Table 1 Surface Conductances and Resistances for Air

Position of Surface	Direction of Heat Flow	Surface Emittance, ε: Non-reflective ε = 0.90 h_i	R	Reflective ε = 0.20 h_i	R	Reflective ε = 0.05 h_i	R
STILL AIR							
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping—45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping—45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
MOVING AIR (Any position)		h_o	R				
15 mph wind (for winter)	Any	6.00	0.17	—	—	—	—
7.5 mph wind (for summer)	Any	4.00	0.25	—	—	—	—

Notes:
1. Surface conductance h_i and h_o measured in Btu/h·ft²·°F; resistance R in ft²·°F·h/Btu.
2. No surface has both an air space resistance value and a surface resistance value.
3. Conductances are for surfaces of the stated emittance facing virtual blackbody surroundings at the same temperature as the ambient air. Values are based on a surface-air temperature difference of 10°F and for surface temperatures of 70°F.
4. See Chapter 3 for more detailed information.
5. Condensate can have a significant impact on surface emittance (see Table 2).

Table 2 Emittance Values of Various Surfaces and Effective Emittances of Air Spaces[a]

Surface	Average Emittance ε	Effective Emittance ε_{eff} of Air Space: One Surface Emittance ε; Other, 0.9	Both Surfaces Emittance ε
Aluminum foil, bright	0.05	0.05	0.03
Aluminum foil, with condensate just visible (> 0.7 gr/ft²)	0.30[b]	0.29	—
Aluminum foil, with condensate clearly visible (> 2.9 gr/ft²)	0.70[b]	0.65	—
Aluminum sheet	0.12	0.12	0.06
Aluminum coated paper, polished	0.20	0.20	0.11
Steel, galvanized, bright	0.25	0.24	0.15
Aluminum paint	0.50	0.47	0.35
Building materials: wood, paper, masonry, nonmetallic paints	0.90	0.82	0.82
Regular glass	0.84	0.77	0.72

[a]These values apply in the 4 to 40 μm range of the electromagnetic spectrum.
[b]Values are based on data presented by Bassett and Trethowen (1984).

was tested. In addition, surface oxidation, dust accumulation, condensation, and other factors that change the condition of the low-emittance surface can reduce the thermal effectiveness of these insulation systems (Hooper and Moroz 1952). Deterioration results from contact with several types of solutions, either acidic or basic (e.g., wet cement mortar or the preservatives found in decay-resistant lumber). Polluted environments may cause rapid and severe material degradation. However, site inspections show a predominance of well-preserved installations and only a small number of cases in which rapid and severe deterioration has occurred. An extensive review of the reflective building insulation system performance literature is provided by Goss and Miller (1989).

CALCULATING OVERALL THERMAL RESISTANCES

Relatively small, highly conductive elements in an insulating layer called thermal bridges can substantially reduce the average thermal resistance of a component. Examples include wood and metal studs in frame walls, concrete webs in concrete masonry walls, and metal ties or other elements in insulated wall panels. The following examples illustrate the calculation of R-values and U-factors for components containing thermal bridges.

The following conditions are assumed in calculating the design R-values:

- Equilibrium or steady-state heat transfer, disregarding effects of thermal storage
- Surrounding surfaces at ambient air temperature
- Exterior wind velocity of 15 mph for winter (surface with R = 0.17 ft²·°F·h/Btu) and 7.5 mph for summer (surface with R = 0.25 ft²·°F·h/Btu)
- Surface emittance of ordinary building materials is 0.90

Wood Frame Walls

The average overall R-values and U-factors of wood frame walls can be calculated by assuming either parallel heat flow paths through areas with different thermal resistances or by assuming

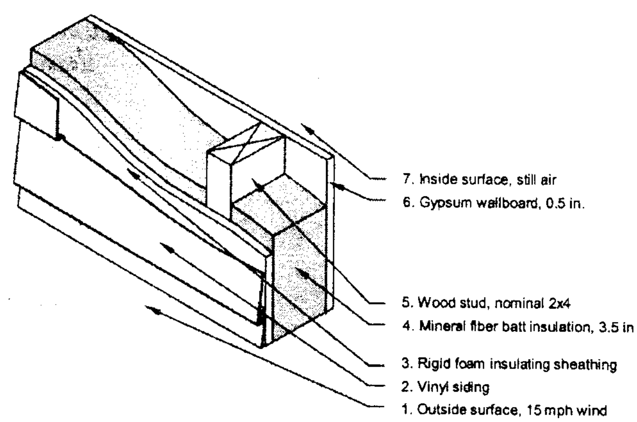


Fig. 2 Insulated Wood Frame Wall (Example 1)

isothermal planes. Equations (4), (5), (7), and (11) from Chapter 23 are used.

The framing factor or fraction of the building component that is framing depends on the specific type of construction, and it may vary based on local construction practices—even for the same type of construction. For stud walls 16 in. on center (OC), the fraction of insulated cavity may be as low as 0.75, where the fraction of studs, plates, and sills is 0.21 and the fraction of headers is 0.04. For studs 24 in. OC, the respective values are 0.78, 0.18, and 0.04. These fractions contain an allowance for multiple studs, plates, sills, extra framing around windows, headers, and band joists. These assumed framing fractions are used in the following example, to illustrate the importance of including the effect of framing in determining the overall thermal conductance of a building. The actual framing fraction should be calculated for each specific construction.

Example 1. Calculate the U-factor of the 2 by 4 stud wall shown in Figure 2. The studs are at 16 in. OC. There is 3.5 in. mineral fiber batt insulation (R-13) in the stud space. The inside finish is 0.5 in. gypsum wallboard; the outside is finished with rigid foam insulating sheathing (R-4) and 0.5 in. by 8 in. vinyl siding. The insulated cavity occupies approximately 75% of the transmission area; the studs, plates, and sills occupy 21%; and the headers occupy 4%.

Solution: Obtain the R-values of the various building elements from Tables 1 and 4. Assume R = 1.25 per inch for the wood framing. Also,

Table 3 Thermal Resistances of Plane Air Spaces[a,b,c], ft²·°F·h/Btu

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d], °F	Air Space Temp. Diff.[d], °F	0.5-in. Air Space[c] Effective Emittance ε_{eff}[d,e] 0.03	0.05	0.2	0.5	0.82	0.75-in. Air Space[c] Effective Emittance ε_{eff}[d,e] 0.03	0.05	0.2	0.5	0.82
Horiz.	Up	90	10	2.13	2.03	1.51	0.99	0.73	2.34	2.22	1.61	1.04	0.75
		50	30	1.62	1.57	1.29	0.96	0.75	1.71	1.66	1.35	0.99	0.77
		50	10	2.13	2.05	1.60	1.11	0.84	2.30	2.21	1.70	1.16	0.87
		0	20	1.73	1.70	1.45	1.12	0.91	1.83	1.79	1.52	1.16	0.93
		0	10	2.10	2.04	1.70	1.27	1.00	2.23	2.16	1.78	1.31	1.02
		−50	20	1.69	1.66	1.49	1.23	1.04	1.77	1.74	1.55	1.27	1.07
		−50	10	2.04	2.00	1.75	1.40	1.16	2.16	2.11	1.84	1.46	1.20
45° Slope	Up	90	10	2.44	2.31	1.65	1.06	0.76	2.96	2.78	1.88	1.15	0.81
		50	30	2.06	1.98	1.56	1.10	0.83	1.99	1.92	1.52	1.08	0.82
		50	10	2.55	2.44	1.83	1.22	0.90	2.90	2.75	2.00	1.29	0.94
		0	20	2.20	2.14	1.76	1.30	1.02	2.13	2.07	1.72	1.28	1.00
		0	10	2.63	2.54	2.03	1.44	1.10	2.72	2.62	2.08	1.47	1.12
		−50	20	2.08	2.04	1.78	1.42	1.17	2.05	2.01	1.76	1.41	1.16
		−50	10	2.62	2.56	2.17	1.66	1.33	2.53	2.47	2.10	1.62	1.30
Vertical	Horiz.	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		−50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		−50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
45° Slope	Down	90	10	2.48	2.34	1.67	1.06	0.77	3.53	3.27	2.10	1.22	0.84
		50	30	2.64	2.52	1.87	1.24	0.91	3.43	3.23	2.24	1.39	0.99
		50	10	2.67	2.55	1.89	1.25	0.92	3.81	3.57	2.40	1.45	1.02
		0	20	2.91	2.80	2.19	1.52	1.15	3.75	3.57	2.63	1.72	1.26
		0	10	2.94	2.83	2.21	1.53	1.15	4.12	3.91	2.81	1.80	1.30
		−50	20	3.16	3.07	2.52	1.86	1.45	3.78	3.65	2.90	2.05	1.57
		−50	10	3.26	3.16	2.58	1.89	1.47	4.35	4.18	3.22	2.21	1.66
Horiz.	Down	90	10	2.48	2.34	1.67	1.06	0.77	3.55	3.29	2.10	1.22	0.85
		50	30	2.66	2.54	1.88	1.24	0.91	3.77	3.52	2.38	1.44	1.02
		50	10	2.67	2.55	1.89	1.25	0.92	3.84	3.59	2.41	1.45	1.02
		0	20	2.94	2.83	2.20	1.53	1.15	4.18	3.96	2.83	1.81	1.30
		0	10	2.96	2.85	2.22	1.53	1.16	4.25	4.02	2.87	1.82	1.31
		−50	20	3.25	3.15	2.58	1.89	1.47	4.60	4.41	3.36	2.28	1.69
		−50	10	3.28	3.18	2.60	1.90	1.47	4.71	4.51	3.42	2.30	1.71

