APPENDIX 3-1
SELECTED VALUES OF THERMAL CONDUCTIVITY[a]

Material	Thermal Conductivity, W/mK
Metals	
Aluminum (alloy 1100)	221
Brass, red (85% Cu, 15% Zn)	150
Brass, yellow (65% Cu, 35% Zn)	120
Copper (electrolytic)	393
Gold	297
Iron, cast 鑄鐵	47.7 (327 K)
Iron, wrought 熟鐵, 鍛鐵	60.4
Lead	34.8
Nickel	59.5
Silver	424
Steel, mild	45.3
Tin	64.9
Zinc, galvanizing	110
Wood	
Ash, white	0.172
Elm, American	0.153
Fir, white	0.12
Mahogony	0.13
Maple, sugar	0.187
Oak, white	0.176
Pine, white	0.11
Spruce	0.11
Other	
Brick, building	0.7
Cardboard	0.07
Cellulose	.057
Charcoal, wood	0.05 (473 K)
Concrete stone	0.93
Cork granulated	0.048 (268 K)
Cotton, fiber	0.042
Earth, dry and packed	0.064
Glass, soda-lime	1.0 (366 K)
Ice, 0 C	2.24
Leather	0.16
Marble	2.6
Paper	0.13
Plaster	0.74 (348 K)
Sand, dry	0.33
Sawdust	0.05
Snow, fresh at 32 C	0.598

Selected from the 1985 ASHRAE Handbook of Fundamentals.

a. values at room temperature unless noted in parentheses.

例 一般土壤 正常含水率 正常孔隙度 1.38 W/mK

水 20°C 0.594

空氣 20°C 0.0257 W/mK

APPENDIX 3-2
DESIGN HEAT TRANSMISSION COEFFICIENTS
Taken from the 1985 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta GA. (Used by permission.)

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

Description	Density kg/m³	Conductivity λ W/m·°C	Conductance (C) W/m²·°C	Resistance (R) Per meter thickness (1/λ) m·°C/W	Resistance (R) For thickness listed (1/C) m²·°C/W	Specific Heat kJ/(kg·°C)
BUILDING BOARD						
Boards, Panels, Subflooring, Sheathing Woodboard Panel Products						
Asbestos-cement board	1920	0.576	—	*1.74*	—	1.01
Asbestos-cement board .... 3.18 mm	1920	—	187.4	—	*0.005*	
Asbestos-cement board .... 6.35 mm	1920	—	93.72	—	*0.011*	
Gypsum or plaster board .... 9.53 mm	800	—	17.61	—	*0.056*	1.09
Gypsum or plaster board .... 12.70 mm	800	—	12.61	—	*0.079*	
Gypsum or plaster board .... 15.88 mm	800	—	10.11	—	*0.099*	
Plywood (Douglas Fir)	544	0.115	—	*8.68*	—	1.22
Plywood (Douglas Fir) .... 6.35 mm	544	—	18.18	—	*0.055*	
Plywood (Douglas Fir) .... 9.53 mm	544	—	12.10	—	*0.083*	
Plywood (Douglas Fir) .... 12.70 mm	544	—	9.09	—	*0.11*	
Plywood (Douglas Fir) .... 15.88 mm	544	—	7.33	—	*0.14*	
Plywood or wood panels .... 19.05 mm	544	—	6.08	—	*0.16*	1.22
Vegetable Fiber Board						
Sheathing, regular density .... 12.70 mm	288	—	4.32	—	*0.23*	1.30
.... 19.84 mm	288	—	2.78	—	*0.36*	
Sheathing intermediate density .... 12.70 mm	352	—	4.66	—	*0.21*	1.30
Nail-base sheathing .... 12.70 mm	400	—	5.00	—	*0.20*	1.30
Shingle backer .... 9.53 mm	288	—	6.02	—	*0.17*	1.30
Shingle backer .... 7.94 mm	288	—	7.27	—	*0.14*	
Sound deadening board .... 12.70 mm	240	—	4.20	—	*0.24*	1.26
Tile and lay-in panels, plain or acoustic	288	0.058	—	*17.35*	—	0.59
.... 12.70 mm	288	—	4.54	—	*0.22*	
.... 19.05 mm	288	—	3.01	—	*0.33*	
Laminated paperboard	480	0.072	—	*13.88*	—	1.38
Homogeneous board from repulped paper	480	0.072	—	*13.88*	—	1.17
Hardboard						
Medium density	800	0.105	—	*9.51*	—	1.30
High density, service temp. service underlay	880	0.118	—	*8.47*	—	1.34
High density, std. tempered	1008	0.144	—	*6.94*	—	1.34
Particleboard						
Low density	592	0.078	—	*12.84*	—	1.30
Medium density	800	0.135	—	*7.36*	—	1.30
High density	1000	0.170	—	*5.90*	—	1.30
Underlayment .... 15.88 mm	640	—	6.93	—	*0.14*	1.22
Wood subfloor .... 19.05 mm		—	6.02	—	*0.17*	1.38
BUILDING MEMBRANE						
Vapor—permeable felt	—	—	94.86	—	*0.011*	
Vapor—seal, 2 layers of mopped 0.73 kg/m² felt	—	—	47.43	—	*0.021*	
Vapor—seal, plastic film	—	—	—	—	Negl.	
FINISH FLOORING MATERIALS						
Carpet and fibrous pad	—	—	2.73	—	*0.37*	1.42
Carpet and rubber pad	—	—	4.60	—	*0.22*	1.38
Cork tile .... 3.18 mm	—	—	20.45	—	*0.049*	2.01
Terrazzo .... 25.40 mm	—	—	71.00	—	*0.014*	0.80
Tile—asphalt, linoleum, vinyl, rubber	—	—	113.6	—	*0.009*	1.26
vinyl asbestos						1.01
ceramic						0.80
Wood, hardwood finish .... 19.05 mm			8.35		*0.12*	
INSULATING MATERIALS						
Blanket and Batt[b]						
Mineral Fiber, fibrous form processed from rock, slag, or glass						
approx.[c] 76.2–101.6 mm	4.8–32.0	—	0.52	—	*1.94[b]*	
approx.[c] 88.9 mm	4.8–32.0		0.44	—	*2.29[b]*	
approx.[c] 139.7–165.1 mm	4.8–32.0	—	0.30	—	*3.34[b]*	
approx.[c] 152.4–177.8 mm	4.8–32.0		0.26		*3.87[b]*	
approx.[c] 215.9–228.6 mm	4.8–32.0		0.19		*5.28[b]*	
approx. 304.8 mm	4.8–32.0	—	0.15		*6.69[b]*	

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

Description	Density kg/m³	Conductivity (λ) W/m·°C	Conductance (C) W/m²·°C	Resistance (R) Per meter thickness	Resistance (R) For thickness listed	Specific Heat kJ/(kg·°C)
Board and Slabs						
Cellular glass (蜂窩狀)	136	0.050	—	19.85	—	0.75
Glass fiber, organic bonded	64–144	0.036	—	27.76	—	0.96
Expanded perlite, organic bonded	16.0	0.052	—	19.29	—	1.26
Expanded rubber (rigid)	72.0	0.032	—	31.58	—	1.68
Expanded polystyrene extruded						
Cut cell surface	28.8	0.036	—	27.76	—	1.22
Smooth skin surface	28.8–56.0	0.029	—	34.70	—	1.22
Expanded polystyrene, molded beads	16.0	0.037	—	23.25	—	—
	20.0	0.036	—	27.76	—	—
	24.0	0.035	—	28.94	—	—
	28.0	0.035	—	28.94	—	—
	32.0	0.033	—	30.19	—	—
Cellular polyurethane[c] (R-11 exp.)(unfaced)	24.0	0.023	—	43.38	—	1.59
Foil-faced, glass fiber-reinforced cellular Polyisocyanurate (R-11 exp.)[d]	32.0	0.020	—	49.97	—	0.92
Nominal 12.70 mm		—	1.58	—	0.63	
Nominal 25.40 mm		—	0.79	—	1.27	
Nominal 50.80 mm		—	0.39	—	2.53	
Mineral fiber with resin binder	240	0.042	—	23.94	—	0.71
Mineral fiberboard, wet felted						
Core or roof insulation	256–272	0.049	—	20.40	—	0.80
Acoustical tile	288	0.050	—	19.85	—	
Acoustical tile	336	0.053	—	18.74	—	
Mineral fiberboard, wet molded						
Acoustical tile[c]	368	0.060	—	16.52	—	0.59
Wood or cane fiberboard						
Acoustical tile[c] 12.70 mm	—	—	4.54	—	0.22	1.30
Acoustical tile[c] 19.05 mm	—	—	3.01	—	0.33	
Interior finish (plank, tile)	240	0.050	—	19.85	—	1.34
Cement fiber slabs (shredded wood with Portland cement binder)	400–432	0.072–0.070	—	13.88–13.12	—	—
Cement fiber slabs (shredded wood with magnesia oxysulfide binder)	352	0.082	—	12.15	—	1.30
LOOSE FILL						
Cellulosic insulation (milled paper or wood pulp)	36.8–51.2	0.039–0.046	—	25.68–21.72	—	1.38
Sawdust or shavings	128–240	0.065	—	15.41	—	1.38
Wood fiber, softwoods	32.0–56.0	0.043	—	23.11	—	1.38
Perlite, expanded	32.0–65.6	0.039–0.045		25.68–22.90		
	65–118	0.045–0.052		22.90–19.43		
	118–176	0.052–0.060		19.43–16.66		
Mineral fiber (rock, slag or glass)						0.71
approx. 95.3–127.0 mm	9.6–32.0	—	—		1.94	
approx. 165.1–222.3 mm	9.6–32.0	—	—		3.34	
approx. 190.5–254.0 mm	9.6–32.0	—	—		3.87	
approx. 260.4–349.3 mm	9.6–32.0	—	—		5.28	
Mineral fiber (rock, slag or glass) approx. 83.8 mm (closed sidewall application)	32.0–56.0	—	—	—	2.46	
Vermiculite, exfoliated	112–131	0.068	—	14.78	—	1.34
	64.0–96.0	0.063	—	15.75	—	
FIELD APPLIED						
Polyurethane foam	24.0–40.0	0.023–0.026	—	43.38–36.50	—	
Ureaformaldehyde foam	11.2–25.6	0.032–0.040	—	24.78–31.58	—	
Spray cellulosic fiber base	32.0–96.0	0.035–0.043	—	23.11–28.94	—	
PLASTERING MATERIALS						
Cement plaster, sand aggregate	1865	0.720	—	1.39	—	0.84
Sand aggregate 9.53 mm	—	—	75.54	—	0.014	0.84
Sand aggregate 19.05 mm	—	—	37.83	—	0.026	0.84
Gypsum plaster:						
Lightweight aggregate 12.70 mm	720	—	17.72	—	0.056	
Lightweight aggregate 15.88 mm	720	—	15.17	—	0.069	
Lightweight agg. on metal lath 19.05 mm	—	—	12.10	—	0.083	
Perlite aggregate	720	0.216	—	4.65	—	1.34

矽酸鈣板 (防火) 6 mm, 8 mm, 9 mm, 10 mm, 12 mm — 800 — 0.15 — 250, 187.5, 166.7, 150, 125 — 6.67 — 0.004, 0.0053, 0.006, 0.0067, 0.008

