—	—	3.2	—	Van Geem (1985)
with molded EPS inserts in cores	—	—	2.7	—	Van Geem (1985)
Lightweight aggregate (expanded shale, clay, slate or slag, pumice)					
6 in., 16 to 17 lb, 85 to 87 lb/ft³ concrete, 2 or 3 cores	—	—	1.93 to 1.65	—	Van Geem (1985)
with perlite-filled cores	—	—	4.2	—	Van Geem (1985)
with vermiculite-filled cores	—	—	3.0	—	Van Geem (1985)
8 in., 19 to 22 lb, 72 to 86 lb/ft³ concrete	—	—	3.2 to 1.90	0.21	Van Geem (1985)
with perlite-filled cores	—	—	6.8 to 4.4	—	Van Geem (1985)
with vermiculite-filled cores	—	—	5.3 to 3.9	—	Shu et al. (1979)
with molded-EPS-filled (beads) cores	—	—	4.8	—	Shu et al. (1979)
with UF foam-filled cores	—	—	4.5	—	Shu et al. (1979)
with molded EPS inserts in cores	—	—	3.5	—	Shu et al. (1979)
12 in., 32 to 36 lb, 80 to 90 lb/ft³, concrete, 2 or 3 cores	—	—	2.6 to 2.3	—	Van Geem (1985)
with perlite-filled cores	—	—	9.2 to 6.3	—	Van Geem (1985)
with vermiculite-filled cores	—	—	5.8	—	Valore (1988)
Stone, lime, or sand	180	72	—	—	Valore (1988)
Quartzitic and sandstone	160	43	—	—	Valore (1988)
	140	24	—	—	Valore (1988)
	120	13	—	0.19	Valore (1988)
Calcitic, dolomitic, limestone, marble, and granite	180	30	—	—	Valore (1988)
	160	22	—	—	Valore (1988)
	140	16	—	—	Valore (1988)
	120	11	—	0.19	Valore (1988)
	100	8	—	—	Valore (1988)
Gypsum partition tile					
3 by 12 by 30 in., solid	—	—	1.26	0.19	Rowley (1937)
4 cells	—	—	1.35	—	Rowley (1937)
4 by 12 by 30 in., 3 cells	—	—	1.67	—	Rowley (1937)
Limestone	150	3.95	—	0.2	Kumaran (2002)
	163	6.45	—	0.2	Kumaran (2002)
Concretes[i]					
Sand and gravel or stone aggregate concretes (concretes with >50% quartz or quartzite sand have conductivities in higher end of range)	150	10.0 to 20.0	—	—	Valore (1988)
	140	9.0 to 18.0	—	0.19 to 0.24	Valore (1988)
	130	7.0 to 13.0	—	—	Valore (1988)
Lightweight aggregate or limestone concretes	120	6.4 to 9.1	—	—	Valore (1988)
Expanded shale, clay, or slate; expanded slags; cinders; pumice (with density up to 100 lb/ft³); scoria (sanded concretes have conductivities in higher end of range)	100	4.7 to 6.2	—	0.2	Valore (1988)
	80	3.3 to 4.1	—	0.2	Valore (1988)
	60	2.1 to 2.5	—	—	Valore (1988)
	40	1.3	—	—	Valore (1988)

Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values[a] *(Continued)*

(2009 Fundamentals, Chapter 26, pp. 5-9)

Description	Density, lb/ft³	Conductivity[b] *k*, Btu·in/h·ft²·°F	Resistance *R*, h·ft²·°F/Btu	Specific Heat, Btu/lb·°F	Reference[n]
Gypsum/fiber concrete					
(87.5% gypsum, 12.5% wood chips)	51	1.66	—	0.2	Rowley (1937)
Cement/lime, mortar, and stucco	120	9.7	—	—	Valore (1988)
	100	6.7	—	—	Valore (1988)
	80	4.5	—	—	Valore (1988)
Perlite, vermiculite, and polystyrene beads	50	1.8 to 1.9	—	—	Valore (1988)
	40	1.4 to 1.5	—	0.15 to 0.23	Valore (1988)
	30	1.1	—	—	Valore (1988)
	20	0.8	—	—	Valore (1988)
Foam concretes	120	5.4	—	—	Valore (1988)
	100	4.1	—	—	Valore (1988)
	80	3.0	—	—	Valore (1988)
	70	2.5	—	—	Valore (1988)
Foam concretes and cellular concretes	60	2.1	—	—	Valore (1988)
	40	1.4	—	—	Valore (1988)
	20	0.8	—	—	Valore (1988)
Aerated concrete (oven-dried)	27 to 50	1.4	—	0.2	Kumaran (1996)
Polystyrene concrete (oven-dried)	16 to 50	2.54	—	0.2	Kumaran (1996)
Polymer concrete	122	11.4	—	—	Kumaran (1996)
	138	7.14	—	—	Kumaran (1996)
Polymer cement	117	5.39	—	—	Kumaran (1996)
Slag concrete	60	1.5	—	—	Touloukian et al (1970)
	80	2.25	—	—	Touloukian et al. (1970)
	100	3	—	—	Touloukian et al. (1970)
	125	8.53	—	—	Touloukian et al. (1970)
Woods (12% moisture content)[l]					
Hardwoods	—	—	—	0.39[m]	Wilkes (1979)
Oak	41 to 47	1.12 to 1.25	—	—	Cardenas and Bible (1987)
Birch	43 to 45	1.16 to 1.22	—	—	Cardenas and Bible (1987)
Maple	40 to 44	1.09 to 1.19	—	—	Cardenas and Bible (1987)
Ash	38 to 42	1.06 to 1.14	—	—	Cardenas and Bible (1987)
Softwoods	—	—	—	0.39[m]	Wilkes (1979)
Southern pine	36 to 41	1.00 to 1.12	—	—	Cardenas and Bible (1987)
Southern yellow pine	31	1.06 to 1.16	—	—	Kumaran (2002)
Eastern white pine	25	0.85 to 0.94	—	—	Kumaran (2002)
Douglas fir/larch	34 to 36	0.95 to 1.01	—	—	Cardenas and Bible (1987)
Southern cypress	31 to 32	0.90 to 0.92	—	—	Cardenas and Bible (1987)
Hem/fir, spruce/pine/fir	24 to 31	0.74 to 0.90	—	—	Cardenas and Bible (1987)
Spruce	25	0.74 to 0.85	—	—	Kumaran (2002)
Western red cedar	22	0.83 to 0.86	—	—	Kumaran (2002)
West coast woods, cedars	22 to 31	0.68 to 0.90	—	—	Cardenas and Bible (1987)
Eastern white cedar	22	0.82 to 0.89	—	—	Kumaran (2002)
California redwood	24 to 28	0.74 to 0.82	—	—	Cardenas and Bible (1987)
Pine (oven-dried)	23	0.64	—	0.45	Kumaran (1996)
Spruce (oven-dried)	25	0.69	—	0.45	Kumaran (1996)