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d], °F	Air Space Temp. Diff.[d], °F	1.5 in. Air Space[c] 0.03	0.05	0.2	0.5	0.82	3.5 in. Air Space[c] 0.03	0.05	0.2	0.5	0.82
Horiz.	Up	90	10	2.55	2.41	1.71	1.08	0.77	2.84	2.66	1.83	1.13	0.80
		50	30	1.87	1.81	1.45	1.04	0.80	2.09	2.01	1.58	1.10	0.84
		50	10	2.50	2.40	1.81	1.21	0.89	2.80	2.66	1.95	1.28	0.93
		0	20	2.01	1.95	1.63	1.23	0.97	2.25	2.18	1.79	1.32	1.03
		0	10	2.43	2.35	1.90	1.38	1.06	2.71	2.62	2.07	1.47	1.12
		−50	20	1.94	1.91	1.68	1.36	1.13	2.19	2.14	1.86	1.47	1.20
		−50	10	2.37	2.31	1.99	1.55	1.26	2.65	2.58	2.18	1.67	1.33
45° Slope	Up	90	10	2.92	2.73	1.86	1.14	0.80	3.18	2.96	1.97	1.18	0.82
		50	30	2.14	2.06	1.61	1.12	0.84	2.26	2.17	1.67	1.15	0.86
		50	10	2.88	2.74	1.99	1.29	0.94	3.12	2.95	2.10	1.34	0.96
		0	20	2.30	2.23	1.82	1.34	1.04	2.42	2.35	1.90	1.38	1.06
		0	10	2.79	2.69	2.12	1.49	1.13	2.98	2.87	2.23	1.54	1.16
		−50	20	2.22	2.17	1.88	1.49	1.21	2.34	2.29	1.97	1.54	1.25
		−50	10	2.71	2.64	2.23	1.69	1.35	2.87	2.79	2.33	1.75	1.39
Vertical	Horiz.	90	10	3.99	3.66	2.25	1.27	0.87	3.69	3.40	2.15	1.24	0.85
		50	30	2.58	2.46	1.84	1.23	0.90	2.67	2.55	1.89	1.25	0.91
		50	10	3.79	3.55	2.39	1.45	1.02	3.63	3.40	2.32	1.42	1.01
		0	20	2.76	2.66	2.10	1.48	1.12	2.88	2.78	2.17	1.51	1.14
		0	10	3.51	3.35	2.51	1.67	1.23	3.49	3.33	2.50	1.67	1.23
		−50	20	2.64	2.58	2.18	1.66	1.33	2.82	2.75	2.30	1.73	1.37
		−50	10	3.31	3.21	2.62	1.91	1.48	3.40	3.30	2.67	1.94	1.50
45° Slope	Down	90	10	5.07	4.55	2.56	1.36	0.91	4.81	4.33	2.49	1.34	0.90
		50	30	3.58	3.36	2.31	1.42	1.00	3.51	3.30	2.28	1.40	1.00
		50	10	5.10	4.66	2.85	1.60	1.09	4.74	4.36	2.73	1.57	1.08
		0	20	3.85	3.66	2.68	1.74	1.27	3.81	3.63	2.66	1.74	1.27
		0	10	4.92	4.62	3.16	1.94	1.37	4.59	4.32	3.02	1.88	1.34
		−50	20	3.62	3.50	2.80	2.01	1.54	3.77	3.64	2.90	2.05	1.57
		−50	10	4.67	4.47	3.40	2.29	1.70	4.50	4.32	3.31	2.25	1.68
Horiz.	Down	90	10	6.09	5.35	2.79	1.43	0.94	10.07	8.19	3.41	1.57	1.00
		50	30	6.27	5.63	3.18	1.70	1.14	9.60	8.17	3.86	1.88	1.22
		50	10	6.61	5.90	3.27	1.73	1.15	11.15	9.27	4.09	1.93	1.24
		0	20	7.03	6.43	3.91	2.19	1.49	10.90	9.52	4.87	2.47	1.62
		0	10	7.31	6.66	4.00	2.22	1.51	11.97	10.32	5.08	2.52	1.64
		−50	20	7.73	7.20	4.77	2.85	1.99	11.64	10.49	6.02	3.25	2.18
		−50	10	8.09	7.52	4.91	2.89	2.01	12.98	11.56	6.36	3.34	2.22

[a]See Chapter 23. Thermal resistance values were determined from the relation. $R = 1/C$, where $C = h_c + \varepsilon_{eff} h_r$, h_c is the conduction-convection coefficient, $\varepsilon_{eff} h_r$ is the radiation coefficient ≈ $0.0068\varepsilon_{eff}[(t_m + 460)/100]^3$, and t_m is the mean temperature of the air space. Values for h_c were determined from data developed by Robinson et al. (1954). Equations (5) through (7) in Yarbrough (1983) show the data in this table in analytic form. For extrapolation from this table to air spaces less than 0.5 in. (as in insulating window glass), assume $h_c = 0.159(1 + 0.0016\,t_m)/l$ where l is the air space thickness in inches, and h_c is heat transfer through the air space only.

[b]Values are based on data presented by Robinson et al. (1954). (Also see Chapter 3, Tables 5 and 6, and Chapter 39). Values apply for ideal conditions (i.e., air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no air leakage to or from the space). When accurate values are required, use overall U-factors determined through calibrated hot box (ASTM C976) or guarded hot box (ASTM C236) testing. Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space.

[c]A single resistance value cannot account for multiple air spaces; each air space requires a separate resistance calculation that applies only for the established boundary conditions. Resistances of horizontal spaces with heat flow downward are substantially independent of temperature difference.

[d]Interpolation is permissible for other values of mean temperature, temperature difference, and effective emittance ε_{eff}. Interpolation and moderate extrapolation for air spaces greater than 3.5 in. are also permissible.

[e]Effective emittance ε_{eff} of the air space is given by $1/\varepsilon_{eff} = 1/\varepsilon_1 + 1/\varepsilon_2 - 1$, where ε_1 and ε_2 are the emittances of the surfaces of the air space (see Table 2).

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

Description	Density, lb/ft³	Conductivity[b] (k), Btu·in / h·ft²·°F	Conductance (C), Btu / h·ft²·°F	Resistance[c] (R): Per Inch Thickness (1/k), ft²·°F·h / Btu·in	Resistance[c] (R): For Thickness Listed (1/C), ft²·°F·h / Btu	Specific Heat, Btu / lb·°F
BUILDING BOARD						
Asbestos-cement board	120	4.0	—	0.25	—	0.24
Asbestos-cement board 0.125 in.	120	—	33.00	—	0.03	
Asbestos-cement board 0.25 in.	120	—	16.50	—	0.06	
Gypsum or plaster board 0.375 in.	50	—	3.10	—	0.32	0.26
Gypsum or plaster board 0.5 in.	50	—	2.22	—	0.45	
Gypsum or plaster board 0.625 in.	50	—	1.78	—	0.56	
Plywood (Douglas fir)[d]	34	0.80	—	1.25	—	0.29
Plywood (Douglas fir) 0.25 in.	34	—	3.20	—	0.31	
Plywood (Douglas fir) 0.375 in.	34	—	2.13	—	0.47	
Plywood (Douglas fir) 0.5 in.	34	—	1.60	—	0.62	
Plywood (Douglas fir) 0.625 in.	34	—	1.29	—	0.77	
Plywood or wood panels 0.75 in.	34	—	1.07	—	0.93	0.29
Vegetable fiber board						
Sheathing, regular density[e] 0.5 in.	18	—	0.76	—	1.32	0.31
0.78125 in.	18	—	0.49	—	2.06	
Sheathing intermediate density[e] 0.5 in.	22	—	0.92	—	1.09	0.31
Nail-base sheathing[e] 0.5 in.	25	—	0.94	—	1.06	0.31
Shingle backer 0.375 in.	18	—	1.06	—	0.94	0.31
Shingle backer 0.3125 in.	18	—	1.28	—	0.78	
Sound deadening board 0.5 in.	15	—	0.74	—	1.35	0.30
Tile and lay-in panels, plain or acoustic	18	0.40	—	2.50	—	0.14
0.5 in.	18	—	0.80	—	1.25	
0.75 in.	18	—	0.53	—	1.89	
Laminated paperboard	30	0.50	—	2.00	—	0.33
Homogeneous board from repulped paper	30	0.50	—	2.00	—	0.28
Hardboard[e]						
Medium density	50	0.73	—	1.37	—	0.31
High density, service-tempered grade and service grade	55	0.82	—	1.22	—	0.32
High density, standard-tempered grade	63	1.00	—	1.00	—	0.32
Particleboard[e]						
Low density	37	0.71	—	1.41	—	0.31
Medium density	50	0.94	—	1.06	—	0.31
High density	62	.5	1.18	—	0.85	—
Underlayment 0.625 in.	40	—	1.22	—	0.82	0.29
Waferboard	37	0.63	—	1.59	—	—
Wood subfloor 0.75 in.	—	—	1.06	—	0.94	0.33
BUILDING MEMBRANE						
Vapor—permeable felt	—	—	16.70	—	0.06	
Vapor—seal, 2 layers of mopped 15 lb felt	—	—	8.35	—	0.12	
Vapor—seal, plastic film	—	—	—	—	Negl.	
FINISH FLOORING MATERIALS						
Carpet and fibrous pad	—	—	0.48	—	2.08	0.34
Carpet and rubber pad	—	—	0.81	—	1.23	0.33
Cork tile 0.125 in.	—	—	3.60	—	0.28	0.48
Terrazzo 1 in.	—	—	12.50	—	0.08	0.19
Tile—asphalt, linoleum, vinyl, rubber	—	—	20.00	—	0.05	0.30
vinyl asbestos						0.24
ceramic						0.19
Wood, hardwood finish 0.75 in.	—	—	1.47	—	0.68	
INSULATING MATERIALS						
Blanket and Batt[f,g]						
Mineral fiber, fibrous form processed from rock, slag, or glass						
approx. 3-4 in.	0.4-2.0	—	0.091	—	11	
approx. 3.5 in.	0.4-2.0	—	0.077	—	13	
approx. 3.5 in.	1.2-1.6	—	0.067	—	15	
approx. 5.5-6.5 in.	0.4-2.0	—	0.053	—	19	
approx. 5.5 in.	0.6-1.0	—	0.048	—	21	
approx. 6-7.5 in.	0.4-2.0	—	0.045	—	22	
approx. 8.25-10 in.	0.4-2.0	—	0.033	—	30	
approx. 10-13 in.	0.4-2.0	—	0.026	—	38	
Board and Slabs						
Cellular glass	8.0	0.33	—	3.03	—	0.18
Glass fiber, organic bonded	4.0-9.0	0.25	—	4.00	—	0.23
Expanded perlite, organic bonded	1.0	0.36	—	2.78	—	0.30
Expanded rubber (rigid)	4.5	0.22	—	4.55	—	0.40
Expanded polystyrene, extruded (smooth skin surface) (CFC-12 exp.)	1.8-3.5	0.20	—	5.00	—	0.29

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

				Resistance[c] (*R*)		
Description	Density, lb/ft³	Conductivity[b] (*k*), Btu·in / h·ft²·°F	Conductance (*C*), Btu / h·ft²·°F	Per Inch Thickness (1/*k*), ft²·°F·h / Btu·in	For Thickness Listed (1/*C*), ft²·°F·h / Btu	Specific Heat, Btu / lb·°F
Expanded polystyrene, extruded (smooth skin surface) (HCFC-142b exp.)[h]	1.8-3.5	0.20	—	5.00	—	0.29
Expanded polystyrene, molded beads	1.0	0.26	—	3.85	—	—
	1.25	0.25	—	4.00	—	—
	1.5	0.24	—	4.17	—	—
	1.75	0.24	—	4.17	—	—
	2.0	0.23	—	4.35	—	—
Cellular polyurethane/polyisocyanurate[i] (CFC-11 exp.) (unfaced)	1.5	0.16-0.18	—	6.25-5.56	—	0.38
Cellular polyisocyanurate[i] (CFC-11 exp.) (gas-permeable facers)	1.5-2.5	0.16-0.18	—	6.25-5.56	—	0.22
Cellular polyisocyanurate[j] (CFC-11 exp.) (gas-impermeable facers)	2.0	0.14	—	7.04	—	0.22
Cellular phenolic (closed cell) (CFC-11, CFC-113 exp.)[k]	3.0	0.12	—	8.20	—	—
Cellular phenolic (open cell)	1.8-2.2	0.23	—	4.40	—	—
Mineral fiber with resin binder	15.0	0.29	—	3.45	—	0.17
Mineral fiberboard, wet felted						
Core or roof insulation	16-17	0.34	—	2.94	—	—
Acoustical tile	18.0	0.35	—	2.86	—	0.19
Acoustical tile	21.0	0.37	—	2.70	—	—
Mineral fiberboard, wet molded						
Acoustical tile[l]	23.0	0.42	—	2.38	—	0.14
Wood or cane fiberboard						
Acoustical tile[l] ... 0.5 in.	—	—	0.80	—	1.25	0.31
Acoustical tile[l] ... 0.75 in.	—	—	0.53	—	1.89	—
Interior finish (plank, tile)	15.0	0.35	—	2.86	—	0.32
Cement fiber slabs (shredded wood with Portland cement binder)	25-27.0	0.50-0.53		2.0-1.89	—	
Cement fiber slabs (shredded wood with magnesia oxysulfide binder)	22.0	0.57	—	1.75	—	0.31
Loose Fill						
Cellulosic insulation (milled paper or wood pulp)	2.3-3.2	0.27-0.32	—	3.70-3.13	—	0.33
Perlite, expanded	2.0-4.1	0.27-0.31	—	3.7-3.3	—	0.26
	4.1-7.4	0.31-0.36	—	3.3-2.8	—	—
	7.4-11.0	0.36-0.42	—	2.8-2.4	—	—
Mineral fiber (rock, slag, or glass)[g]						
approx. 3.75-5 in.	0.6-2.0	—	—	—	11.0	0.17
approx. 6.5-8.75 in.	0.6-2.0	—	—	—	19.0	—
approx. 7.5-10 in.	0.6-2.0	—	—	—	22.0	—
approx. 10.25-13.75 in.	0.6-2.0	—	—	—	30.0	—
Mineral fiber (rock, slag, or glass)[g]						
approx. 3.5 in. (closed sidewall application)	2.0-3.5	—	—	—	12.0-14.0	—
Vermiculite, exfoliated	7.0-8.2	0.47	—	2.13	—	0.32
	4.0-6.0	0.44	—	2.27	—	—
Spray Applied						
Polyurethane foam	1.5-2.5	0.16-0.18	—	6.25-5.56	—	—
Ureaformaldehyde foam	0.7-1.6	0.22-0.28	—	4.55-3.57	—	—
Cellulosic fiber	3.5-6.0	0.29-0.34	—	3.45-2.94	—	—
Glass fiber	3.5-4.5	0.26-0.27	—	3.85-3.70	—	—
Reflective Insulation						
Reflective material ($\varepsilon < 0.5$) in center of 3/4 in. cavity forms two 3/8 in. vertical air spaces[m]	—	—	0.31	—	3.2	—
METALS						
(See Chapter 39, Table 3)						
ROOFING						
Asbestos-cement shingles	120	—	4.76	—	0.21	0.24
Asphalt roll roofing	70	—	6.50	—	0.15	0.36
Asphalt shingles	70	—	2.27	—	0.44	0.30
Built-up roofing ... 0.375 in.	70	—	3.00	—	0.33	0.35
Slate ... 0.5 in.	—	—	20.00	—	0.05	0.30
Wood shingles, plain and plastic film faced	—	—	1.06	—	0.94	0.31
PLASTERING MATERIALS						
Cement plaster, sand aggregate	116	5.0	—	0.20	—	0.20
Sand aggregate ... 0.375 in.	—	—	13.3	—	0.08	0.20
Sand aggregate ... 0.75 in.	—	—	6.66	—	0.15	0.20