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

Description	Density kg/m³	Conductivity (λ) W/m·°C	Conductance (C) W/m²·°C	Resistance (R) Per meter thickness	Resistance (R) For thickness listed	Specific Heat kJ/(kg·°C)
PLASTERING MATERIALS						
Sand aggregate	1680	0.806	—	*1.25*	—	0.84
Sand aggregate 12.70 mm	1680	—	63.05	—	*0.016*	
Sand aggregate 15.88 mm	1680	—	51.69	—	*0.019*	
Sand aggregate on metal lath 19.05 mm	—	—	43.74	—	*0.023*	
Vermiculite aggregate	720	0.245	—	*4.09*	—	
MASONRY MATERIALS						
Concretes						
Cement mortar	1856	0.720	—	*1.39*	—	
Gypsum-fiber concrete 87.5% gypsum, 12.5% wood chips	816	0.239	—	*4.16*	—	0.88
Lightweight aggregates including expanded shale, clay or slate; expanded slags; cinders; pumice; vermiculite; also cellular concretes	1920	0.749	—	*1.32*	—	
	1600	0.518	—	*1.94*	—	
	1280	0.360	—	*2.78*	—	
	960	0.245	—	*4.09*	—	
	640	0.166	—	*5.97*	—	
	480	0.130	—	*7.70*	—	
	320	0.101		*9.92*		
Perlite, expanded	640	0.134		*7.50*		
	480	0.102		*9.79*		
	320	0.072		*13.88*		1.34
Sand and gravel or stone aggregate (oven dried)	2240	1.296	—	*0.76*		0.92
Sand and gravel or stone aggregate (not dried)	2240	1.728	—	*0.56*		
Stucco	1856	0.720	—	*1.39*		
MASONRY UNITS						
Brick, common[f]	1920	0.720	—	*1.39*	—	0.80
Brick, face[f]	2080	1.296	—	*0.76*	—	
Clay tile, hollow:						
1 cell deep 76.2 mm	—	—	7.10	—	*0.14*	0.88
1 cell deep 101.6 mm	—	—	5.11	—	*0.20*	
2 cells deep 152.4 mm	—	—	3.75	—	*0.27*	
2 cells deep 203.2 mm	—	—	3.07	—	*0.33*	
2 cells deep 254.0 mm	—	—	2.56	—	*0.39*	
3 cells deep 304.8 mm	—	—	2.27	—	*0.44*	
Concrete blocks, three oval core:						
Sand and gravel aggregate 101.6 mm	—	—	7.95	—	*0.12*	0.92
203.2 mm	—	—	5.11	—	*0.20*	
304.8 mm	—	—	4.43	—	*0.23*	
Cinder aggregate 76.2 mm	—	—	6.59	—	*0.15*	0.88
101.6 mm	—	—	5.11	—	*0.20*	
203.2 mm	—	—	3.29	—	*0.30*	
304.8 mm	—	—	3.01	—	*0.33*	
Lightweight aggregate 76.2 mm	—	—	4.49	—	*0.22*	0.88
expanded shale, clay, slate 101.6 mm	—	—	3.81	—	*0.26*	
or slag; pumice 203.2 mm	—	—	2.84	—	*0.35*	
304.8 mm	—	—	2.50	—	*0.40*	
Concrete blocks, rectangular core.[g]						
Sand and gravel aggregate						
2 core,[h] 203.2 mm, 16.3 kg	—	—	5.45	—	*0.18*	0.92
Same with filled cores[i]	—	—	2.95	—	*0.34*	0.92
Lightweight aggregate (expanded shale, clay, slate or slag, pumice):						
3 core,[h] 152.4 mm, 8.6 kg	—	—	3.46	—	*0.29*	0.88
Same with filled cores[i]	—	—	1.87	—	*0.53*	
2 core,[h] 203.2 mm, 10.9 kg	—	—	2.61	—	*0.38*	
Same with filled cores[i]	—	—	1.14	—	*0.89*	
3 core,[h] 304.8 mm, 17.3 kg	—	—	2.27	—	*0.44*	
Same with filled cores[i]	—	—	0.97	—	*1.02*	
Stone, lime or sand	—	1.800	—	*0.56*	—	0.80
Gypsum partition tile:						
76.2 · 304.8 · 762.0 mm, solid	—	—	4.49	—	*0.22*	*0.80*
76.2 · 304.8 · 762.0 mm, 4-cell	—	—	4.20	—	*0.24*	
101.6 · 304.8 · 762.0 mm, 3-cell	—	—	3.41	—	*0.29*	

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

Description	Density kg/m³	Conductivity λ W/m·°C	Conductance (C) W/m²°C	Resistance (R) Per meter thickness (1/λ) m·°C/W	Resistance (R) For thickness listed (1/C) m²·°C/W	Specific Heat kJ/(kg·°C)
METALS (See Chapter 39, Table 3)						
ROOFING						
Asbestos-cement shingles	1920	—	27.04	—	*0.037*	1.01
Asphalt roll roofing	1120	—	36.92	—	*0.026*	1.51
Asphalt shingles	1120	—	12.89	—	*0.077*	1.26
Built-up, 9.53 mm	1120	—	17.04	—	*0.058*	1.47
Slate, 12.70 mm	—	—	113.6	—	*0.009*	1.26
Wood shingles, plain and plastic film faced	—	—	6.02	—	*0.17*	1.30
SIDING MATERIALS (on flat surface)						
Shingles						
Asbestos-cement	1920	—	26.98	—	*0.037*	
Wood, 406.4 mm, 190.5 mm exposure	—	—	6.53	—	*0.15*	1.30
Wood, double, 406.4 mm, 304.8 mm exposure	—	—	4.77	—	*0.21*	1.17
Wood, plus insul. backer board, 7.94 mm	—	—	4.03	—	*0.25*	1.30
Siding						
Asbestos-cement, 6.35 mm, lapped	—	—	27.04	—	*0.037*	1.01
Asphalt roll siding	—	—	36.92	—	*0.026*	1.47
Asphalt insulating siding (12.70 mm bed.)	—	—	3.92	—	*0.26*	1.47
Hardboard siding, 11.11 mm	640	0.215	—	*4.65*	0.05	1.17
Wood, drop, 25.4 • 203.2 mm	—	—	7.21	—	*0.14*	1.17
Wood, bevel, 12.7 • 203.2 mm, lapped	—	—	6.99	—	*0.14*	1.17
Wood, bevel, 19.1 • 254.0 mm, lapped	—	—	5.40	—	*0.18*	1.17
Wood, plywood, 9.53 mm, lapped	—	—	9.03	—	*0.10*	1.22
Aluminum or Steel[j], over sheathing						
Hollow-backed	—	—	9.14	—	*0.11*	1.22
Insulating-board backed nominal 9.53 mm	—	—	3.12	—	*0.32*	1.34
Insulating-board backed nominal 9.53 mm, foil backed			1.93		*0.52*	
Architectural glass	—	—	56.80	—	*0.018*	0.84
WOODS (12% Moisture Content)[k,l]						
Hardwoods						1.63
Oak	659-749	0.161-0.180	—	*6.18-5.55*	—	
Birch	682-726	0.167-0.176	—	*6.04-5.69*	—	
Maple	637-704	0.157-0.171	—	6.52-6.11	—	
Ash	614-670	0.153-0.164	—	6.52-6.11	-	
Softwoods						1.63
Southern Pine	570-659	0.144-0.161	—	6.94-6.18	—	
Douglas Fir-Larch	536-581	0.137-0.145	—	7.36-6.87	—	
Southern Cypress	502-514	0.130-0.132	—	7.70-7.56	—	
Hem-Fir, Spruce-Pine-Fir	392-502	0.107-0.130	—	9.37-7.70	—	
West Coast Woods, Cedars	347-502	0.098-0.130	—	10.27-7.70	—	
California Redwood	392-448	0.107-0.118	—	9.37-8.47	—	

Notes

[a]Except where otherwise noted, all values are for a mean temperature of 23.9°C. Representative values for dry materials, selected by ASHRAE TC 4.4, are intended as design (not specification) values for materials in normal use. Insulation materials in actual service may have thermal values that vary from design values depending on their in-situ properties (e.g., density and moisture content). For properties of a particular product, use the value supplied by the manufacturer or by unbiased tests.

[b]Does not include paper backing and facing, if any. Where insulation forms a boundary (reflective or otherwise) of an air space, see Tables 1, 2A and 2B for the insulating value of an air space with the appropriate effective emittance and temperature conditions of the space.

[c]Values are for aged, unfaced, board stock. For change in conductivity with age of expanded urethane, see Chapter 20, Factors Affecting Thermal Conductivity.

[d]Time-aged values for board stock with gas-barrier quality (0.025 mm thickness or greater) aluminum foil facers on two major surfaces.

[e]Insulating values of acoustical tile vary, depending on density of the board and on type, size and depth of perforations.

[f]Face brick and common brick do not always have these specific densities. When density differs from that shown, there is a change in thermal conductivity.

[g]Data on rectangular core concrete blocks differ from the above data on oval core blocks, due to core configuration, different mean temperatures, and possibly differences in unit weights. Weight data on the oval core blocks tested are not available.

[h]Weights of units approximately 193.7 mm high and 400.1 mm long. These weights are given as a means of describing the blocks tested, but conductance values are all for 0.093m² of area.

[i]Vermiculite, perlite, or mineral wool insulation. Where insulation is used, vapor barriers or other precautions must be considered to keep insulation dry.

[j]Values for metal siding applied over flat surfaces vary widely, depending on amount of ventilation of air space beneath the siding; whether air space is reflective or nonreflective; and on thickness, type, and application of insulating backing-board used. Values given are averages for use as design guides, and were obtained from several guarded hotbox tests (ASTM C236) or calibrated hotbox (BSS 77) on hollow-backed types and types made using backing-boards of wood fiber, foamed plastic, and glass fiber. Departures of ±50% or more from the values given may occur.

[k]Forest Products Laboratory Wood Handbook, U.S. Dept. of Agriculture #72, 1974, Tables 3 and 4.

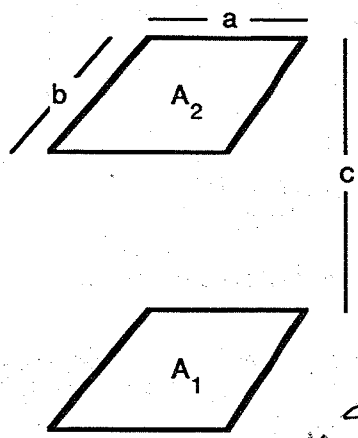
[l]L. Adams: Supporting cryogenic equipment with wood (*Chemical Engineering*, May 17, 1971).