Table 4 Energy Cost Percentiles from 2003 Commercial Survey
(2011 HVAC Applications, Chapter 36, p. 9)

Building Use	Weighted Energy Cost Values, $/yr per gross square foot					
	Percentiles					
	10th	25th	50th	75th	90th	Mean
Administrative/professional office	0.50	0.82	1.36	1.92	2.58	1.55
Bank/other financial	1.09	1.37	2.00	2.93	4.47	2.41
Clinic/other outpatient health	0.61	0.87	1.53	2.03	4.13	1.74
College/university	0.44	1.20	1.37	2.27	$3.01	1.82
Convenience store	2.48	3.75	5.26	8.02	10.12	6.17
Convenience store with gas station	1.99	2.75	4.61	6.83	8.74	5.12
Distribution/shipping center	0.24	0.33	0.54	0.88	1.37	0.74
Dormitory/fraternity/sorority	0.58	0.69	0.87	1.29	2.13	1.07
Elementary/middle school	0.54	0.78	1.09	1.57	2.60	1.48
Entertainment/culture	0.14	0.42	0.56	2.25	17.82	2.83
Fast food	2.93	4.98	8.87	12.29	14.14	8.92
Fire station/police station	0.10	0.53	1.15	1.73	2.83	1.31
Government office	0.52	0.90	1.40	1.88	2.66	1.52
Grocery store/food market	2.60	3.07	4.31	5.27	6.85	4.84
High school	0.60	0.87	1.02	1.60	2.19	1.30
Hospital/inpatient health	1.37	2.16	2.46	3.17	3.55	2.70
Hotel	0.74	1.05	1.33	1.76	2.52	1.58
Laboratory	1.34	3.09	4.52	7.64	10.81	5.18
Library	0.78	1.06	1.37	2.41	2.92	1.68
Medical office (diagnostic)	0.33	0.68	1.02	2.13	2.53	1.33
Medical office (nondiagnostic)	0.58	0.79	1.06	1.44	1.92	1.15
Mixed-use office	0.46	0.85	1.30	1.96	2.90	1.78
Motel or inn	0.49	0.83	1.21	1.82	2.67	1.48
Nonrefrigerated warehouse	0.06	0.17	0.38	0.80	1.43	0.61
Nursing home/assisted living	0.73	1.12	1.52	2.47	2.99	1.78
Other	0.15	0.51	0.93	1.81	2.41	1.35
Other classroom education	0.21	0.50	0.92	1.26	2.14	0.96
Other food sales	0.60	0.72	0.95	2.35	6.02	2.20
Other food service	0.79	1.60	2.44	6.50	11.56	4.72
Other lodging	0.55	0.56	1.13	1.71	2.76	1.30
Other office	0.37	0.71	1.19	2.16	2.56	1.47
Other public assembly	0.35	0.50	0.81	1.56	2.06	1.15
Other public order and safety	1.00	1.13	1.56	3.38	4.74	2.06
Other retail	0.97	1.19	1.59	2.98	5.60	2.43
Other service	0.76	1.13	1.58	2.92	7.29	2.71
Post office/postal center	0.32	0.78	1.09	1.44	1.89	1.07
Preschool/daycare	0.46	0.77	1.09	1.57	2.63	1.30
Recreation	0.30	0.53	0.87	1.38	2.33	1.14
Refrigerated warehouse	0.38	0.38	2.21	4.00	5.25	2.45
Religious worship	0.25	0.37	0.60	0.84	1.32	0.72
Repair shop	0.20	0.35	0.61	1.15	1.47	0.75
Restaurant/cafeteria	1.12	1.86	3.33	7.44	10.48	4.80
Retail store	0.36	0.53	0.98	1.77	2.90	1.38
Self-storage	0.05	0.10	0.20	0.27	0.52	0.23
Social/meeting	0.19	0.33	0.66	1.02	2.27	0.89
Vacant	0.04	0.08	0.27	0.70	1.19	0.48
Vehicle dealership/showroom	0.67	0.89	1.37	2.97	3.98	2.07
Vehicle service/repair shop	0.29	0.50	0.77	1.38	2.07	1.10
Vehicle storage/maintenance	0.04	0.16	0.48	1.12	1.96	0.83
SUM or Mean for sector	0.26	0.54	1.06	2.00	3.93	1.80

Source: Calculated based on DOE/EIA preliminary 2003 CBECS microdata.