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

Description	Density, lb/ft³	Conductivity[b] (k), Btu·in / h·ft²·°F	Conductance (C), Btu / h·ft²·°F	Resistance[c] (R): Per Inch Thickness (1/k), ft²·°F·h / Btu·in	Resistance[c] (R): For Thickness Listed (1/C), ft²·°F·h / Btu	Specific Heat, Btu / lb·°F
Gypsum plaster:						
Lightweight aggregate....0.5 in.	45	—	3.12	—	0.32	—
Lightweight aggregate....0.625 in.	45	—	2.67	—	0.39	—
Lightweight aggregate on metal lath....0.75 in.	—	—	2.13	—	0.47	—
Perlite aggregate....	45	1.5	—	0.67	—	0.32
Sand aggregate....	105	5.6	—	0.18	—	0.20
Sand aggregate....0.5 in.	105	—	11.10	—	0.09	—
Sand aggregate....0.625 in.	105	—	9.10	—	0.11	—
Sand aggregate on metal lath....0.75 in.	—	—	7.70	—	0.13	—
Vermiculite aggregate....	45	1.7	—	0.59	—	—
MASONRY MATERIALS						
Masonry Units						
Brick, fired clay....	150	8.4-10.2	—	0.12-0.10	—	—
	140	7.4-9.0	—	0.14-0.11	—	—
	130	6.4-7.8	—	0.16-0.12	—	—
	120	5.6-6.8	—	0.18-0.15	—	0.19
	110	4.9-5.9	—	0.20-0.17	—	—
	100	4.2-5.1	—	0.24-0.20	—	—
	90	3.6-4.3	—	0.28-0.24	—	—
	80	3.0-3.7	—	0.33-0.27	—	—
	70	2.5-3.1	—	0.40-0.33	—	—
Clay tile, hollow						
1 cell deep....3 in.	—	—	1.25	—	0.80	0.21
1 cell deep....4 in.	—	—	0.90	—	1.11	—
2 cells deep....6 in.	—	—	0.66	—	1.52	—
2 cells deep....8 in.	—	—	0.54	—	1.85	—
2 cells deep....10 in.	—	—	0.45	—	2.22	—
3 cells deep....12 in.	—	—	0.40	—	2.50	—
Concrete blocks[n, o]						
Limestone aggregate						
8 in., 36 lb, 138 lb/ft³ concrete, 2 cores....	—	—	—	—	—	—
Same with perlite filled cores....	—	—	0.48	—	2.1	—
12 in., 55 lb, 138 lb/ft³ concrete, 2 cores....	—	—	—	—	—	—
Same with perlite filled cores....	—	—	0.27	—	3.7	—
Normal weight aggregate (sand and gravel)						
8 in., 33-36 lb, 126-136 lb/ft³ concrete, 2 or 3 cores	—	—	0.90-1.03	—	1.11-0.97	0.22
Same with perlite filled cores....	—	—	0.50	—	2.0	—
Same with vermiculite filled cores....	—	—	0.52-0.73	—	1.92-1.37	—
12 in., 50 lb, 125 lb/ft³ concrete, 2 cores....	—	—	0.81	—	1.23	0.22
Medium weight aggregate (combinations of normal weight and lightweight aggregate)						
8 in., 26-29 lb, 97-112 lb/ft³ concrete, 2 or 3 cores..	—	—	0.58-0.78	—	1.71-1.28	—
Same with perlite filled cores....	—	—	0.27-0.44	—	3.7-2.3	—
Same with vermiculite filled cores....	—	—	0.30	—	3.3	—
Same with molded EPS (beads) filled cores....	—	—	0.32	—	3.2	—
Same with molded EPS inserts in cores....	—	—	0.37	—	2.7	—
Lightweight aggregate (expanded shale, clay, slate or slag, pumice)						
6 in., 16-17 lb 85-87 lb/ft³ concrete, 2 or 3 cores....	—	—	0.52-0.61	—	1.93-1.65	—
Same with perlite filled cores....	—	—	0.24	—	4.2	—
Same with vermiculite filled cores....	—	—	0.33	—	3.0	—
8 in., 19-22 lb, 72-86 lb/ft³ concrete....	—	—	0.32-0.54	—	3.2-1.90	0.21
Same with perlite filled cores....	—	—	0.15-0.23	—	6.8-4.4	—
Same with vermiculite filled cores....	—	—	0.19-0.26	—	5.3-3.9	—
Same with molded EPS (beads) filled cores....	—	—	0.21	—	4.8	—
Same with UF foam filled cores....	—	—	0.22	—	4.5	—
Same with molded EPS inserts in cores....	—	—	0.29	—	3.5	—
12 in., 32-36 lb, 80-90 lb/ft³ concrete, 2 or 3 cores...	—	—	0.38-0.44	—	2.6-2.3	—
Same with perlite filled cores....	—	—	0.11-0.16	—	9.2-6.3	—
Same with vermiculite filled cores....	—	—	0.17	—	5.8	—
Stone, lime, or sand....	180	72	—	0.01	—	—
Quartzitic and sandstone	160	43	—	0.02	—	—
	140	24	—	0.04	—	—
	120	13	—	0.08	—	0.19
Calcitic, dolomitic, limestone, marble, and granite....	180	30	—	0.03	—	—
	160	22	—	0.05	—	—
	140	16	—	0.06	—	—
	120	11	—	0.09	—	0.19
	100	8	—	0.13	—	—

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

Description	Density, lb/ft³	Conductivity[b] (k), Btu·in/h·ft²·°F	Conductance (C), Btu/h·ft²·°F	Resistance[c] (R) Per Inch Thickness (1/k), ft²·°F·h/Btu·in	For Thickness Listed (1/C), ft²·°F·h/Btu	Specific Heat, Btu/lb·°F
Gypsum partition tile						
3 by 12 by 30 in., solid	—	—	0.79	—	1.26	0.19
3 by 12 by 30 in., 4 cells	—	—	0.74	—	1.35	—
4 by 12 by 30 in., 3 cells	—	—	0.60	—	1.67	—
Concretes[o]						
Sand and gravel or stone aggregate concretes (concretes with more than 50% quartz or quartzite sand have conductivities in the higher end of the range)	150	10.0-20.0	—	0.10-0.05	—	—
	140	9.0-18.0	—	0.11-0.06	—	0.19-0.24
	130	7.0-13.0	—	0.14-0.08	—	—
Limestone concretes	140	11.1	—	0.09	—	—
	120	7.9	—	0.13	—	—
	100	5.5	—	0.18	—	—
Gypsum-fiber concrete (87.5% gypsum, 12.5% wood chips)	51	1.66	—	0.60	—	0.21
Cement/lime, mortar, and stucco	120	9.7	—	0.10	—	—
	100	6.7	—	0.15	—	—
	80	4.5	—	0.22	—	—
Lightweight aggregate concretes						
Expanded shale, clay, or slate; expanded slags; cinders; pumice (with density up to 100 lb/ft³); and scoria (sanded concretes have conductivities in the higher end of the range)	120	6.4-9.1	—	0.16-0.11	—	—
	100	4.7-6.2	—	0.21-0.16	—	0.20
	80	3.3-4.1	—	0.30-0.24	—	0.20
	60	2.1-2.5	—	0.48-0.40	—	—
	40	1.3	—	0.78	—	—
Perlite, vermiculite, and polystyrene beads	50	1.8-1.9	—	0.55-0.53	—	—
	40	1.4-1.5	—	0.71-0.67	—	0.15-0.23
	30	1.1	—	0.91	—	—
	20	0.8	—	1.25	—	—
Foam concretes	120	5.4	—	0.19	—	—
	100	4.1	—	0.24	—	—
	80	3.0	—	0.33	—	—
	70	2.5	—	0.40	—	—
Foam concretes and cellular concretes	60	2.1	—	0.48	—	—
	40	1.4	—	0.71	—	—
	20	0.8	—	1.25	—	—
SIDING MATERIALS (on flat surface)						
Shingles						
Asbestos-cement	120	—	4.75	—	0.21	—
Wood, 16 in., 7.5 exposure	—	—	1.15	—	0.87	0.31
Wood, double, 16 in., 12 in. exposure	—	—	0.84	—	1.19	0.28
Wood, plus ins. backer board, 0.312 in.	—	—	0.71	—	1.40	0.31
Siding						
Asbestos-cement, 0.25 in., lapped	—	—	4.76	—	0.21	0.24
Asphalt roll siding	—	—	6.50	—	0.15	0.35
Asphalt insulating siding (0.5 in. bed.)	—	—	0.69	—	1.46	0.35
Hardboard siding, 0.4375 in.	—	—	1.49	—	0.67	0.28
Wood, drop, 1 by 8 in.	—	—	1.27	—	0.79	0.28
Wood, bevel, 0.5 by 8 in., lapped	—	—	1.23	—	0.81	0.28
Wood, bevel, 0.75 by 10 in., lapped	—	—	0.95	—	1.05	0.28
Wood, plywood, 0.375 in., lapped	—	—	1.69	—	0.59	0.29
Aluminum, steel, or vinyl[p, q], over sheathing						
Hollow-backed	—	—	1.64	—	0.61	0.29[q]
Insulating-board backed nominal 0.375 in.	—	—	0.55	—	1.82	0.32
Insulating-board backed nominal 0.375 in., foil backed	—	—	0.34	—	2.96	—
Architectural (soda-lime float) glass	158	6.9	—	—	—	0.21
WOODS (12% moisture content)[e,r]						
Hardwoods						0.39[s]
Oak	41.2-46.8	1.12-1.25	—	0.89-0.80	—	
Birch	42.6-45.4	1.16-1.22	—	0.87-0.82	—	
Maple	39.8-44.0	1.09-1.19	—	0.92-0.84	—	
Ash	38.4-41.9	1.06-1.14	—	0.94-0.88	—	
Softwoods						0.39[s]
Southern pine	35.6-41.2	1.00-1.12	—	1.00-0.89	—	
Douglas fir-Larch	33.5-36.3	0.95-1.01	—	1.06-0.99	—	
Southern cypress	31.4-32.1	0.90-0.92	—	1.11-1.09	—	
Hem-Fir, Spruce-Pine-Fir	24.5-31.4	0.74-0.90	—	1.35-1.11	—	
West coast woods, Cedars	21.7-31.4	0.68-0.90	—	1.48-1.11	—	
California redwood	24.5-28.0	0.74-0.82	—	1.35-1.22	—	