APPENDIX 3-3
SURFACE EMITTANCE DATA FOR COMMON MATERIALS

Material	Surface Emittance	Condition
A. Metals		
Aluminum	0.04-0.06	polished, 200-600 C
	0.09	commercial, 95 C
	0.20-0.33	oxidized, 90-540 C
Brass	0.07	polished, 40 C
	0.46-0.56	oxidized, 40-260 C
Chromium	0.08-0.27	polished, 40-540 C
Copper	0.04	polished, 40 C
	0.05	tarnished, 40 C
	0.76	black oxidized, 40 C
Gold	0.02-0.04	polished, 90-590 C
Iron and steel		
mild steel	0.14-0.32	polished, 150-480 C
rolled sheet steel	0.66	new, 40 C
	0.80	oxidized, 40 C
cast iron	0.44	new, 40 C
	0.57-0.66	oxidized, 40-260 C
iron	0.61	red rust, 40 C
	0.85	heavy rust, 40 C
stainless steel	0.07-0.17	new, 40 C
	0.50-0.70	used, 230-900 C
wrought iron	0.35	new, 40 C
	0.94	oxidized, 20-360 C
Nickel	0.05-0.07	polished, 40-260 C
	0.35-0.49	oxidized, 40-260 C
Silver	0.01-0.03	polished, 40-540 C
	0.02-0.04	oxidized, 40-540 C
Tin	0.06	bright, 40 C
Zinc	0.23	galv., bright, 40 C
	0.28	galv., gray, 40 C
	0.21	dull, 40-260 C
B. Nonmetals		
Brick	0.93	red building, 40 C
	0.75	fireclay, 980 C
Carbon, soot	0.95	40 C
Concrete	0.94	rough, 40 C
Glass	0.94	smooth crown, 40 C
Ice	0.97	smooth, 0 C
	0.99	rough crystals, 0 C
	0.99	hoarfrost, -20 C
Paints	0.27-0.62	aluminum, var. ages and compositions
	0.90	black gloss
	0.89-0.97	white paint
	0.92-0.96	various colors
Paper	0.95	white, 40 C
	0.92-0.94	any color, 40 C
	0.91	roofing, 40 C
Plaster	0.92	rough, 40-260 C
Snow	0.82	-10 C
Water	0.96	>0.1 mm thick, 40 C
Wood	0.80-0.90	various, 40 C

APPENDIX 3-4
ANGLE FACTORS FOR THERMAL RADIATION HEAT TRANSFER
SEVEN SIMPLE CONFIGURATIONS

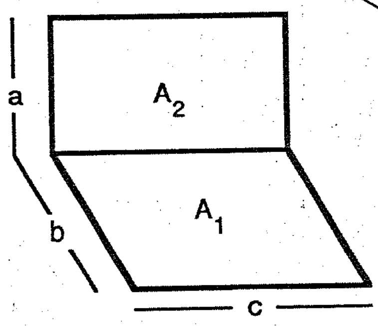
I. Configuration 1, parallel rectangular planes,
$X = a/c$; $Y = b/c$; $W^2 = 1+X^2$; $Z^2 = 1+Y^2$



$$F_{1-2}(\pi XY/2) = \ln((W^2 Z^2)/(1+X^2+Y^2))^{1/2} + YW\tan^{-1}(Y/W) +$$

$$XZ\tan^{-1}(X/Z) - Y\tan^{-1}Y - X\tan^{-1}X.$$

II. Configuration 2, rectangular planes intersecting at right angles, $X = a/b$; $Y = c/b$; $Z^2 = X^2+Y^2$

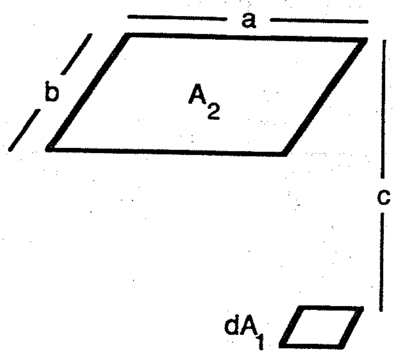


$$F_{1-2}(\pi Y) = (1/4)\ln\left(\frac{(1+X^2)(1+Y^2)}{1+Z^2}\right) + (1/4)Y^2\ln\left(\frac{Y^2(1+Z^2)}{(1+Y^2)Z^2}\right) +$$

$$(1/4)X^2\ln\left(\frac{X^2(1+Z^2)}{Z^2(1+X^2)}\right) + Y\tan^{-1}(1/Y) +$$

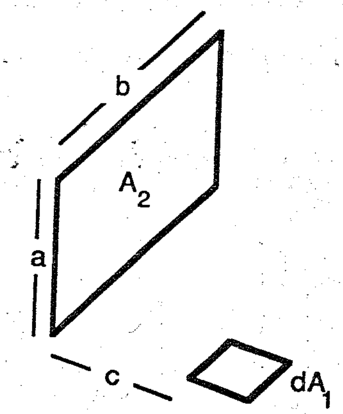
$$X\tan^{-1}(1/X) - Z\tan^{-1}(1/Z).$$

III. Configuration 3, small area facing rectangular plane, $X = a/c$; $Y = b/c$; $W^2 = (1+X^2)$; $Z^2 = (1+Y^2)$



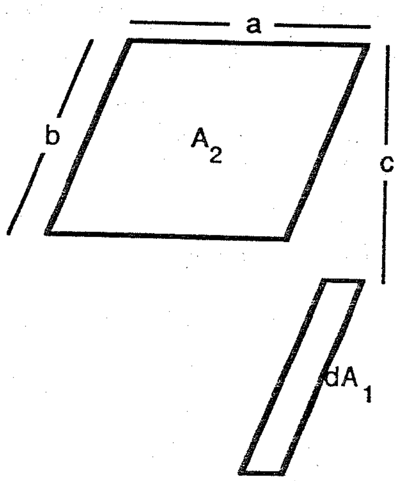
$$F_{1-2}(2\pi) = (X/W)\tan^{-1}(Y/W) + (Y/Z)\tan^{-1}(X/Z)$$

IV. Configuration 4, small area perpendicular to rectangular plane, $X = a/b$; $Y = c/b$; $Z = (X^2+Y^2)^{-1/2}$



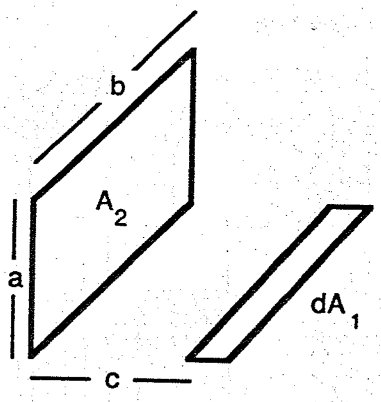
$$F_{1-2}(2\pi) = \tan^{-1}(1/Y) - ZY\tan^{-1}Z$$

V. Configuration 5, strip parallel to rectangular plane, $X = b/c$; $Y = a/c$; $W^2 = 1+X^2$; $Z^2 = 1+Y^2$.



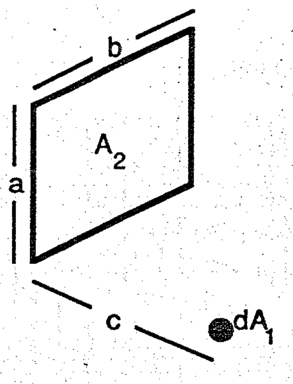
$$F_{1-2}(\pi X) = W\tan^{-1}(Y/W) - \tan^{-1}Y + (XY/Z)\tan^{-1}(X/Z)$$

VI. Configuration 6, strip perpendicular to rectangular plane, $X = a/b$; $Y = c/b$; $Z^2 = X^2+Y^2$.



$$F_{1-2}(\pi) = \tan^{-1}(1/Y) + (Y/2)\ln\left[\frac{Y^2(Z^2+1)}{Z^2(Y^2+1)}\right] - (Y/Z)\tan^{-1}(1/Z)$$

VII. Configuration 7, small sphere and a rectangular plane, $X = b/c$ and $Y = a/c$



$$F_{1-2}(4\pi) = \tan^{-1}\left[\frac{x(y - \cos\emptyset)}{\sqrt{(1+x^2+y^2-2y\cos\emptyset)}}\right] + \tan^{-1}[(x\cos\emptyset)/\sqrt{(1+x^2)}]$$

and for $\emptyset = 90°$,

$$F_{1-2}(4\pi) = \tan^{-1}[xy/\sqrt{(1+x^2+y^2)}]$$

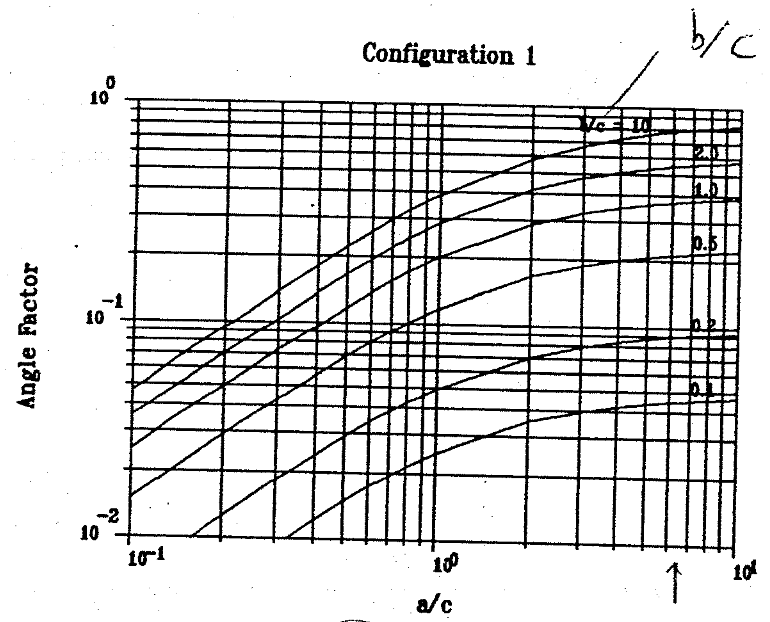
$$\lim_{x\to\infty} F_{1-2} = (1/4\pi)\tan^{-1}(y)$$

$$\lim_{\substack{x\to\infty \\ y\to\infty}} F_{1-2} = 1/8$$

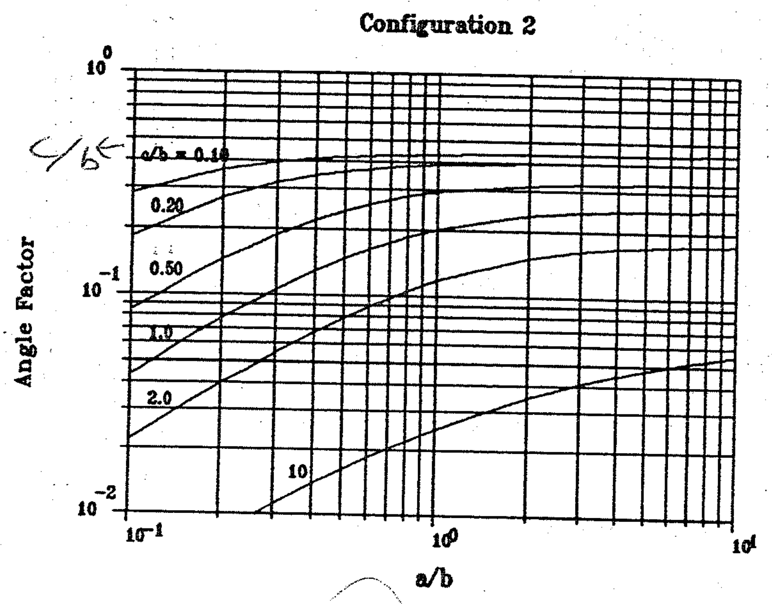
Note: angle factors for more complex configurations can be built using the above. For example, the angle factor from a small animal in a barn to the ceiling of the barn can be built using four applications of configuration 3 above. The ceiling is divided into four quadrants, intersecting above the location of the animal. The angle factor from the animal to each quadrant of the ceiling is calculated, and the four angle factors added to obtain the angle factor from the animal to the entire ceiling. The animal need not be centered below the middle of the ceiling for this technique to work.

Also note that reciprocity applies in calculating F_{2-1} for each configuration above.

For additional angle factors see, for example: Sparrow, E.M. and R.D. Cess, 1978, Radiation heat transfer, Hemisphere Publishing Corp., Washington, 366 pp.

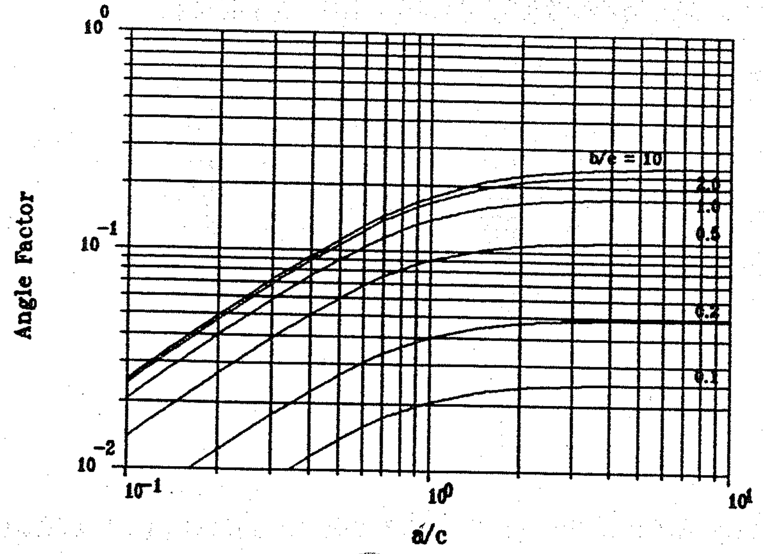


Angle factors for configuration 1, for b/c of 10, 2, 1, 0.5, 0.2 and 0.1 (top to bottom).



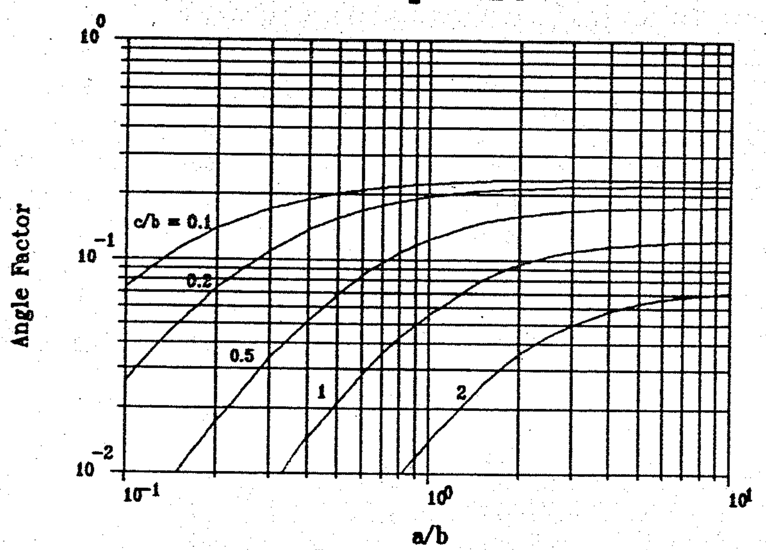
Angle factors for configuration 2, for c/b of 0.1, 0.2, 0.5, 1, 2, and 10 (top to bottom).

Configuration 3



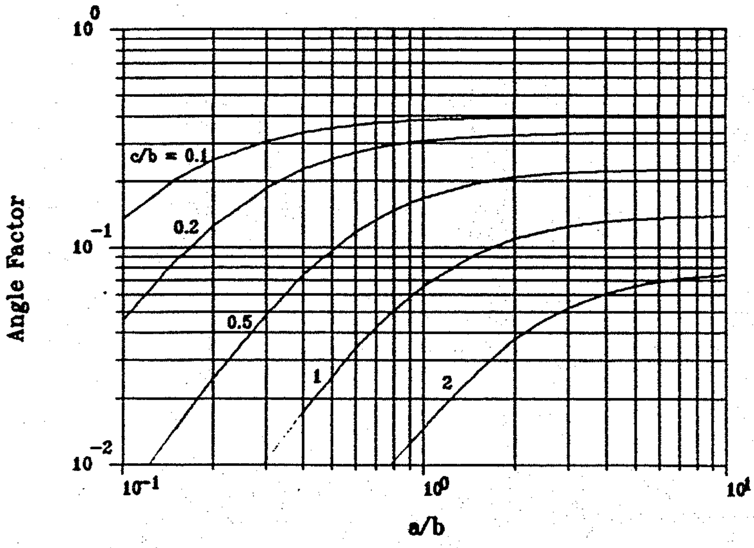
Angle factors for configuration 3, for b/c of 10, 2, 1, 0.5, 0.2 and 0.1 (top to bottom).

Configuration 4



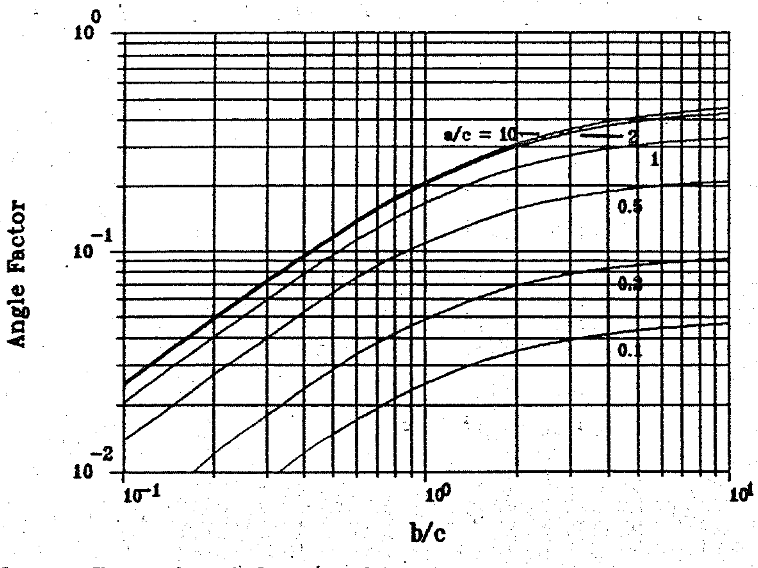
Angle factors for configuration 4, for c/b of 0.1, 0.2, 0.5, 1 and 2 (top to bottom). Factors for c/b of 10 are less than 0.01.

Configuration 6



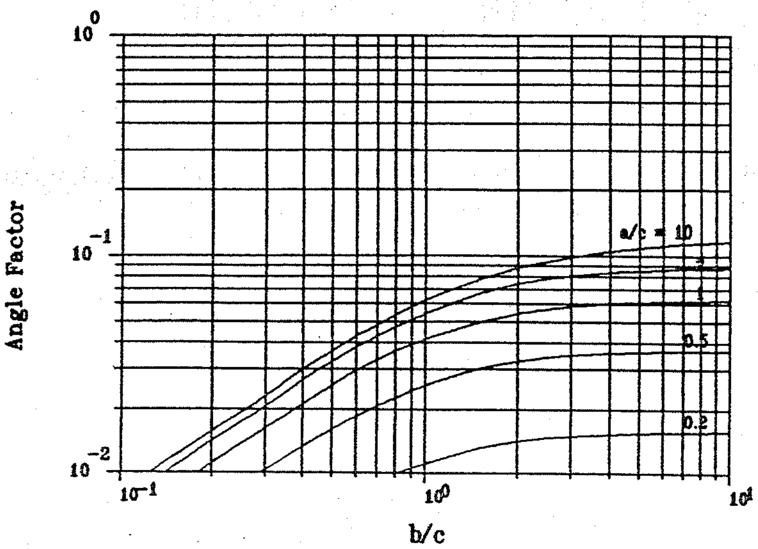
Angle factors for configuration 5, for a/c of 10, 2, 1, 0.5, 0.2 and 0.1 (top to bottom).

Configuration 5



Angle factors for configuration 6, for c/b of 0.1, 0.2, 0.5, 1 and 2 (top to bottom). Factors for c/b of 10 are less than 0.01.

Configuration 7



Angle factors for configuration 7, for a/c of 10, 2, 1, 0.5 and 0.2 (top to bottom). Factors for a/c of 0.1 are less than 0.01.

APPENDIX 3-5
SURFACE CONDUCTANCES AND RESISTANCES FOR AIR
(h IN W/M^2K; R IN M^2K/W)

A. Standard data for still air, as inside a building:

Orientation of surface	Heat Flow Direction	Surface Emittance 0.90 h	0.90 R	0.20 h	0.20 R	0.05 h	0.05 R
vertical	horizontal	8.29	0.12	4.20	0.24	3.35	0.30
horizontal	upward	9.26	0.11	5.17	0.19	4.32	0.23
	downward	6.13	0.16	2.10	0.48	1.25	0.80
45 degree slope	upward	9.09	0.11	5.00	0.20	4.15	0.24
	downward	7.50	0.13	3.41	0.29	2.56	0.39

B. Moving air, as outside a building, surface in any orientation:

Wind Velocity, m/s	h	R	
6.7	34.08	0.030	(for winter)
3.4	22.72	0.044	(for summer)

NOTES: 1. Based on data in the ASHRAE Handbook of Fundamentals.

2. Assumes air temperature and mean radiant temperature of the surroundings are identical.

3. Values are based on a surface-air temperature difference of 5.5 K, and a surface temperature of 21 C.

4. Does not apply to ventilated attics above ceilings in summer conditions.

5. Values are based on smooth surfaces. For effect of surface roughness, see the ASHRAE Handbook of Fundamentals.

6. A plane air space does not have both surface resistances and air space resistance. For air space resistance, see Appendix 3-6.

7. For more precise values of surface coefficients between still air and glass, use

$$h_i = 1.77(T_g - T_a)^{0.25} + \epsilon\sigma(T_g^4 - T_a^4)/(T_g - T_a),$$

where T_g and T_a are the glass and air temperatures, K, respectively, ϵ is the surface emittance of the glass, and h_i is the surface coefficient, W/m^2K.