glazing is added on site. These products are typically installed in high-rise residential and larger commercial/institutional/industrial buildings. Curtain walls are typically made up of vision (transparent) and spandrel (opaque) panels. Table 4 contains representative U-factors for the vision panel (including mullions) for these assemblies. The spandrel portion of curtain walls usually consists of a metal pan filled with insulation and covered with a sheet of glass or other weatherproof covering. Although the U-factor in the center of the spandrel panel can be quite low, the metal pan is a thermal bridge, significantly increasing the U-factor of the assembly. Two-dimensional simulation, validated by testing of a curtain wall having an aluminum frame with a thermal break, found that the U-factor for the edge of the spandrel panel (the 2-1/2 in. band around the perimeter adjacent to the frame) was 40% of the way toward the U-factor of the frame. The U-factor was 0.34 for the center of the spandrel, 2.56 for the edge of the spandrel, and 6.02 for the frame (Carpenter and Elmahdy 1994). Two-dimensional heat transfer analysis or physical testing is recommended to determine the U-factor of spandrel panels. Use the sloped/overhead glazing category for sloped glazing panels comparable to curtain walls.

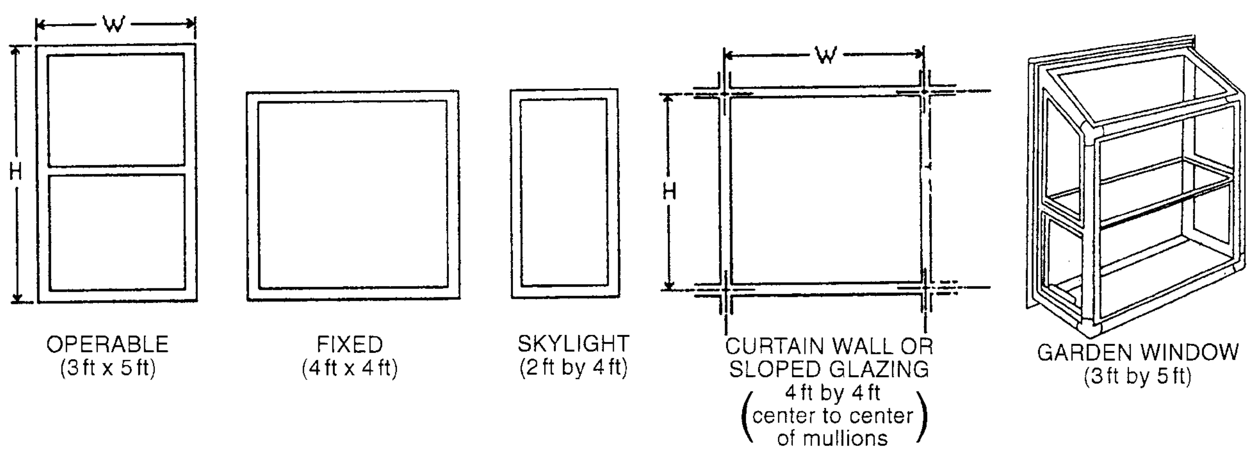
Physical testing of double-glazed units showed U-factors of 1.0 Btu/(h·ft^2·°F for a thermally broken aluminum pyramidal skylight and 1.3 Btu/(h·ft^2·°F) for an aluminum-frame half-round barrel vault (both normalized to a rough opening of 8 by 8 ft). Until more conclusive results are available, U-factors for these systems can be estimated by multiplying the "site-assembled sloped/overhead glazing" values in Table 4 by the ratio of total product surface area (including curbs) to rough opening area. These ratios range from 1.2 to 2.0 for low-slope skylights, 1.4 to 2.1 for pyramid assemblies sloped at 45°, and 1.7 to 2.9 for semicircular barrel vault assemblies. An example calculation is provided in Example 4.

U-factors in Table 4 are based on the definitions of the six product types, frame sizes, and proportion of frame to glass area shown in Figure 4. Four of the products are manufactured type. The operable glazing units are 15 ft^2 in area, and the overall size corresponds to a 3 by 5 ft fenestration product. The fixed (nonoperable) category is about 16 ft^2 in area, and the overall size corresponds to a 4 by 4 ft window. The garden window category is 15 ft^2 in projected area (35 ft^2 in surface area) and 5 ft (wide) by 3 ft (high) by 15 in. (deep). The manufactured skylight category is a nominal 8 ft^2 in area, corresponding to a 2 by 4 ft skylight. The nominal dimensions of a roof-mounted skylight correspond to centerline spacing of roof framing members; consequently, the rough opening dimensions are 22.5 by 46.5 in. The curtain wall and sloped/overhead glazing categories are a nominal 16 ft^2 in area, representing repeating 4 by 4 ft panels. The nominal dimensions correspond to centerline spacing of the head and sill and vertical mullions.

Six frame types are listed (although not all for any one category) in order of improving thermal performance. The most conservative assumption is to use the frame category of aluminum frame without a thermal break (although there are products on the market that have higher U-factors). The aluminum frame with a thermal break is for frames having at least a 3/8 in. thermal break between the inside and outside for all members, including both the frame and the operable

Table 5 Glazing U-Factors for Various Wind Speeds

Wind Speed, mph		
15	7.5	0
U-Factor, Btu/h·ft^2·°F		
0.10	0.10	0.10
0.20	0.20	0.19
0.30	0.29	0.28
0.40	0.38	0.37
0.50	0.47	0.45
0.60	0.56	0.53
0.70	0.65	0.61
0.80	0.74	0.69
0.90	0.83	0.78
1.00	0.92	0.86
1.10	1.01	0.94
1.20	1.10	1.02
1.30	1.19	1.10



Frame Material	Frame Width, inches					
	Operable	Fixed	Garden Window	Skylight	Curtainwall	Sloped/Overhead Glazing
Aluminum without thermal break	1.5	1.3	1.75	0.7	2.25	2.25
Aluminum with thermal break	2.1	1.3	n/a	0.7	2.25	2.25
Aluminum-clad wood/reinforcing vinyl	2.8	1.6	n/a	0.9	n/a	n/a
Wood/vinyl	2.8	1.6	1.75	0.9	n/a	n/a
Insulated fiberglass/vinyl	3.1	1.8	n/a	n/a	n/a	n/a
Structural glazing	n/a	n/a	n/a	n/a	2.25	2.5

Fig. 4 Standard Fenestration Units

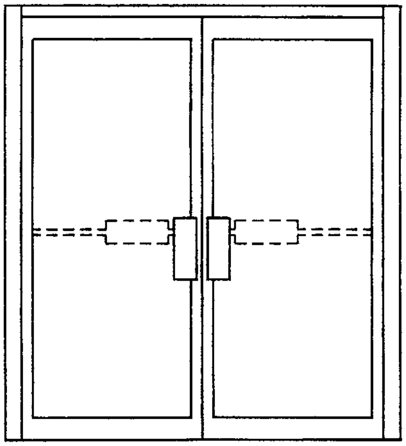


Fig. 5 Details of Stile-and-Rail Door

sash, if applicable. (Products are available with significantly wider thermal breaks, which achieve considerable improvement.) The reinforced vinyl/aluminum clad wood category represents vinyl-frame products, such as sliding glass doors or large windows that have extensive metal reinforcing within the frame and wood products with extensive metal, usually on the exterior surface of the frame. Both of these factors provide short circuits, which degrade the thermal performance of the frame material. The wood/vinyl frame is meant to represent the improved thermal performance that is possible if the thermal short circuits from the previous frame category do not exist. Insulated fiberglass/vinyl represents fiberglass or vinyl frames that do not have metal reinforcing and whose frame cavities are filled with insulation. For several site-assembled product types, there is a structural glazing frame category that is intended to represent products where sheets of glass are butt-glazed to each other using a sealant only, and none of the framing members is exposed to the exterior. For glazing with a steel frame, use aluminum frame values. For aluminum window with wood trim or vinyl cladding, use the values for aluminum. Frame type refers to the primary unit. Thus, when storm sash is added over another fenestration product, use the values given for the nonstorm product.

To estimate the overall U-factor of a fenestration product that differs significantly from the assumptions given in Table 4 and/or Figure 4, first determine the area that is frame/sash, center-of-glass, and edge-of-glass (based on a 2-1/2 in. band around the perimeter of each glazing unit). Next, determine the appropriate component U-factors. These can be taken either from the standard values listed in italics in Table 4 for glass, from the values in Table 1 for frames, or from some other source such as test data or computed factors. Finally, multiply the area and the component U-factors, sum these products, and then divide by the rough opening in the building envelope where this product will fit to obtain the overall U-factor U_o.

Table 5 provides approximate data to convert the overall U-factor at one wind condition to a U-factor at another.

REPRESENTATIVE U-FACTORS FOR DOORS

Doors are often an overlooked component in the thermal integrity of the building envelope. Although swinging and revolving doors represent a small portion of the shell in residential, commercial, and institutional buildings, their U-factor is usually many times higher than that of the walls or ceilings. In some storage and industrial buildings, loading bay doors (overhead doors) represent a significant area of high heat loss. Table 6 contains representative U-factors for swinging, overhead, and revolving doors determined

Table 6 U-Factors of Doors in Btu/h·ft²·°F

Door Type	No Glazing	Single Glazing	Double Glazing with 1/2 in. Air Space	Double Glazing with $e = 0.10$, 1/2 in. Argon
SWINGING DOORS (Rough Opening, 38 × 82 in.)				
Slab Doors				
Wood slab in wood frame[a]	0.46			
6% glazing (22 in. × 8 in. lite)	—	0.48	0.46	0.44
25% glazing (22 in. × 36 in. lite)	—	0.58	0.46	0.42
45% glazing (22 in. × 64 in. lite)	—	0.69	0.46	0.39
More than 50% glazing		Use Table 4 (operable)		
Insulated steel slab with wood edge in wood frame[a]	0.16			
6% glazing (22 in. × 8 in. lite)	—	0.21	0.19	0.18
25% glazing (22 in. × 36 in. lite)	—	0.39	0.26	0.23
45% glazing (22 in. × 64 in. lite)	—	0.58	0.35	0.26
More than 50% glazing		Use Table 4 (operable)		
Foam insulated steel slab with metal edge in steel frame[b]	0.37			
6% glazing (22 in. × 8 in. lite)	—	0.44	0.41	0.39
25% glazing (22 in. × 36 in. lite)	—	0.55	0.48	0.44
45% glazing (22 in. × 64 in. lite)	—	0.71	0.56	0.48
More than 50% glazing		Use Table 4 (operable)		
Cardboard honeycomb slab with metal edge in steel frame	0.61			
Stile- and -Rail Doors				
Sliding glass doors/ French doors		Use Table 4 (operable)		
Site-Assembled Stile- and -Rail Doors				
Aluminum in aluminum frame	—	1.32	0.93	0.79
Aluminum in aluminum frame with thermal break	—	1.13	0.74	0.63
REVOLVING DOORS (Rough Opening, 82 × 84 in.)				
Aluminum in aluminum frame				
Open	—	1.32	—	—
Closed	—	0.65	—	—
SECTIONAL OVERHEAD DOORS (Nominal, 10 × 10 ft)				
Annunciated steel (nominal U = 1.15)[c]	1.15	—	—	—
Insulated steel (nominal U = 0.11)[c]	0.24	—	—	—
Insulated steel with thermal break (nominal U = 0.08)[c]	0.13	—	—	—

[a] Thermally broken sill (add 0.03 Btu/h·ft²·°F for non-thermally broken sill)
[b] Non-thermally broken sill
[c] Nominal U-factors are through the center of the insulated panel before consideration of thermal bridges around the edges of the door sections and due to the frame.

through computer simulation (Carpenter and Hogan 1996). These are generic values, and product-specific values determined in accordance with standards should be used whenever available. NFRC *Technical Document* 100 and CSA *Standard* A453 give procedures for evaluating performance of swinging doors. Overhead doors are often evaluated in accordance with National Association of Garage Door Manufacturers (NAGDM) *Standard* 105. Where these standards are cited in codes, they must be used for compliance.