APPENDIX 3-6
THERMAL RESISTANCES OF PLANE AIR SPACES
Taken from the 1985 ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta GA
Used by permission

Table 2A Thermal Resistances of Plane[a] Air Spaces[b,c]
$m^2 \cdot °C/W$

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d] (°C)	Air Space Temp Diff.[d] (°C)	12.7-mm Air Space[c] Value of E[d,e]					19.1-mm Air Space[c] Value of E[d,e]				
				0.03	0.05	0.2	0.5	0.82	0.03	0.05	0.2	0.5	0.82
Horiz.	Up ↑	32.2	5.6	0.37	0.36	0.27	0.17	0.13	0.41	0.39	0.28	0.18	0.13
		10.0	16.7	0.29	0.28	0.23	0.17	0.13	0.30	0.29	0.24	0.17	0.14
		10.0	5.6	0.37	0.36	0.28	0.20	0.15	0.40	0.39	0.30	0.20	0.15
		-17.8	11.1	0.30	0.30	0.26	0.20	0.16	0.32	0.32	0.27	0.20	0.16
		-17.8	5.6	0.37	0.36	0.30	0.22	0.18	0.39	0.38	0.31	0.23	0.18
		-45.6	11.1	0.30	0.29	0.26	0.22	0.18	0.31	0.31	0.27	0.22	0.19
		-45.6	5.6	0.36	0.35	0.31	0.25	0.20	0.38	0.37	0.32	0.26	0.21
45° Slope	Up ↗	32.2	5.6	0.43	0.41	0.29	0.19	0.13	0.52	0.49	0.33	0.20	0.14
		10.0	16.7	0.36	0.35	0.27	0.19	0.15	0.35	0.34	0.27	0.19	0.14
		10.0	5.6	0.45	0.43	0.32	0.21	0.16	0.51	0.48	0.35	0.23	0.17
		-17.8	11.1	0.39	0.38	0.31	0.23	0.18	0.37	0.36	0.30	0.23	0.18
		-17.8	5.6	0.46	0.45	0.36	0.25	0.19	0.48	0.46	0.37	0.26	0.20
		-45.6	11.1	0.37	0.36	0.31	0.25	0.21	0.36	0.35	0.31	0.25	0.20
		-45.6	5.6	0.46	0.45	0.38	0.29	0.23	0.45	0.43	0.37	0.25	0.23
Vertical	Horiz. →	32.2	5.6	0.43	0.41	0.29	0.19	0.14	0.62	0.57	0.37	0.21	0.15
		10.0	16.7	0.45	0.43	0.32	0.22	0.16	0.51	0.49	0.35	0.23	0.17
		10.0	5.6	0.47	0.45	0.33	0.22	0.16	0.65	0.61	0.41	0.25	0.18
		-17.8	11.1	0.50	0.48	0.38	0.26	0.20	0.55	0.53	0.41	0.28	0.21
		-17.8	5.6	0.52	0.50	0.39	0.27	0.20	0.66	0.63	0.46	0.30	0.22
		-45.6	11.1	0.51	0.50	0.41	0.31	0.24	0.51	0.50	0.42	0.31	0.24
		-45.6	5.6	0.56	0.55	0.45	0.33	0.26	0.65	0.63	0.51	0.36	0.27
45° Slope	Down ↘	32.2	5.6	0.44	0.41	0.29	0.19	0.14	0.62	0.58	0.37	0.21	0.15
		10.0	16.7	0.46	0.44	0.33	0.22	0.16	0.60	0.57	0.39	0.24	0.17
		10.0	5.6	0.47	0.45	0.33	0.22	0.16	0.67	0.63	0.42	0.26	0.18
		-17.8	11.1	0.51	0.49	0.39	0.27	0.20	0.66	0.63	0.46	0.30	0.22
		-17.8	5.6	0.52	0.50	0.39	0.27	0.20	0.73	0.69	0.49	0.32	0.23
		-45.6	11.1	0.56	0.54	0.44	0.33	0.25	0.67	0.64	0.51	0.36	0.28
		-45.6	5.6	0.57	0.56	0.45	0.33	0.26	0.77	0.74	0.57	0.39	0.29
Horiz.	Down ↓	32.2	5.6	0.44	0.41	0.29	0.19	0.14	0.62	0.58	0.37	0.21	0.15
		10.0	16.7	0.47	0.45	0.33	0.22	0.16	0.66	0.62	0.42	0.25	0.18
		10.0	5.6	0.47	0.45	0.33	0.22	0.16	0.68	0.63	0.42	0.26	0.18
		-17.8	11.1	0.52	0.50	0.39	0.27	0.20	0.74	0.70	0.50	0.32	0.23
		-17.8	5.6	0.52	0.50	0.39	0.27	0.20	0.75	0.71	0.51	0.32	0.23
		-45.6	11.1	0.57	0.55	0.45	0.33	0.26	0.81	0.78	0.59	0.40	0.30
		-45.6	5.6	0.58	0.56	0.46	0.33	0.26	0.83	0.79	0.60	0.40	0.30

88.9

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d] (°C)	Air Space Temp Diff.[d] (°C)	38.1 mm Air Space[c] Value of E[d,e]					88.9 mm Air Space[c] Value of E[d,e]				
				0.03	0.05	0.2	0.5	0.82	0.03	0.05	0.2	0.5	0.82
Horiz	Up ↑	32.2	5.6	0.45	0.42	0.30	0.19	0.14	0.50	0.47	0.32	0.20	0.14
		10.0	16.7	0.33	0.32	0.26	0.18	0.14	0.27	0.35	0.28	0.19	0.15
		10.0	5.6	0.44	0.42	0.32	0.21	0.16	0.49	0.47	0.34	0.23	0.16
		-17.8	11.1	0.35	0.34	0.29	0.22	0.17	0.40	0.38	0.32	0.23	0.18
		-17.8	5.6	0.43	0.41	0.33	0.24	0.19	0.48	0.46	0.36	0.26	0.20
		-45.6	11.1	0.34	0.34	0.30	0.24	0.20	0.39	0.38	0.33	0.26	0.21
		-45.6	5.6	0.42	0.41	0.35	0.27	0.22	0.47	0.45	0.38	0.29	0.23
45° Slope	Up ↗	32.2	5.6	0.51	0.48	0.33	0.20	0.14	0.56	0.52	0.35	0.21	0.14
		10.0	16.7	0.38	0.36	0.28	0.20	0.15	0.40	0.38	0.29	0.20	0.15
		10.0	5.6	0.51	0.48	0.35	0.23	0.17	0.55	0.52	0.37	0.24	0.17
		-17.8	11.1	0.40	0.39	0.32	0.24	0.18	0.43	0.41	0.33	0.24	0.19
		-17.8	5.6	0.49	0.47	0.37	0.26	0.20	0.52	0.51	0.39	0.27	0.20
		-45.6	11.1	0.39	0.38	0.33	0.26	0.21	0.41	0.40	0.35	0.27	0.22
		-45.6	5.6	0.48	0.46	0.39	0.30	0.24	0.51	0.49	0.41	0.31	0.24
Vertical	Horiz. →	32.2	5.6	0.70	0.64	0.40	0.22	0.15	0.65	0.60	0.38	0.22	0.15
		10.0	16.7	0.45	0.43	0.32	0.22	0.16	0.47	0.45	0.33	0.22	0.16
		10.0	5.6	0.67	0.62	0.42	0.26	0.18	0.64	0.60	0.41	0.25	0.18
		-17.8	11.1	0.49	0.47	0.37	0.26	0.20	0.51	0.49	0.38	0.27	0.20
		-17.8	5.6	0.62	0.59	0.44	0.29	0.22	0.61	0.59	0.44	0.29	0.22
		-45.6	11.1	0.46	0.45	0.38	0.29	0.23	0.50	0.48	0.40	0.30	0.24
		-45.6	5.6	0.58	0.56	0.46	0.34	0.26	0.60	0.58	0.47	0.34	0.26
45° Slope	Down ↘	32.2	5.6	0.89	0.80	0.45	0.24	0.16	0.85	0.76	0.44	0.24	0.16
		10.0	16.7	0.63	0.59	0.41	0.25	0.18	0.62	0.58	0.40	0.25	0.18
		10.0	5.6	0.90	0.82	0.50	0.28	0.19	0.83	0.77	0.48	0.28	0.19
		-17.8	11.1	0.68	0.64	0.47	0.31	0.22	0.67	0.64	0.47	0.31	0.22
		-17.8	5.6	0.87	0.81	0.56	0.34	0.24	0.81	0.76	0.53	0.33	0.24
		-45.6	11.1	0.54	0.62	0.49	0.35	0.27	0.66	0.64	0.51	0.36	0.28
		-45.6	5.6	0.82	0.79	0.60	0.40	0.30	0.79	0.76	0.58	0.40	0.30
Horiz.	Down ↓	32.2	5.6	1.07	0.94	0.49	0.25	0.17	1.77	1.44	0.60	0.28	0.18
		10.0	16.7	1.10	0.99	0.56	0.30	0.20	1.69	1.44	0.68	0.33	0.21
		10.0	5.6	1.16	1.04	0.58	0.30	0.20	1.96	1.63	0.72	0.34	0.22
		-17.8	11.1	1.24	1.13	0.69	0.39	0.26	1.92	1.68	0.86	0.43	0.29
		-17.8	5.6	1.29	1.17	0.70	0.39	0.27	2.11	1.82	0.89	0.44	0.29
		-45.6	11.1	1.36	1.27	0.84	0.50	0.35	2.05	1.85	1.06	0.57	0.38
		-45.6	5.6	1.42	1.32	0.86	0.51	0.35	2.28	2.03	1.12	0.59	0.39

Value of E 由 0.82 降至 0.05 / 0.03，熱阻可增加近4倍 5 .5

APPENDIX 4-1
SKETCHES OF COMMON WALL CONSTRUCTION TYPES
Taken in part from the 1985 ASHRAE Handbook of Fundamentals,
American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta GA
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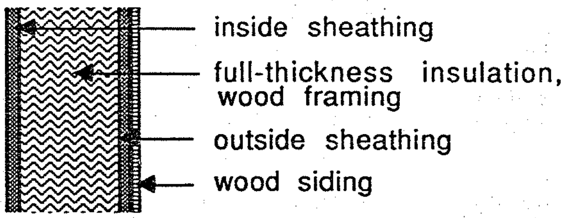
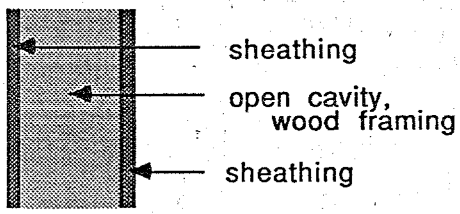
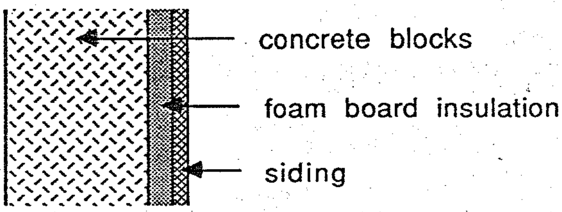
standard wood-framed outside wall



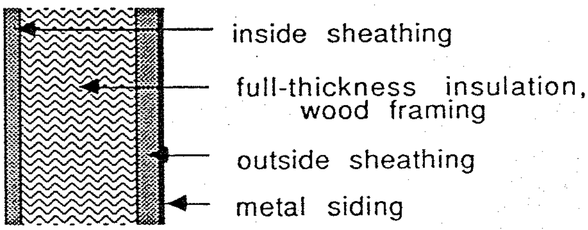
standard wood-framed partition wall



insulated concrete block wall



metal-sided wall with wood framing



APPENDIX 4-2
OVERALL THERMAL RESISTANCES OF GLAZINGS

A. Windows (vertical), no indoor shades, no storm sash

Type	Thermal Resistance, m^2K/W Winter	Summer
Single glass, clear,		
surface emittance of 0.84	0.16	0.17
0.60	0.17	0.18
0.40	0.19	0.20
0.20	0.22	0.23
Insulating glass, double,		
5 mm air space, 3 mm glass	0.29	0.27
6 mm air space, 3 mm glass	0.30	0.29
13 mm air space, 6 mm glass	0.36	0.31
Insulating glass, triple,		
6 mm air space, 3 mm glass	0.45	0.40

B. Windows (vertical), no indoor shades, glass outdoor storm sash with 25 mm air space

Type	Thermal Resistance, m^2K/W Winter	Summer
Single glass, clear,		
surface emittance of 0.84	0.43	0.36
0.60	0.37	0.29
0.40	0.40	0.29
0.20	0.43	0.36
Insulating glass, double,		
5 mm air space, 3 mm glass	0.48	0.43
6 mm air space, 3 mm glass	0.50	0.45
13 mm air space, 6 mm glass	0.56	0.45
Insulating glass, triple,		
6 mm air space, 3 mm glass	0.67	0.56

C. Adjustment factors for windows (multiply R-values in parts A and B by these factors)

	Wood Frame	Metal Frame
Single glass	1.05 - 1.18	0.91 - 1.00
Double glass	1.00 - 1.11	0.77 - 0.83
Triple glass	1.00 - 1.05	0.67 - 0.77
Storm sash applied over single glass	1.00 - 1.11	0.71 - 0.83
Storm sash applied over double or triple glass	1.00 - 1.05	0.67 - 0.77

D. Greenhouse Glazings

Material (includes surface resistance)	Unit Area Thermal Resistance, m^2K/W
Glass, single	0.16
Glass, double, 6 mm air space	0.25
Polyethylene film, single	0.14
Polyethylene film, double, 100 mm space	0.25
Fiberglass reinforced panel	0.15
Double panel, acrylic or polycarbonate	0.35

Notes:

a. Winter conditions are −18 C outdoor air, 21 C indoor air, and 24 km/hr (6.67 m/s) wind speed.
b. Summer conditions are 32 C outdoor air, 24 C indoor air, solar radiation of 782 W/m^2, and 12 km/hr (3.33 m/s) wind speed.
c. Manufacturer's data should be consulted for more accurate data for specific products, especially for thermally improved windows.
d. Data obtained from the ASHRAE Handbook of Fundamentals. Consult that reference for more detail and other glazing configurations.

APPENDIX 4-3
OVERALL THERMAL RESISTANCES OF DOORS

A. Wood doors, no storm doors

Type	Thermal Resistance, m^2K/W Winter	Summer
Flush doors		
hollow core, 35 mm thick	0.37	0.39
hollow core, 44 mm thick	0.38	0.40
with single glazing	0.28	0.33
solid core, 35 mm thick	0.45	0.46
solid core, 44 mm thick	0.53	0.55
with single glazing	0.38	0.40
with double glazing	0.48	0.49
solid core, 57 mm thick	0.65	0.68
with single glazing	0.43	0.44
with double glazing	0.53	0.55
Panel doors		
11 mm panels, 35 mm thick door	0.31	0.33
11 mm panels, 44 mm thick door	0.33	0.34
with single glazing	0.26	0.28
with double glazing	0.35	0.37
29 mm panels, 44 mm thick door	0.45	0.46
with single glazing	0.29	0.30
with double glazing	0.40	0.42

B. Wood doors, with storm doors, winter conditions only

Type	Thermal Resistance, m^2K/W wood storm door	metal storm door
Flush doors		
hollow core, 35 mm thick	0.59	0.55
hollow core, 44 mm thick	0.61	0.55
with single glazing	0.53	0.49
solid core, 35 mm thick	0.68	0.63
solid core, 44 mm thick		
with single glazing	0.61	0.55
with double glazing	0.70	0.65
solid core, 57 mm thick	0.88	0.84
with single glazing	0.65	0.61
with double glazing	0.76	0.70
Panel doors		
11 mm panels, 35 mm thick door	0.53	0.48
11 mm panels, 44 mm thick door	0.55	0.49
with single glazing	0.49	0.43
with double glazing	0.57	0.52
29 mm panels, 44 mm thick door	0.68	0.63
with single glazing	0.52	0.46
with double glazing	0.63	0.57

C. Steel doors

Type	Thermal Resistance, m^2K/W Winter	Summer
Solid urethane foam core, no thermal break, 44 mm thick, no storm door	0.44	0.45
Solid urethane foam core, with thermal break, 44 mm thick,		
no storm door	0.93	0.98
wood storm door	1.10	
metal storm door	1.03	

Notes:

a. Data is based on nominal door size of 1.12 m by 2.03 m.
b. Winter conditions are −17.8 C outdoor air temperature, 21.1 C indoor air temperature, and 24 km/hr (6.67 m/s) wind speed.
c. Summer conditions are 31.7 C outdoor air temperature, 23.9 C indoor air temperature, and 12 km/hr (3.33 m/s) wind speed.
d. Wood storm door values are for 50% glass area; metal storm door values are for any glass area.
e. Flush door values are for 17% glass area; double glazing with 6.35 mm air space.
f. Panel door values are for 55% panel area; glazed panel door values are for 33% glass area and 22% panel area; double glazing with 6.35 mm air space.
g. Data obtained from the ASHRAE Handbook of Fundamentals.

APPENDIX 5-1
ANIMAL HEAT AND MOISTURE PRODUCTION

Moisture production (MP), latent heat production (LHP), sensible heat production (SHP) and total heat production (THP) of livestock. Adapted from data reference D270.4 of the American Society of Agricultural Engineers, and other sources. Heat of vaporization of water taken as 2410 kJ/kg (at animal body temperature). All data are taken from housing studies.

NOTE: Although these data are presented as design numbers; such data are frequently updated. Actual designs of environmental control systems should incorporate the latest research information. Such data would be available, for example, in reports in the Transactions of the American Society of Agricultural Engineers, Canadian Agricultural Engineering, and the Journal of Agricultural Engineering Research.

Animal	Air Temperature	MP mg/kg s	LHP W/kg	SHP W/kg	THP W/kg
Dairy cow,	-1 C	0.21	0.5	1.9	2.4
500 kg	10	0.28	0.7	1.5	2.2
	15	0.36	0.9	1.2	2.1
	21	0.36	0.9	1.1	2.0
	27	0.50	1.3	0.6	1.9
Brown Swiss and					
Holstein, 16 wk	10	0.56	1.4	2.3	3.7
	27	0.83	2.0	1.5	3.5
32 wk	10	0.33	0.9	1.5	2.4
	27	0.61	1.5	1.1	2.6
48 wk	10	0.33	0.7	1.5	2.2
	27	0.53	1.2	1.0	2.2
Jersey, 16 wk	10	0.67	1.6	2.5	4.1
	27	1.06	2.5	1.4	3.9
32 wk	10	0.42	1.0	1.8	2.8
	27	0.69	1.7	1.0	2.7
48 wk	10	0.36	0.9	1.6	2.5
	27	0.64	1.2	1.0	2.2
Calf, Ayreshire					
male, 39 kg	3	0.19	0.4	2.5	2.9
	23	0.19	0.4	2.0	2.4
40 kg	3	0.19	0.4	2.4	2.8
	23	0.19	0.4	1.9	2.3
45 kg	3	0.19	0.4	2.6	3.0
	23	0.19	0.4	2.0	2.4
Laying hen,	8	0.72	1.7	5.2	6.9
leghorn,	12	0.82	2.0	4.6	6.6
1.8 kg (a)	18	0.97	2.3	4.5	6.8
	28	1.19	2.9	3.7	6.6
Broilers, 0.1 kg	29	6.11	15.0	4.5	19.5
0.4 kg	24	3.47	8.5	6.5	15.0
0.7 kg	16	2.92	7.0	6.0	13.0
	27	2.92	7.0	3.0	10.0
1.0 kg	16	2.22	5.5	5.0	10.5
	27	2.64	6.5	3.0	9.5
1.5 kg	16	2.08	5.0	4.5	9.5
	27	2.50	6.0	3.0	9.0
2.0 kg	16	1.81	4.5	4.0	8.5
Growing/finishing	5	0.69	1.7	4.2	5.9
pigs, solid	10	0.75	1.4	4.0	5.4
floor, 20 kg	15	0.86	2.0	3.0	5.0
	20	1.03	2.5	2.3	4.8
	25	1.31	3.1	1.6	4.8
	30	1.75	4.2	0.6	4.8

40 kg	5	0.42	1.0	3.0	4.0
	10	0.44	1.1	2.5	3.6
	15	0.53	1.3	2.0	3.3
	20	0.61	1.5	1.6	3.1
	25	0.78	1.8	1.2	3.0
	30	1.00	2.4	0.6	3.0
60 kg	5	0.33	0.8	2.5	3.3
	10	0.36	0.9	2.0	2.9
	15	0.39	0.9	1.7	2.6
	20	0.47	1.1	1.3	2.4
	25	0.56	1.3	1.0	2.3
	30	0.75	1.8	0.5	2.3
80 kg	5	0.31	0.7	2.2	2.9
	10	0.31	0.7	1.8	2.5
	15	0.33	0.8	1.5	2.3
	20	0.39	0.9	1.2	2.1
	25	0.47	1.15	0.85	2.0
	30	0.61	1.4	0.5	1.9
100 kg	5	0.26	0.6	2.0	2.6
	10	0.28	0.7	1.6	2.3
	15	0.31	0.7	1.3	2.0
	20	0.33	0.8	1.1	1.9
	25	0.39	1.0	0.8	1.8
	30	0.50	1.2	0.5	1.7
Gilts, sows and boars, solid floor, 140 kg	5	0.22	0.5	1.8	2.3
	10	0.22	0.5	1.5	2.0
	15	0.23	0.6	1.2	1.8
	20	0.26	0.6	1.0	1.6
	25	0.31	0.7	0.8	1.5
	30	0.36	0.9	0.5	1.4
180 kg	5	0.18	0.4	1.7	2.1
	10	0.18	0.4	1.4	1.8
	15	0.18	0.4	1.2	1.6
	20	0.19	0.4	1.0	1.4
	25	0.22	0.5	0.8	1.3
	30	0.27	0.7	0.6	1.3

a. Moisture production estimated from data in ASAE data D270.4, then scaled according to:

Timmons, M.B. and R.S. Gates. 1985. Risk analysis methodology applied to environmental control options for animal housing: Part I, poultry layers. Paper No. 85-4507, American Society of Agricultural Engineers, St. Joseph MI.

Moisture calculated as equal to respired moisture, plus 13% of defecated moisture, with the sum increased by 15% because of the higher egg production of today's laying hens (the original data was published in 1966). The sensible heat production is also scaled by 15% for the same reason.