Swinging doors can be divided into two categories: slab and stile-and-rail. A stile-and-rail door is a swinging door with a full-glass insert supported by horizontal rails and vertical stiles. The stiles and rails are typically either solid wood or extruded aluminum or vinyl, as shown in Figure 5. Most residential doors are slab type with either solid wood, steel, or fiberglass skin over foam insulation in a wood frame with aluminum sill. The edges of the steel skin door are normally wood to provide a thermal break. In commercial construction, doors are either steel skin over foam insulation in a steel

Table 4 U-Factors for Various Fenestration Products in Btu/h·ft^2·°F

Product Type		Glass Only		Vertical Installation									
				Operable (including sliding and swinging glass doors)					Fixed				
Frame Type		Center of Glass	Edge of Glass	Aluminum Without Thermal Break	Aluminum with Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl	Aluminum Without Thermal Break	Aluminum with Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Insulated Fiberglass/ Vinyl
ID	**Glazing Type**												
	Single Glazing												
1	1/8 in. glass	*1.04*	*1.04*	1.27	1.08	0.90	0.89	0.81	1.13	1.07	0.98	0.98	0.94
2	1/4 in. acrylic/polycarbonate	*0.88*	*0.88*	1.14	0.96	0.79	0.78	0.71	0.99	0.92	0.84	0.84	0.81
3	1/8 in. acrylic/polycarbonate	*0.96*	*0.96*	1.21	1.02	0.85	0.83	0.76	1.06	1.00	0.91	0.91	0.87
	Double Glazing												
4	1/4 in. air space	*0.55*	*0.64*	0.87	0.65	0.57	0.55	0.49	0.69	0.63	0.56	0.56	0.53
5	1/2 in. air space	*0.48*	*0.59*	0.81	0.60	0.53	0.51	0.44	0.64	0.57	0.50	0.50	0.48
6	1/4 in. argon space	*0.51*	*0.61*	0.84	0.62	0.55	0.53	0.46	0.66	0.59	0.53	0.52	0.50
7	1/2 in. argon space	*0.45*	*0.57*	0.79	0.58	0.51	0.49	0.43	0.61	0.54	0.48	0.48	0.45
	Double Glazing, e = 0.60 on surface 2 or 3												
8	1/4 in. air space	*0.52*	*0.62*	0.84	0.63	0.55	0.53	0.47	0.67	0.60	0.54	0.53	0.51
9	1/2 in. air space	*0.44*	*0.56*	0.78	0.57	0.50	0.48	0.42	0.60	0.53	0.47	0.47	0.45
10	1/4 in. argon space	*0.47*	*0.58*	0.81	0.59	0.52	0.50	0.44	0.63	0.56	0.50	0.49	0.47
11	1/2 in. argon space	*0.41*	*0.54*	0.76	0.55	0.48	0.46	0.40	0.58	0.51	0.45	0.44	0.42
	Double Glazing, e = 0.40 on surface 2 or 3												
12	1/4 in. air space	*0.49*	*0.60*	0.82	0.61	0.53	0.51	0.45	0.64	0.58	0.51	0.51	0.49
13	1/2 in. air space	*0.40*	*0.54*	0.75	0.54	0.48	0.45	0.40	0.57	0.50	0.44	0.44	0.41
14	1/4 in. argon space	*0.43*	*0.56*	0.78	0.57	0.50	0.47	0.41	0.59	0.53	0.46	0.46	0.44
15	1/2 in. argon space	*0.36*	*0.51*	0.72	0.52	0.45	0.43	0.37	0.53	0.47	0.41	0.40	0.38
	Double Glazing, e = 0.20 on surface 2 or 3												
16	1/4 in. air space	*0.45*	*0.57*	0.79	0.58	0.51	0.49	0.43	0.61	0.54	0.48	0.48	0.45
17	1/2 in. air space	*0.35*	*0.50*	0.71	0.51	0.44	0.42	0.36	0.53	0.46	0.40	0.39	0.37
18	1/4 in. argon space	*0.38*	*0.52*	0.74	0.53	0.46	0.44	0.38	0.55	0.48	0.42	0.42	0.40
19	1/2 in. argon space	*0.30*	*0.46*	0.67	0.47	0.41	0.39	0.33	0.48	0.41	0.36	0.35	0.33
	Double Glazing, e = 0.10 on surface 2 or 3												
20	1/4 in. air space	*0.42*	*0.55*	0.77	0.56	0.49	0.47	0.41	0.59	0.52	0.46	0.45	0.43
21	1/2 in. air space	*0.32*	*0.48*	0.69	0.49	0.42	0.40	0.35	0.50	0.43	0.37	0.37	0.35
22	1/4 in. argon space	*0.35*	*0.50*	0.71	0.51	0.44	0.42	0.36	0.53	0.46	0.40	0.39	0.37
23	1/2 in. argon space	*0.27*	*0.44*	0.65	0.45	0.39	0.37	0.31	0.46	0.39	0.33	0.33	0.31
	Double Glazing, e = 0.05 on surface 2 or 3												
24	1/4 in. air space	*0.41*	*0.54*	0.76	0.55	0.48	0.46	0.40	0.58	0.51	0.45	0.44	0.42
25	1/2 in. air space	*0.30*	*0.46*	0.67	0.47	0.41	0.39	0.33	0.48	0.41	0.36	0.35	0.33
26	1/4 in. argon space	*0.33*	*0.48*	0.70	0.49	0.43	0.41	0.35	0.51	0.44	0.38	0.38	0.36
27	1/2 in. argon space	*0.25*	*0.42*	0.63	0.44	0.38	0.36	0.30	0.44	0.37	0.32	0.31	0.29
	Triple Glazing												
28	1/4 in. air spaces	*0.38*	*0.52*	0.72	0.51	0.44	0.43	0.38	0.55	0.48	0.42	0.41	0.40
29	1/2 in. air spaces	*0.31*	*0.47*	0.67	0.46	0.40	0.39	0.34	0.49	0.42	0.36	0.35	0.34
30	1/4 in. argon spaces	*0.34*	*0.49*	0.69	0.48	0.42	0.41	0.35	0.51	0.45	0.39	0.38	0.36
31	1/2 in. argon spaces	*0.29*	*0.45*	0.65	0.44	0.38	0.37	0.32	0.47	0.40	0.34	0.34	0.32
	Triple Glazing, e = 0.20 on surface 2, 3, 4, or 5												
32	1/4 in. air spaces	*0.33*	*0.48*	0.69	0.47	0.41	0.40	0.35	0.50	0.44	0.38	0.37	0.36
33	1/2 in. air spaces	*0.25*	*0.42*	0.62	0.41	0.36	0.35	0.30	0.43	0.37	0.31	0.30	0.29
34	1/4 in. argon spaces	*0.28*	*0.45*	0.65	0.44	0.38	0.37	0.32	0.46	0.40	0.34	0.33	0.32
35	1/2 in. argon spaces	*0.22*	*0.40*	0.60	0.39	0.34	0.33	0.28	0.41	0.34	0.29	0.28	0.27
	Triple Glazing, e = 0.20 on surfaces 2 or 3 and 4 or 5												
36	1/4 in. air spaces	*0.29*	*0.45*	0.65	0.44	0.38	0.37	0.32	0.47	0.40	0.34	0.34	0.32
37	1/2 in. air spaces	*0.20*	*0.39*	0.58	0.38	0.32	0.31	0.27	0.39	0.33	0.27	0.26	0.25
38	1/4 in. argon spaces	*0.23*	*0.41*	0.61	0.40	0.34	0.33	0.29	0.42	0.35	0.30	0.29	0.28
39	1/2 in. argon spaces	*0.17*	*0.36*	0.56	0.36	0.30	0.29	0.25	0.37	0.30	0.25	0.24	0.23
	Triple Glazing, e = 0.10 on surfaces 2 or 3 and 4 or 5												
40	1/4 in. air spaces	*0.27*	*0.44*	0.64	0.43	0.37	0.36	0.31	0.45	0.39	0.33	0.32	0.31
41	1/2 in. air spaces	*0.18*	*0.37*	0.57	0.36	0.31	0.30	0.25	0.37	0.31	0.25	0.25	0.23
42	1/4 in. argon spaces	*0.21*	*0.39*	0.59	0.39	0.33	0.32	0.27	0.40	0.34	0.28	0.27	0.26
43	1/2 in. argon spaces	*0.14*	*0.34*	0.54	0.33	0.28	0.27	0.23	0.34	0.28	0.22	0.21	0.20
	Quadruple Glazing, e = 0.10 on surfaces 2 or 3 and 4 or 5												
44	1/4 in. air spaces	*0.22*	*0.40*	0.60	0.39	0.34	0.33	0.28	0.41	0.34	0.29	0.28	0.27
45	1/2 in. air spaces	*0.15*	*0.35*	0.54	0.34	0.29	0.28	0.24	0.35	0.28	0.23	0.22	0.21
46	1/4 in. argon spaces	*0.17*	*0.36*	0.56	0.36	0.30	0.29	0.25	0.37	0.30	0.25	0.24	0.23
47	1/2 in. argon spaces	*0.12*	*0.32*	0.52	0.32	0.27	0.26	0.22	0.32	0.26	0.20	0.20	0.19
48	1/4 in. krypton spaces	*0.12*	*0.32*	0.52	0.32	0.27	0.26	0.22	0.32	0.26	0.20	0.20	0.19

Notes:

1. All heat transmission coefficients in this table include film resistances and are based on winter conditions of 0°F outdoor air temperature and 70°F indoor air temperature, with 15 mph outdoor air velocity and zero solar flux. With the exception of single glazing, small changes in indoor and outdoor temperatures will not significantly affect overall U-factors. The coefficients are for vertical position except skylight and sloped glazing values, which are for 20° from horizontal with heat flow up.

2. Glazing layer surfaces are numbered from the outdoor to the indoor. *Double, triple,* and *quadruple* refer to the number of glazing panels. All data are based on 1/8 in. glass, unless otherwise noted. Thermal conductivities are 0.53 Btu/h·ft·°F for glass and 0.11 Btu/h·ft·°F for acrylic and polycarbonate.

3. Standard spacers are metal. Edge-of-glass effects assumed to extend over the 2-1/2 in. band around perimeter of each glazing unit.