APPENDIX 6-1
DESIGN AIR TEMPERATURES FOR SELECTED STATIONS

	Winter Air Temp.		Summer Air Temp.		Summer MCWB		Summer DWB	
Station	99%	97.5%	1%	2.5%	1%	2.5%	1%	2.5%
Alabama								
Auburn	-8	-6	36	~~24~~ 34	25	24	26	26
Huntsville	-12	-9	35	34	24	23	26	25
Mobile	-4	-2	35	34	25	25	27	26
Alaska								
Anchorage	-31	-28	20	19	15	14	16	15
Fairbanks	-46	-44	28	26	17	16	18	17
Juneau	-20	-17	23	21	16	14	16	15
Arizona								
Flagstaff	-19	-16	29	28	13	13	17	16
Phoenix	-1	1	43	42	22	22	24	24
Tucson	-2	0	40	39	19	19	22	22
Arkansas								
Fayetteville	-14	-11	36	34	24	23	25	24
Hot Springs	-8	-5	38	36	25	25	27	26
Little Rock	-9	-7	37	36	26	25	27	26
California								
Bakersfield	-1	0	40	38	21	21	23	22
Riverside	-2	0	38	37	20	19	22	22
Ukiah	-3	-2	37	35	21	20	21	20
Colorado								
Boulder	-17	-13	34	33	15	15	18	17
Denver	-21	-17	34	33	15	15	18	17
Fort Collins	-23	-20	34	33	15	15	18	17
Connecticut								
Bridgeport	-14	-13	30	29	23	22	24	23
New Haven	-16	-14	31	29	24	23	24	24
Waterbury	-20	-17	31	29	22	21	24	23
Delaware								
Dover	-12	-9	33	32	24	24	26	25
Wilmington	-12	-10	33	32	23	23	25	24
Florida								
Gainesville	-2	-1	35	34	25	25	27	26
Orlando	2	3	34	34	24	24	26	26
Tampa	2	4	33	33	25	25	26	26
Georgia								
Atlanta	-8	-6	34	33	23	23	25	24
Brunswick	-2	0	33	32	26	26	27	26
Columbus	-6	-4	35	34	24	24	26	26
Hawaii								
Hilo	16	17	29	28	23	22	24	23
Honolulu	17	17	31	30	23	23	24	24
Idaho								
Boise	-16	-12	36	34	18	18	20	19
Moscow	-22	-18	32	31	17	17	18	18
Twin Falls	-19	-17	37	35	16	16	18	17
Illinois								
Chicago	-21	-18	34	33	23	23	25	24
Peoria	-22	-20	33	32	24	23	26	24
Springfield	-19	-17	34	33	24	23	26	25
Indiana								
Evansville	-16	-13	35	34	24	24	26	26
Fort Wayne	-20	-17	33	32	23	22	25	24
Indianapolis	-19	-17	33	32	23	23	26	24
Iowa								
Ames	-24	-21	34	32	24	23	26	24
Des Moines	-23	-21	34	33	24	23	26	25
Ottumwa	-22	-20	34	33	24	23	26	25
Kansas								
Chanute	-16	-14	38	36	23	23	26	25
Hutchinson	-16	-13	39	37	22	22	25	24
Liberal	-17	-14	37	36	20	20	23	22
Kentucky								
Ashland	-15	-12	34	33	24	23	26	25
Lexington	-16	-13	34	33	23	23	25	24
Madisonville	-15	-12	36	34	24	24	26	26

Louisana								
Bogalusa	-4	-2	35	34	25	25	27	27
Minden	-7	-4	37	36	25	24	26	26
Shreveport	-7	-4	37	36	25	24	26	26
Maine								
Augusta	-22	-19	31	29	23	21	23	22
Caribou	-28	-25	29	27	21	19	22	21
Portland	-21	-18	31	29	22	22	23	22
Maryland								
Cumberland	-14	-12	33	32	24	23	25	24
Frederick	-13	-11	34	33	24	24	26	25
Salisbury	-11	-9	34	33	24	24	26	25
Massachusetts								
Fall River	-15	-13	31	29	22	22	23	23
Gloucester	-17	-15	32	30	23	22	24	23
Springfield	-21	-18	32	31	22	22	24	23
Michigan								
Alpena	-24	-21	32	29	21	21	23	22
Detroit	-16	-14	33	31	23	22	24	23
Lansing	-19	-17	32	31	23	22	24	23
Minnesota								
Duluth	-29	-27	29	28	21	20	22	21
Rochester	-27	-24	32	31	23	22	25	24
St. Cloud	-26	-24	33	31	23	22	24	23
Mississippi								
Biloxi	-2	-1	34	33	26	26	28	27
Jackson	-6	-4	36	35	24	24	26	26
Tupelo	-10	-7	36	34	25	25	27	26
Missouri								
Joplin	-14	-12	38	36	23	23	26	25
Rolla	-16	-13	34	33	25	24	26	25
Springfield	16	-13	36	34	23	23	26	25
Montana								
Bozeman	-29	-26	32	31	16	16	17	17
Cut Bank	-32	-29	31	29	16	16	18	17
Lewiston	-30	-27	32	31	17	16	18	17
Nebraska								
Fremont	-21	-19	37	35	24	23	26	25
Lincoln	-21	-19	37	35	24	23	26	25
Scottsbluff	-22	-19	35	33	18	18	21	20
Nevada								
Carson City	-16	-13	34	33	16	15	17	16
Ely	-23	-20	31	29	13	13	16	15
Las Vegas	-4	-2	42	41	19	18	22	21
New Hampshire								
Berlin	-26	-23	31	29	22	21	23	22
Concord	-22	-19	32	31	22	21	23	23
Portsmouth	-19	-17	32	29	23	22	24	23
New Jersey								
Paterson	-14	-12	34	33	23	23	25	24
Trenton	-12	-10	33	31	24	23	26	24
Vineland	-13	-12	33	32	24	23	26	24
New Mexico								
Albuquerque	-11	-9	36	34	16	16	19	18
Gallup	-18	-15	32	32	15	14	18	17
Roswell	-11	-8	38	37	19	19	22	21
New York								
Albany	-21	-18	33	31	23	22	24	23
Ithaca	-21	-18	31	29	22	22	23	23
Riverhead	-14	-12	30	28	22	22	24	23
North Carolina								
Raleigh	-9	-7	34	33	24	24	26	25
Rocky Mount	-8	-6	34	33	24	24	26	26
Wilmington	-5	-3	34	33	26	26	27	27
North Dakota								
Bismarck	-31	-28	35	33	20	20	23	22
Grand Forks	-32	-30	33	31	21	21	23	22
Minot	-31	-29	33	32	20	19	22	21
Ohio								
Cincinnati	-17	-14	33	32	23	22	25	24
Cleveland	-18	-15	33	32	23	23	25	24
Columbus	-18	-15	33	32	23	22	25	24
Oklahoma								
McAlester	-10	-7	37	36	23	23	25	24
Stillwater	-13	-11	38	36	23	23	25	24
Tulsa	-13	-11	38	37	23	24	26	26

Oregon								
Corvallis	-8	-6	33	32	19	19	21	19
Medford	-7	-5	37	34	20	19	21	20
Salem	-8	-5	33	31	20	19	21	20
Pennsylvania								
Erie	-16	-13	31	29	23	22	24	23
Harrisburg	-14	-12	34	33	24	23	25	24
Philadelphia	-12	-10	34	32	24	23	25	24
Rhode Island								
Providence	-15	-13	32	30	23	22	24	23
South Carolina								
Charleston	-4	-2	34	33	26	26	27	27
Columbia	-7	-4	36	35	24	24	26	26
Spartanburg	-8	-6	34	33	23	23	25	24
South Dakota								
Brookings	-27	-25	35	33	23	22	25	24
Peirre	-26	-23	37	35	22	22	24	23
Rapid City	-24	-22	35	33	19	18	22	21
Tennessee								
Athens	-11	-8	35	33	23	23	25	24
Knoxville	-11	-7	34	33	23	23	26	26
Memphis	-11	-8	37	35	25	24	27	26
Texas								
Amarillo	-14	-12	37	35	19	19	22	21
Brownsville	2	4	34	34	25	25	27	26
Plainview	-13	-11	37	36	20	20	22	22
Utah								
Logan	-19	-17	34	33	17	16	18	18
Provo	-17	-14	37	36	17	17	19	18
Richfield	-19	-15	34	33	16	16	19	18
Vermont								
Barre	-27	-24	29	27	22	21	23	22
Burlington	-24	-22	31	29	22	21	23	22
Rutland	-25	-22	31	29	22	21	23	22
Virginia								
Norfolk	-7	-6	34	33	25	24	26	26
Richmond	-10	-8	35	33	24	24	26	26
Roanoke	-11	-9	34	33	22	22	24	23
Washington								
Bellingham	-12	-9	27	25	19	18	20	18
Spokane	-21	-17	34	32	18	17	18	18
Yakima	-19	-15	36	34	18	18	20	19
West Virginia								
Clarksburg	-14	-12	33	32	23	23	24	24
Huntington	-15	-12	34	33	24	23	26	25
Wheeling	-17	-15	32	30	22	22	23	23
Wisconsin								
Ashland	-29	-27	29	28	21	20	22	21
Beloit	-22	-19	33	32	24	24	26	25
Madison	-24	-22	33	31	23	23	25	24
Wyoming								
Cheyenne	-23	-18	32	30	14	14	17	17
Rawlins	-24	-20	30	28	14	14	17	16
Sheridan	-26	-22	34	33	17	17	19	18
Alberta								
Calgary	-33	-31	29	27	17	16	18	17
Edmonton	-34	-32	29	28	19	18	20	19
Medicine Hat	-34	-31	34	32	19	18	21	20
British Columbia								
Dawson Creek	-38	-36	28	26	18	17	19	18
Trail	-21	-18	33	32	19	18	20	19
Vancouver	-9	-7	26	25	19	18	20	19
Manitoba								
Churchill	-41	-39	27	25	19	18	19	18
Dauphin	-35	-33	31	29	22	21	23	22
Winnipeg	-34	-33	32	30	23	22	24	23
New Brunswick								
Edmundston	-29	-27	31	28	21	20	23	22
Fredericton	-27	-24	32	29	22	21	23	22
Saint John	-24	-22	27	25	19	18	21	20
Newfoundland								
Gander	-21	-18	28	26	19	18	21	19
Goose Bay	-33	-31	29	27	19	18	20	19

Northwest Territories								
Inuvik	-49	-47	26	25	17	16	18	17
Nova Scotia								
Halifax	-17	-15	26	24	19	18	21	19
Sydney	-18	-16	28	27	21	20	22	21
Yarmouth	-15	-13	23	22	18	18	20	19
Ontario								
Hamilton	-19	-17	31	30	23	22	24	23
Sarnia	-18	-16	31	30	23	22	24	23
Timmins	-36	-34	31	29	21	20	22	21
Prince Edward Island								
Summerside	-22	-20	27	26	21	20	22	21
Quebec								
Hull	-28	-26	32	31	22	22	24	23
Montreal	-27	-23	31	29	23	22	24	23
Quebec	-28	-26	31	29	22	21	23	22
Saskatchewan								
Regina	-36	-34	33	31	21	20	22	21
Saskatoon	-37	-35	32	30	20	19	21	20
Yorkton	-37	-34	31	29	21	20	22	21
Yukon Territory								
Whitehorse	-43	-42	27	25	15	14	16	15

a. Mean Coincident Wet Bulb Temperature
b. Design Wet Bulb Temperature

Data abstracted from the ASHRAE Handbook of Fundamentals

APPENDIX 6-2
WEATHER BIN DATA FOR SELECTED STATIONS

Data listed are hours per year during which air temperature is expected to be in the range indicated. Data are for stations with 24 hourly observations per day for at least 5 years.

Temperature Ranges, C (hrs)

Station	−∞ / −34.4	−34.4 / −28.9	−28.9 / −23.3	−23.3 / −17.8	−17.8 / −12.2	−12.2 / −6.7	−6.7 / −1.1	−1.1 / 4.4
Huntsville Alabama	0	0	0	2	16	79	350	871
Anchorage, Alaska	1	9	68	271	554	921	1361	1528
Tucson, Arizona	0	0	0	0	0	1	25	296
Little Rock, Arkansas	0	0	0	0	7	60	334	859
Merced, California	0	0	0	0	0	0	33	556
Denver, Colorado	0	1	8	35	137	380	948	1427
Dover, Delaware	0	0	0	0	17	169	611	1387
Orlando, Florida	0	0	0	0	0	0	3	82

Station	4.4 / 10.0	10.0 / 15.6	15.6 / 21.1	21.1 / 26.7	26.7 / 32.2	32.2 / 37.8	37.8 / +∞
Huntsville Alabama	1182	1291	1645	1975	1076	273	0
Anchorage, Alaska	1431	1932	629	53	2	0	0
Tucson, Arizona	1042	1589	1584	1830	1452	829	112
Little Rock, Arkansas	1217	1311	1574	1939	1143	311	5
Merced, California	1585	2198	1769	1289	822	446	62
Denver, Colorado	1481	1513	1411	876	465	78	0
Dover, Delaware	1430	1369	1573	1547	591	65	1
Orlando, Florida	413	1011	1949	3435	1667	200	0

80%的水牆(Evaporative cooling pad)位於長邊，高 2.5 m，長 100 m，空氣經過水牆通過溫室

Atlanta,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Georgia	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	2	32	185	775

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	1274	1483	1832	2041	979	156	1

Honolulu,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Hawaii	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	0	0	0	0

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	0	20	1175	5614	1950	1	0

Pocatello,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Idaho	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	1	15	43	162	415	1057	1738

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	1483	1338	1101	796	491	120	0

Springfield,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Illinois	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	2	35	144	314	797	1415

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	1116	1121	1433	1469	765	147	2

South Bend,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Indiana	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	3	38	141	405	1025	1572

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	1148	1199	1479	1211	483	56	0

Des Moines,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Iowa	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	16	114	273	506	929	1343

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	993	1139	1475	1273	593	104	2

Wichita,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Kansas	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	8	69	266	662	1154

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	1184	1219	1506	1528	857	276	27

Fort Knox,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Kentucky	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	1	13	65	213	649	1209

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	1211	1279	1637	1621	779	83	0

New Orleans,	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Louisiana	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	0	3	36	301

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	+∞
hrs:	808	1326	1703	2851	1583	149	0

Presque Isle, Maine	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	3	65	257	530	829	1151	1488
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1268	1413	1208	464	83	1	0	

Laurel, Maryland	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	3	80	468	1221
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1443	1425	1572	1764	711	73	0	

Spring-field, Mass.	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	7	40	161	448	954	1598
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1293	1389	1439	1027	370	34	0	

Lansing, Michigan	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	1	40	176	504	1139	1561
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1153	1277	1466	1038	376	29	0	

Duluth, Minnesota	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	1	21	131	330	529	819	1223	1289
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1193	1448	1118	525	130	3	0	

Jackson, Mississippi	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	4	11	140	561
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1065	1321	1722	2279	1237	410	10	

Columbia, Missouri	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	25	102	292	702	1260
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1155	1184	1515	1497	810	209	9	

Billings, Montana	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	−34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	4	52	134	237	395	835	1521
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1546	1433	1255	811	424	110	3	

6. 溫室長寬高分別為 100、40 與 5 m，通風量為每分鐘一換氣……
若 80% 的水牆(Evaporative cooling pad)位於長邊，高 2.5 m，長 100 m，空氣經過水牆通過溫室

Grand Island, Nebraska	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	1	10	83	267	502	968	1299
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1092	1190	1380	1138	627	187	16	

Ely, Nevada	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	1	18	85	270	636	1175	1635
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1462	1300	989	724	451	14	0	

Portsmouth, New Hampshire	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
	0	0	1	30	162	477	964	1607
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1384	1477	1494	870	274	20	0	

Wrightstown, New Jersey	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	35	238	687	1483
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1389	1379	1571	1371	556	51	0	

Albuquerque, New Mexico	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	1	11	99	535	1227
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1432	1347	1587	1390	864	265	2	

Syracuse, New York	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	1	31	171	492	954	1536
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1262	1376	1450	1070	386	31	0	

Greensboro, North Carolina	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	6	83	437	1126
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1303	1426	1809	1660	798	112	0	

Bismarck, North Dakota	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	3	34	147	352	550	686	990	1246
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1065	1213	1165	804	404	97	4	

Dayton, Ohio	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	1	24	111	336	816	1354
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1224	1250	1558	1394	637	55	0	

Oklahoma City, Oklahoma	−∞	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	1	25	134	457	984
	4.4	10.0	15.6	21.1	26.7	32.2	37.8	
	10.0	15.6	21.1	26.7	32.2	37.8	+∞	
hrs:	1201	1282	1549	1778	996	334	19	

Eugene,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Oregon	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	1	5	32	169	1168

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	2468	2527	1369	677	288	55	1

Harrisburg,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Pennsylvania	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	1	33	208	672	1596

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1378	1304	1492	1362	610	102	2

Warwick,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Rhode	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
Island hrs:	0	0	0	5	61	269	748	1526

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1520	1547	1698	1099	270	17	0

Sumter,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
South	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
Carolina hrs:	0	0	0	0	0	14	165	679

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1134	1420	1747	2268	1112	219	2

Huron,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
South	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
Dakota hrs:	0	12	93	262	467	691	1025	1205

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	992	1114	1256	980	515	139	9

Nashville,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Tennessee	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	6	23	132	495	1043

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1221	1341	1676	1689	935	196	3

Austin,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Texas	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	0	6	77	430

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	910	1248	1614	2366	1449	640	20

Ogden,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Utah	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	1	4	47	283	986	1665

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1489	1274	1254	1011	599	147	0

Richmond,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Virginia	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	0	0	2	94	447	1142

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1358	1421	1680	1634	795	183	4

Moses Lake,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Washington	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	0	2	15	63	201	749	1662

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1583	1520	1351	934	497	173	10

Charleston,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
West	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
Virginia hrs:	0	0	0	3	36	183	576	1248

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1259	1441	1739	1485	710	79	1

Madison,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Wisconsin	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	1	19	130	305	561	1121	1458

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1033	1188	1416	1056	424	48	0

Casper,	$-\infty$	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1
Wyoming	-34.4	-28.9	-23.3	-17.8	-12.2	-6.7	-1.1	4.4
hrs:	0	3	23	84	195	522	1152	1585

	4.4	10.0	15.6	21.1	26.7	32.2	37.8
	10.0	15.6	21.1	26.7	32.2	37.8	$+\infty$
hrs:	1466	1266	1125	780	483	75	1

APPENDIX 7-1
HEATING DEGREE-DAY DATA (BASE 18.3 C) FOR SELECTED STATIONS

Station	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Huntsville Alabama	0	0	7	71	237	368	386	309	241	77	11	0	1,707
Anchorage Alaska	136	162	287	517	713	873	906	731	718	488	329	175	6,035
Tucson Arizona	0	0	0	14	128	226	262	191	134	42	3	0	1,000
Little Rock Arkansas	0	0	5	71	258	398	420	321	241	70	5	0	1,789
Fresno California	0	0	0	43	188	310	326	226	177	83	31	0	1,384
Denver Colorado	3	5	65	238	455	575	629	521	493	310	160	37	3,491
Wilmington Delaware	0	0	28	150	327	515	544	486	408	215	62	3	2,738
Orlando Florida	0	0	0	0	40	110	122	92	58	3	0	0	425
Atlanta Georgia	0	0	10	71	230	348	355	294	243	93	14	0	1,658
Honolulu Hawaii	0	0	0	0	0	0	0	0	0	0	0	0	0
Pocatello Idaho	0	0	96	274	500	648	736	588	503	308	177	78	3,908
Springfield Illinois	0	0	40	162	387	568	631	519	427	197	76	10	3,017
South Bend Indiana	0	3	62	207	432	625	678	594	518	292	133	33	3,577
Des Moines Iowa	0	5	55	202	465	684	777	646	537	272	117	22	3,782
Wichita Kansas	0	0	18	127	343	503	568	447	358	150	48	3	2,565
Lexington Kentucky	0	0	30	133	338	501	526	454	381	181	58	0	2,602
New Orleans Louisiana	0	0	0	11	107	179	202	143	107	22	0	0	771
Caribou Maine	43	64	187	379	580	853	939	817	727	477	260	102	5,428
Frederick Maryland	0	0	37	171	347	531	553	487	412	213	71	7	2,829
Pittsfield Mass.	14	33	122	291	462	684	744	664	591	367	181	58	4,211
Lansing Michigan	3	12	77	239	452	646	701	634	562	322	152	38	3,838
Duluth Minnesota	39	61	183	351	628	878	969	843	753	467	272	110	5,554
Jackson Mississippi	0	0	0	36	175	279	303	230	172	48	0	0	1,243
Columbia Missouri	0	0	30	139	362	537	598	486	398	180	67	7	2,804
Billings Montana	3	8	103	271	498	631	720	611	539	317	158	57	3,916
Grand Island Nebraska	0	3	60	212	463	651	730	605	504	257	117	25	3,627
Ely Nevada	16	24	130	329	522	658	727	597	543	373	253	125	4,297
Concord N. Hamp.	3	28	98	281	457	689	754	658	573	353	166	42	4,102
Newark N. Jersey	0	0	17	138	318	512	546	487	405	212	66	0	2,701
Albuquerque N. Mexico	0	0	7	127	357	482	517	391	331	160	45	0	2,417
Syracuse N. York	3	16	73	231	413	641	706	633	558	317	138	25	3,754
Greensboro N. Carolina	0	0	18	107	285	432	436	373	307	130	26	0	2,114
Bismark N. Dakota	19	16	123	321	602	813	949	801	668	358	183	65	4,918
Dayton Ohio	0	3	43	172	387	581	609	531	449	238	93	17	3,123

degree-day

Oklahoma City Oklahoma	0	0	8	91	277	426	482	369	293	105	19	0	2,070
Eugene Oregon	19	19	72	203	325	399	446	348	327	237	155	75	2,625
Harrisburg Penn.	0	0	35	166	360	551	581	504	426	220	69	7	2,919
Providence R. Island	0	9	53	207	367	568	617	549	482	297	131	28	3,308
Columbia S. Carolina	0	0	0	47	192	321	317	261	198	45	0	0	1,381
Huron S. Dakota	5	7	92	282	563	796	904	753	625	333	160	48	4,568
Nashville Tennessee	0	0	17	88	275	407	432	358	284	105	22	0	1,988
Austin Texas	0	0	0	17	125	216	260	181	124	28	0	0	951
Salt Lake City Utah	0	0	45	233	472	601	651	506	424	255	129	47	3,363
Richmond Virginia	0	0	20	119	275	436	453	391	303	122	29	0	2,148
Yakima Washington	0	7	80	250	460	577	646	482	396	242	122	38	3,300
Charleston W. Virginia	0	0	35	141	328	481	489	428	360	167	53	5	2,487
Madison Wisconsin	14	22	97	263	517	739	818	708	618	343	172	57	4,368
Casper Wyoming	3	9	107	291	523	649	717	602	567	365	212	72	4,117
Calgary Alberta	61	103	223	399	617	772	875	766	704	443	265	162	5,390
Vancouver Br. Col.	45	48	122	253	365	437	479	402	376	278	172	87	3,064
Winnipeg Manitoba	21	39	179	379	695	976	1116	955	814	452	225	82	5,933
Fredericton N. Bruns.	43	38	130	329	508	773	856	766	651	418	226	78	4,816
Halifax N. Scotia	32	28	100	254	394	597	674	623	572	412	271	132	4,089
Ottawa Ontario	14	45	123	315	520	816	902	801	684	393	189	50	4,852
Montreal Quebec	5	24	92	289	490	773	870	767	653	380	176	38	4,557
Regina Sask.	43	52	200	412	713	951	1092	937	818	446	227	112	6,003

NOTE: Local microclimate effects can make a significant difference in heating degree-day data for a locality (perhaps as much as ten percent). Elevation, proximity to a body of water, local air drainage, and the heat island effect of cities are examples of factors which affect heating needs.