Table 4 U-Factors for Various Fenestration Products in Btu/h·ft²·°F (*Concluded*)

Vertical Installation					Sloped Installation									
Garden Windows		Curtain Wall			Glass Only (Skylights)		Manufactured Skylight				Site-Assembled Sloped/Overhead Glazing			
Aluminum Without Thermal Break	Wood/ Vinyl	Aluminum Without Thermal Break	Aluminum with Thermal Break	Structural Glazing	Center of Glass	Edge of Glass	Aluminum Without Thermal Break	Aluminum with Thermal Break	Reinforced Vinyl/ Aluminum Clad Wood	Wood/ Vinyl	Aluminum Without Thermal Break	Aluminum with Thermal Break	Structural Glazing	ID
2.60	2.31	1.22	1.11	1.11	*1.19*	*1.19*	1.98	1.89	1.75	1.47	1.36	1.25	1.25	1
2.33	2.06	1.08	0.96	0.96	*1.03*	*1.03*	1.82	1.73	1.60	1.31	1.21	1.10	1.10	2
2.46	2.19	1.15	1.04	1.04	*1.11*	*1.11*	1.90	1.81	1.68	1.39	1.29	1.18	1.18	3
1.81	1.61	0.79	0.68	0.63	*0.58*	*0.66*	1.31	1.11	1.05	0.84	0.82	0.70	0.66	4
1.71	1.53	0.73	0.62	0.57	*0.57*	*0.65*	1.30	1.10	1.04	0.84	0.81	0.69	0.65	5
1.76	1.56	0.75	0.64	0.60	*0.53*	*0.63*	1.27	1.07	1.00	0.80	0.77	0.66	0.62	6
1.67	1.49	0.70	0.59	0.55	*0.53*	*0.63*	1.27	1.07	1.00	0.80	0.77	0.66	0.62	7
1.77	1.58	0.76	0.65	0.61	*0.54*	*0.63*	1.27	1.08	1.01	0.81	0.78	0.67	0.63	8
1.65	1.48	0.69	0.58	0.54	*0.53*	*0.63*	1.27	1.07	1.00	0.80	0.77	0.66	0.62	9
1.70	1.52	0.72	0.61	0.56	*0.49*	*0.60*	1.23	1.03	0.97	0.76	0.74	0.63	0.58	10
1.61	1.44	0.67	0.56	0.51	*0.49*	*0.60*	1.23	1.03	0.97	0.76	0.74	0.63	0.58	11
1.73	1.54	0.74	0.63	0.58	*0.51*	*0.61*	1.25	1.05	0.99	0.78	0.76	0.64	0.60	12
1.59	1.43	0.66	0.55	0.51	*0.50*	*0.61*	1.24	1.04	0.98	0.77	0.75	0.64	0.59	13
1.64	1.47	0.69	0.57	0.53	*0.44*	*0.56*	1.18	0.99	0.92	0.72	0.70	0.58	0.54	14
1.53	1.38	0.63	0.51	0.47	*0.46*	*0.58*	1.20	1.00	0.94	0.74	0.71	0.60	0.56	15
1.67	1.49	0.70	0.59	0.55	*0.46*	*0.58*	1.20	1.00	0.94	0.74	0.71	0.60	0.56	16
1.52	1.37	0.62	0.51	0.46	*0.46*	*0.58*	1.20	1.00	0.94	0.74	0.71	0.60	0.56	17
1.56	1.40	0.64	0.53	0.49	*0.39*	*0.53*	1.14	0.94	0.88	0.68	0.65	0.54	0.50	18
1.44	1.30	0.57	0.46	0.42	*0.40*	*0.54*	1.15	0.95	0.89	0.68	0.66	0.55	0.51	19
1.62	1.45	0.68	0.57	0.52	*0.44*	*0.56*	1.18	0.99	0.92	0.72	0.70	0.58	0.54	20
1.47	1.33	0.59	0.48	0.44	*0.44*	*0.56*	1.18	0.99	0.92	0.72	0.70	0.58	0.54	21
1.52	1.37	0.62	0.51	0.46	*0.36*	*0.51*	1.11	0.91	0.85	0.65	0.63	0.52	0.47	22
1.40	1.26	0.55	0.44	0.39	*0.38*	*0.52*	1.13	0.93	0.87	0.67	0.65	0.53	0.49	23
1.61	1.44	0.67	0.56	0.51	*0.42*	*0.55*	1.17	0.97	0.91	0.70	0.68	0.57	0.52	24
1.44	1.30	0.57	0.46	0.42	*0.43*	*0.56*	1.17	0.98	0.91	0.71	0.69	0.58	0.53	25
1.49	1.34	0.60	0.49	0.44	*0.34*	*0.49*	1.09	0.89	0.83	0.63	0.61	0.50	0.45	26
1.37	1.24	0.53	0.42	0.38	*0.36*	*0.51*	1.11	0.91	0.85	0.65	0.63	0.52	0.47	27
see	see	0.63	0.52	0.47	*0.39*	*0.53*	1.12	0.89	0.84	0.64	0.64	0.53	0.48	28
note	note	0.57	0.46	0.41	*0.36*	*0.51*	1.10	0.87	0.81	0.61	0.62	0.51	0.45	29
7	7	0.60	0.49	0.43	*0.35*	*0.50*	1.09	0.86	0.80	0.60	0.61	0.50	0.44	30
		0.55	0.45	0.39	*0.33*	*0.48*	1.07	0.84	0.79	0.59	0.59	0.48	0.42	31
see	see	0.59	0.48	0.42	*0.34*	*0.49*	1.08	0.85	0.79	0.59	0.60	0.49	0.43	32
note	note	0.52	0.41	0.35	*0.31*	*0.47*	1.05	0.82	0.77	0.57	0.57	0.46	0.41	33
7	7	0.54	0.44	0.38	*0.28*	*0.45*	1.02	0.79	0.74	0.54	0.55	0.44	0.38	34
		0.49	0.38	0.33	*0.27*	*0.44*	1.01	0.78	0.73	0.53	0.54	0.43	0.37	35
see	see	0.55	0.45	0.39	*0.29*	*0.45*	1.03	0.80	0.75	0.55	0.56	0.45	0.39	36
note	note	0.48	0.37	0.31	*0.27*	*0.44*	1.01	0.78	0.73	0.53	0.54	0.43	0.37	37
7	7	0.50	0.39	0.34	*0.24*	*0.42*	0.99	0.75	0.70	0.50	0.51	0.40	0.35	38
		0.45	0.34	0.29	*0.22*	*0.40*	0.97	0.74	0.69	0.49	0.50	0.39	0.33	39
see	see	0.54	0.43	0.37	*0.27*	*0.44*	1.01	0.78	0.73	0.53	0.54	0.43	0.37	40
note	note	0.46	0.35	0.29	*0.25*	*0.42*	0.99	0.76	0.71	0.51	0.52	0.41	0.36	41
7	7	0.48	0.38	0.32	*0.21*	*0.39*	0.96	0.73	0.68	0.48	0.49	0.38	0.32	42
		0.42	0.32	0.26	*0.20*	*0.39*	0.95	0.72	0.67	0.47	0.48	0.37	0.31	43
		0.49	0.38	0.33	*0.22*	*0.40*	0.97	0.74	0.69	0.49	0.50	0.39	0.33	44
see	see	0.43	0.32	0.27	*0.19*	*0.38*	0.94	0.71	0.66	0.46	0.47	0.36	0.30	45
note	note	0.45	0.34	0.29	*0.18*	*0.37*	0.93	0.70	0.65	0.45	0.46	0.35	0.30	46
7	7	0.41	0.30	0.24	*0.16*	*0.35*	0.91	0.68	0.63	0.43	0.44	0.33	0.28	47
		0.41	0.30	0.24	*0.13*	*0.33*	0.88	0.65	0.60	0.40	0.42	0.31	0.25	48

4. Product sizes are described in Figure 4, and frame U-factors are from Table 1.
5. Use $U = 0.60$ Btu/h·ft²·°F for glass block with mortar but without reinforcing or framing.
6. Use of this table should be limited to that of an estimating tool for the early phases of design.
7. Values for triple- and quadruple-glazed garden windows are not listed, because these are not common products.
8. U-factors in this table were determined by NFRC *Technical Document* 100-91. They have not been updated to the current rating methodology and current representative product sizes in NFRC *Technical Document* 100-2004.

Table 3 Properties of Solids

Material Description	Specific Heat, Btu/lb·°F	Density, lb/ft³	Thermal Conductivity, Btu/h·ft·°F	Emissivity	
				Ratio	Surface Condition
Aluminum (alloy 1100)	0.214[b]	171[u]	128[u]	0.09[n]	Commercial sheet
				0.20[n]	Heavily oxidized
Aluminum bronze (76% Cu, 22% Zn, 2% Al)	0.09[u]	517[u]	58[u]		
Asbestos: Fiber	0.25[b]	150[u]	0.097[u]		
Insulation	0.20[t]	36[b]	0.092[b]	0.93[b]	"Paper"
Ashes, wood	0.20[t]	40[b]	0.041[b] (122)		
Asphalt	0.22[b]	132[b]	0.43[b]		
Bakelite	0.35[b]	81[u]	9.7[u]		
Bell metal	0.086[t] (122)				
Bismuth tin	0.040*		37.6*		
Brick, building	0.2[b]	123[u]	0.4[b]	0.93*	
Brass: Red (85% Cu, 15% Zn)	0.09[u]	548[u]	87[u]	0.030[b]	Highly polished
Yellow (65% Cu, 35% Zn)	0.09[u]	519[u]	69[u]	0.033[b]	Highly polished
Bronze	0.104[t]	530[t]	17[d] (32)		
Cadmium	0.055[a]	540[f]	53.7[b]	0.02[d]	
Carbon (gas retort)	0.17[a]		0.20[b] (2)	0.81[a]	
Cardboard			0.04[b]		
Cellulose	0.32[b]	3.4[t]	0.033[t]		
Cement (portland clinker)	0.16[b]	120[i]	0.017[i]		
Chalk	0.215[t]	143[t]	0.48*	0.34*	About 250°F
Charcoal (wood)	0.20[t]	15[a]	0.03[a] (392)		
Chrome brick	0.17[b]	200[b]	0.67[b]		
Clay	0.22[b]	63[t]			
Coal	0.3[b]	90[t]	0.098[f] (32)		
Coal tars	0.35[b] (104)	75[b]	0.07[b]		
Coke (petroleum, powdered)	0.36[b] (752)	62[b]	0.55[b] (752)		
Concrete (stone)	0.156[b] (392)	144[b]	0.54[b]		
Copper (electrolytic)	0.092[u]	556[u]	227[u]	0.072[n]	Commercial, shiny
Cork (granulated)	0.485[t]	5.4[t]	0.028[t] (23)		
Cotton (fiber)	0.319[u]	95[u]	0.024[u]		
Cryolite ($AlF_3 \cdot 3NaF$)	0.253[b]	181[b]			
Diamond	0.147[b]	151[t]	27[t]		
Earth (dry and packed)		95[t]	0.037*	0.41*	
Felt		20.6[b]	0.03[b]		
Fireclay brick	0.198[b] (212)	112[t]	0.58[b] (392)	0.75[n]	At 1832°F
Fluorspar (CaF_2)	0.21[b]	199[v]	0.63[v]		
German silver (nickel silver)	0.09[u]	545[u]	19[u]	0.135[n]	Polished
Glass: Crown (soda-lime)	0.18[b]	154[u]	0.59[t] (200)	0.94[n]	Smooth
Flint (lead)	0.117[b]	267[u]	0.79[r]		
Heat-resistant	0.20[b]	139[t]	0.59[t] (200)		
"Wool"	0.157[b]	3.25[t]	0.022[t]		
Gold	0.0312[u]	1208[u]	172[t]	0.02[n]	Highly polished
Graphite: Powder	0.165*		0.106*		
Impervious	0.16[u]	117[u]	75[u]	0.75[n]	
Gypsum	0.259[b]	78[b]	0.25[b]	0.903[b]	On a smooth plate
Hemp (fiber)	0.323[u]	93[u]			
Ice: 32°F	0.487[t]	57.5[b]	1.3[b]	0.95*	
-4°F	0.465[t]		1.41*		
Iron: Cast	0.12[v] (212)	450[b]	27.6[b] (129)	0.435[b]	Freshly turned
Wrought		485[b]	34.9[b]	0.94[b]	Dull, oxidized
Lead	0.0309[u]	707[u]	20.1[u]	0.28[n]	Gray, oxidized
Leather (sole)		62.4[b]	0.092[b]		
Limestone	0.217[b]	103[b]	0.54[b]	0.36* to 0.90	At 145 to 380°F
Linen			0.05[b]		
Litharge (lead monoxide)	0.055[b]	490[b]			
Magnesia: Powdered	0.234[b] (212)	49.7[b]	0.35[b] (117)		
Light carbonate		13[b]	0.034[b]		
Magnesite brick	0.222[b] (212)	158[b]	2.2[b] (400)		
Magnesium	0.241[b]	108[u]	91[u]	0.55[n]	Oxidized
Marble	0.21[b]	162[b]	1.5[b]	0.931[b]	Light gray, polished
Nickel, polished	0.105[u]	555[u]	34.4[u]	0.045[n]	Electroplated
Paints: White lacquer				0.80[n]	
White enamel				0.91[n]	On rough plate
Black lacquer				0.80[n]	
Black shellac		63[u]	0.15[u]	0.91[n]	"Matte" finish
Flat black lacquer				0.96[n]	
Aluminum lacquer				0.39[n]	On rough plate

*Data source unknown.

Notes: 1. Values are for room temperature unless otherwise noted in parentheses. 2. Superscript letters indicate data source from the section on References.

Table 3 Properties of Solids (Continued)

Material Description	Specific Heat, Btu/lb·°F	Density, lb/ft³	Thermal Conductivity, Btu/h·ft·°F	Emissivity Ratio	Emissivity Surface Condition
Paper	0.32*	58[b]	0.075[b]	0.92[b]	Pasted on tinned plate
Paraffin	0.4[bb]	47[bb]	0.14[b] (32)		
Plaster		132[b]	0.43[b] (167)	0.91[b]	Rough
Platinum	0.032[u]	1340[u]	39.9[u]	0.054[b]	Polished
Porcelain	0.18*	162[u]	1.3[u]	0.92[b]	Glazed
Pyrites (copper)	0.131[b]	262[b]			
Pyrites (iron)	0.136[b] (156)	310[v]			
Rock salt	0.219[u]	136[u]			
Rubber, vulcanized: Soft	0.48*	68.6[t]	0.08[t]	0.86[b]	Rough
Hard		74.3[t]	0.092[t]	0.95[b]	Glossy
Sand	0.191[b]	94.6[b]	0.19[b]		
Sawdust		12[b]	0.03[b]		
Silica	0.316[b]	140[v]	0.83[t] (200)		
Silver	0.0560[u]	654[u]	245[u]	0.02[n]	Polished and at 440°F
Snow: Freshly fallen		7[y]	0.34[t]		
At 32°F		31[t]	1.3[t]		
Steel (mild)	0.12[b]	489[b]	26.2[b]	0.12[n]	Cleaned
Stone (quarried)	0.2[b]	95[t]			
Tar: Pitch	0.59[v]	67[u]	0.51[v]		
Bituminous		75[t]	0.41[u]		
Tin	0.0556[u]	455[u]	37.5[u]	0.06[h]	Bright and at 122°F
Tungsten	0.032[u]	1210[u]	116[u]	0.032[n]	Filament at 80°F
Wood: Hardwoods—	0.45/0.65[b]	23/70[z]	0.065/0.148[z]		
Ash, white		43[z]	0.0992[z]		
Elm, American		36[z]	0.0884[z]		
Hickory		50[z]			
Mahogany		34[u]	0.075[u]		
Maple, sugar		45[z]	0.108[z]		
Oak, white	0.570[b]	47[z]	0.102[z]	0.90[n]	Planed
Walnut, black		39[z]			
Softwoods—	See Table 4, Chapter 25	22/46[z]	0.061/0.093[z]		
Fir, white		27[z]	0.068[z]		
Pine, white		27[z]	0.063[z]		
Spruce		26[z]	0.065[z]		
Wool: Fiber	0.325[u]	82[u]			
Fabric		6.9/20.6[u]	0.021/0.037[u]		
Zinc: Cast	0.092[u]	445[u]	65[u]	0.05[n]	Polished
Hot-rolled	0.094[b]	445[b]	62[b]		
Galvanizing				0.23[n]	Fairly bright

*Data source unknown.

Notes: 1. Values are for room temperature unless otherwise noted in parentheses. 2. Superscript letters indicate data source from References.

REFERENCES

[a] *Handbook of chemistry and physics*. 63rd ed. 1982-83. Chemical Rubber Publishing Co., Cleveland, OH.

[b] Perry, R.H. *Chemical engineers' handbook*, 2nd ed., 1941, 5th ed., 1973. McGraw-Hill, New York.

[c] *Tables of thermodynamic and transport properties of air, argon, carbon dioxide, carbon monoxide, hydrogen, nitrogen, oxygen and steam*. 1960. Pergamon Press, Elmsford, NY.

[d] *American Institute of Physics handbook*, 3rd ed. 1972. McGraw-Hill, New York.

[e] Organick and Studhalter. 1948. *Thermodynamic properties of benzene. Chemical Engineering Progress* (November):847.

[f] Lange. 1972. *Handbook of chemistry*, rev. 12th ed. McGraw-Hill, New York.

[g] ASHRAE. 1969. *Thermodynamic properties of refrigerants*.

[h] Reid and Sherwood. 1969. *The properties of gases and liquids*, 2nd ed. McGraw-Hill, New York.

[i] Chapter 19, 1993 *ASHRAE Handbook—Fundamentals*.

[j] *T.P.R.C. data book*. 1966. Thermophysical Properties Research Center, W. Lafayette, IN.

[k] Estimated.

[l] Canjar, L.N., M. Goldman, and H. Marchman. 1951. Thermodynamic properties of propylene. *Industrial and Engineering Chemistry* (May):1183.

[m] *ASME steam tables*. 1967. American Society of Mechanical Engineers, New York.

[n] McAdams, W.H. 1954. *Heat transmission*. 3rd ed. McGraw-Hill, New York.

[o] Stull, D.R. 1947. Vapor pressure of pure substances (organic compounds). *Industrial and Engineering Chemistry* (April):517.

[p] *JANAF thermochemical tables*. 1965. PB 168 370. National Technical Information Service, Springfield, VA.

[q] *Physical properties of chemical compounds*. 1955–61. American Chemical Society, Washington, D.C.

[r] *International critical tables of numerical data*. 1928. National Research Council of USA, McGraw-Hill, New York.

[s] *Matheson gas data book*, 4th ed. 1966. Matheson Company, Inc., East Rutherford, NJ.

[t] Baumeister and Marks. 1967. *Standard handbook for mechanical engineers*. McGraw-Hill, New York.

[u] Miner and Seastone. *Handbook of engineering materials*. John Wiley and Sons, New York.

[v] Kirk and Othmer. 1966. *Encyclopedia of chemical technology*. Interscience Division, John Wiley and Sons, New York.

[w] Gouse and Stevens. 1960. *Chemical technology of petroleum*, 3rd ed. McGraw-Hill, New York.

[x] *Saline water conversion engineering data book*. 1955. M.W. Kellogg Co. for U.S. Department of Interior.

[y] Timmermans, J. *Physicochemical constants of pure organic compounds*. 2nd ed. American Elsevier, New York.

[z] *Wood handbook*. 1955. Handbook No. 72. Forest Products Laboratory, U.S. Department of Agriculture.

[aa] ASHRAE. 1976. *Thermophysical properties of refrigerants*.

[bb] Lane, G. ed. 1986. *Solar heat storage: Latent heat materials, Vol II—Technology*. CRC Press, Chicago.

CHAPTER 38

UNITS AND CONVERSIONS

Table 1 Conversions to I-P and SI Units

(Multiply I-P values by conversion factors to obtain SI; divide SI values by conversion factors to obtain I-P)

Multiply I-P	By	To Obtain SI
acre (43,506 ft²)	0.4047	ha
	4046.873	m²
atmosphere (standard)	*101.325	kPa
bar	*100	kPa
barrel (42 U.S. gal, petroleum)	159.0	L
	0.1580987	m³
Btu (International Table)	1055.056	J
Btu (thermochemical)	1054.350	J
Btu/ft² (International Table)	11,356.53	J/m²
Btu/ft³ (International Table)	37,258.951	J/m³
Btu/gal	278,717.1765	J/m³
Btu·ft/h·ft²·°F	1.730735	W/(m·K)
Btu·in/h·ft²·°F (thermal conductivity k)	0.1442279	W/(m·K)
Btu/h	0.2930711	W
Btu/h·ft²	3.154591	W/m²
Btu/h·ft²·°F (overall heat transfer coefficient U)	5.678263	W/(m²·K)
Btu/lb	*2.326	kJ/kg
Btu/lb·°F (specific heat c_p)	*4.1868	kJ/(kg·K)
bushel (dry, U.S.)	0.0352394	m³
calorie (thermochemical)	*4.184	J
centipoise (dynamic viscosity μ)	*1.00	mPa·s
centistokes (kinematic viscosity ν)	*1.00	mm²/s
clo	0.155	m²·K/W
dyne	1.0×10^{-5}	N
dyne/cm²	*0.100	Pa
EDR hot water (150 Btu/h)	43.9606	W
EDR steam (240 Btu/h)	70.33706	W
EER	0.293	COP
ft	*0.3048	m
	*304.8	mm
ft/min, fpm	*0.00508	m/s
ft/s, fps	*0.3048	m/s
ft of water	29,989.07	Pa
ft of water per 100 ft pipe	98.1	Pa/m
ft²	0.092903	m²
ft²·h·°F/Btu (thermal resistance R)	0.176110	m²·K/W
ft²/s (kinematic viscosity ν)	92,900	mm²/s
ft³	28.316846	L
	0.02832	m³
ft³/min, cfm	0.471947	L/s
ft³/s, cfs	28.316845	L/s
ft·lb$_f$ (torque or moment)	1.355818	N·m
ft·lb$_f$ (work)	1.356	J
ft·lb$_f$/lb (specific energy)	2.99	J/kg
ft·lb$_f$/min (power)	0.0226	W
footcandle	10.76391	lx
gallon (U.S., *231 in³)	3.785412	L
gph	1.05	mL/s
gpm	0.0631	L/s
gpm/ft²	0.6791	L/(s·m²)
gpm/ton refrigeration	0.0179	mL/J
grain (1/7000 lb)	0.0648	g
gr/gal	17.1	g/m³
gr/lb	0.143	g/kg
horsepower (boiler) (33,470 Btu/h)	9.81	kW
horsepower (550 ft·lb$_f$/s)	0.7457	kW
inch	*25.4	mm
in. of mercury (60°F)	3.37	kPa
in. of water (60°F)	249	Pa
in/100 ft, thermal expansion	0.833	mm/m
To Obtain I-P	**By**	**Divide SI**

Multiply I-P	By	To Obtain SI
in·lb$_f$ (torque or moment)	113	mN·m
in²	645.16	mm²
in³ (volume)	16.3874	mL
in³/min (SCIM)	0.273117	mL/s
in³ (section modulus)	16,387	mm³
in⁴ (section moment)	416,231	mm⁴
kWh	*3.60	MJ
kW/1000 cfm	2.118880	kJ/m³
kilopond (kg force)	9.81	N
kip (1000 lb$_f$)	4.45	kN
kip/in² (ksi)	6.895	MPa
litre	*0.001	m³
met	58.15	W/m²
micron (μm) of mercury (60°F)	133	mPa
mile	1.609	km
mile, nautical	*1.852	km
mile per hour (mph)	1.609344	km/h
	0.447	m/s
millibar	*0.100	kPa
mm of mercury (60°F)	0.133	kPa
mm of water (60°F)	9.80	Pa
ounce (mass, avoirdupois)	28.35	g
ounce (force or thrust)	0.278	N
ounce (liquid, U.S.)	29.6	mL
ounce inch (torque, moment)	7.06	mN·m
ounce (avoirdupois) per gallon	7.489152	kg/m³
perm (permeance at 32°F)	5.72135×10^{-11}	kg/(Pa·s·m²)
perm inch (permeability at 32°F)	1.45362×10^{-12}	kg/(Pa·s·m)
pint (liquid, U.S.)	4.73176×10^{-4}	m³
pound		
lb (avoirdupois, mass)	0.453592	kg
	453.592	g
lb$_f$ (force or thrust)	4.448222	N
lb$_f$/ft (uniform load)	14.59390	N/m
lb/ft·h (dynamic viscosity μ)	0.4134	mPa·s
lb/ft·s (dynamic viscosity μ)	1490	mPa·s
lb$_f$·s/ft² (dynamic viscosity μ)	47.88026	Pa·s
lb/h	0.000126	kg/s
lb/min	0.007559	kg/s
lb/h [steam at 212°F (100°C)]	0.2843	kW
lb$_f$/ft²	47.9	Pa
lb/ft²	4.88	kg/m²
lb/ft³ (density, ρ)	16.0	kg/m³
lb/gallon	120	kg/m³
ppm (by mass)	*1.00	mg/kg
psi	6.895	kPa
quad (10¹⁵ Btu)	1.055	EJ
quart (liquid, U.S.)	0.9463	L
square (100 ft²)	9.29	m²
tablespoon (approximately)	15	mL
teaspoon (approximately)	5	mL
therm (U.S.)	105.5	MJ
ton, long (2240 lb)	1.016	Mg
ton, short (2000 lb)	0.907	Mg; t (tonne)
ton, refrigeration (12,000 Btu/h)	3.517	kW
torr (1 mm Hg at 0°C)	133	Pa
watt per square foot	10.76	W/m²
yd	*0.9144	m
yd²	0.8361	m²
yd³	0.7646	m³
To Obtain I-P	**By**	**Divide SI**

*Conversion factor is exact.

Notes: 1. Units are U.S. values unless noted otherwise.

2. Litre is a special name for the cubic decimetre. 1 L = 1 dm³ and 1 mL = 1 cm³.

The preparation of this chapter is assigned to TC 1.6, Terminology.

Table 2 Conversion Factors

Pressure

psi	in. of water (60°F)	in. Hg (32°F)	atmosphere	mm Hg (32°F)	bar	kgf/cm²	pascal
1	= 27.708	= 2.0360	= 0.068046	= 51.715	= 0.068948	= 0.07030696	= 6894.8
0.036091	1	0.073483	2.4559×10^{-3}	1.8665	2.4884×10^{-3}	2.537×10^{-3}	248.84
0.491154	13.609	1	0.033421	25.400	0.033864	0.034532	3386.4
14.6960	407.19	29.921	1	760.0	1.01325*	1.03323	1.01325×10^{5}*
0.0193368	0.53578	0.03937	1.31579×10^{-3}	1	1.3332×10^{-3}	1.3595×10^{-3}	133.32
14.5038	401.86	29.530	0.98692	750.062	1	1.01972*	10^{5}*
14.223	394.1	28.959	0.96784	735.559	0.980665*	1	9.80665×10^{4}*
1.45038×10^{-4}	4.0186×10^{-3}	2.953×10^{-4}	9.8692×10^{-6}	7.50×10^{-3}	10^{-5}*	1.01972×10^{-5}*	1

Mass

lb (avoir.)	grain	ounce (avoir.)	kg
1	= 7000*	= 16*	= 0.45359
1.4286×10^{-4}	1	2.2857×10^{-3}	6.4800×10^{-5}
0.06250	437.5*	1	0.028350
2.20462	1.5432×10^{4}	35.274	1

Volume

cubic inch	cubic foot	gallon	litre	cubic metre (m³)
1	= 5.787×10^{-4}	= 4.329×10^{-3}	= 0.0163871	= 1.63871×10^{-5}
1728*	1	7.48052	28.317	0.028317
231.0*	0.13368	1	3.7854	0.0037854
61.02374	0.035315	0.264173	1	0.001*
6.102374×10^{4}	35.315	264.173	1000*	1

Energy

Note: MBtu, which is 1000 Btu, is confusing and is not used in the Handbook.

Btu	ft·lb$_f$	calorie (cal)	joule (J) = watt-second (W·s)	watt-hour (W·h)
1	= 778.17	= 251.9958	= 1055.056	= 0.293071
1.2851×10^{-3}	1	0.32383	1.355818	3.76616×10^{-4}
3.9683×10^{-3}	3.08803	1	4.1868*	1.163×10^{-3}*
9.4782×10^{-4}	0.73756	0.23885	1	2.7778×10^{-4}
3.41214	2655.22	859.85	3600*	1

Density

lb/ft³	lb/gal	g/cm³	kg/m³
1	= 0.133680	= 0.016018	= 16.018463
7.48055	1	0.119827	119.827
62.4280	8.34538	1	1000*
0.0624280	0.008345	0.001*	1

Specific Volume

ft³/lb	gal/lb	cm³/g	m³/kg
1	= 7.48055	= 62.4280	= 0.0624280
0.133680	1	8.34538	0.008345
0.016018	0.119827	1	0.001*
16.018463	119.827	1000*	1

Viscosity (absolute)

1 poise = 1 dyne-sec/cm² = 0.1 Pa·s = 1 g/(cm·s)

poise	lb$_f$·s/ft²	lb$_f$·h/ft²	kg/(m·s) = N·s/m²	lb$_m$/ft·s
1	= 2.0885×10^{-3}	= 5.8014×10^{-7}	= 0.1*	= 0.0671955
478.8026	1	2.7778×10^{-4}	47.88026	32.17405
1.72369×10^{6}	3600*	1	1.72369×10^{5}	1.15827×10^{5}
10*	0.020885	5.8014×10^{-6}	1	0.0671955
14.8819	0.031081	8.6336×10^{-6}	1.4882	1

Temperature

Scale		Temperature K	Temperature °C	Temperature °R	Temperature °F
Kelvin	x K =	x	$x - 273.15$	$1.8x$	$1.8x - 459.67$
Celsius	x°C =	$x + 273.15$	x	$1.8x + 491.67$	$1.8x + 32$
Rankine	x°R =	$x/1.8$	$(x - 491.67)/1.8$	x	$x - 459.67$
Fahrenheit	x°F =	$(x + 459.67)/1.8$	$(x - 32)/1.8$	$x + 459.67$	x

	Temperature Interval K	Temperature Interval °C	Temperature Interval °R	Temperature Interval °F
1 K =	1	1	9/5 = 1.8	9/5 = 1.8
1°C =	1	1	9/5 = 1.8	9/5 = 1.8
1°R =	5/9	5/9	1	1
1°F =	5/9	5/9	1	1

Notes: Conversions with * are exact.
The Btu and calorie are based on the International Table.
All temperature conversions and factors are exact.
The term centigrade is obsolete and should not be used.

When making conversions, remember that a converted value is no more precise than the original value. For many applications, rounding off the converted value to the same number of significant figures as those in the original value provides sufficient accuracy.

See ANSI *Standard* SI-10-1997 (available from ASTM or IEEE) for additional conversions.

Converting Resistance Values (English to S.I.)

English Units:	SI Units:
$R = hr\ ft^2\ °F / BTU$	$R = m^2\ °K / Watts$

$1\ ft^2$	=	$0.0929\ m^2$
1 Watt	=	3.413 BTU/hr
1 °K	=	1.8 °F
1 inch	=	25.4 mm

From the above, we can solve for a material or assembly that has an R-value of 1.0 as follows:

$1.0\ hr\ ft^2\ °F / BTU = 0.17611\ m^2\ °K / Watts$

Table One. Wall Section Thermal Characteristics

Wall Type

Wood Frame

2x4 studs w/R11 batts (R-value)10.2 (U-value)0.098 (weight)9.2 (heat capacity)2.2
2x6 studs w/R19 batts (R-value)15.4 (U-value)0.065 (weight)10.5 (heat capacity)2.6

Compressed Straw Panel

uninsulated 4.8" panel (R-value)10.1 (U-value)0.099 (weight)13.4 (heat capacity)4.9
insulated 4.8" panel (R-value)18.4 (U-value)0.054 (weight)13.7 (heat capacity)4.9

Fibrous Concrete Panel

insulated 3" panel (R-value)16.7 (U-value)0.060 (weight)16.9 (heat capacity)4.7
insulated 4" panel (R-value)19.1 (U-value)0.052 (weight)20.1 (heat capacity)5.7

Straw Bale

23" bale @ R-1.8/inch (-25%) (R-value)42.7 (U-value)0.023
23" bale @ R-2.4/inch (R-value)56.5 (U-value)0.018 (weight)21.4 (heat capacity)6.4
23" bale @ R-3.0/inch (+25%) (R-value)70.3 (U-value)0.014

Foam Blocks

6" form w/ concrete/adobe fill (R-value)26.3 (U-value)0.038 (weight)40.8 (heat capacity)7.5
8" form w/ concrete/adobe fill (R-value)28.0 (U-value)0.036 (weight)54.2 (heat capacity)9.8

Adobe

uninsulated 10" (R-value)3.5 (U-value)0.284 (weight)95.0 (heat capacity)17.9
insulated 10" (R-value)11.9 (U-value)0.084 (weight)95.3 (heat capacity)18.0
uninsulated 24" (R-value)6.8 (U-value)0.147 (weight)183.4 (heat capacity)34.2
exterior insulated (R-value)24" 15.1 (U-value)0.066 (weight)183.6 (heat capacity)34.3

Notes:

- All walls have stucco exterior and drywall interior, except adobe and straw walls have plaster.
- Wood frame walls have 25 percent (R-11) and 20 percent (R-19) stud areas. The R-19 batt compresses to R-18.
- Compressed straw panel, insulated case, has 2 inches polystyrene on exterior.
- Fibrous Concrete panel have 1 inch polystyrene inside and out.
- Straw bale wall R-value is calculated for 3 unit R-values for straw to cover potential variability.
- Average material thickness across foam block wall sections are as follows:
- 6 inch foam has 2.9 inches polystryene each side and 3.4 inches of fill.
- 8 inch foam has 3.1 inches polystryene each side and 4.8 inches of fill.
- Wall properties are based on 75 percent adobe and 23 percent concrete fill.
- Adobe walls , insulated case, have 2 inches of polystyrene on exterior.
- 24 inch wall is two 10 inch layers with 4 inch air gap.

Source: Department of Energy Web site (09/07/2006)
http://www.eere.energy.gov/buildings/info/components/envelope/framing/strawbale.html