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

k

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.

soil 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

0.015 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	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[e]	368	0.060	—	16.52	—	0.59
Wood or cane fiberboard						
Acoustical tile[e] 12.70 mm	—	—	4.54	—	0.22	1.30
Acoustical tile[e] 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)						
approx. 95.3–127.0 mm	9.6–32.0	—	—		1.94	0.71
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	1.34
Vermiculite, exfoliated	112–131	0.068	—	14.78	—	
	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

酚醛泡沫板 (防火) 6 mm, 8 mm, 9 mm, 10 mm, 12 mm — 800 — 0.15 — 250, 187.5, 166.7, 150, 125 — 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*		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.

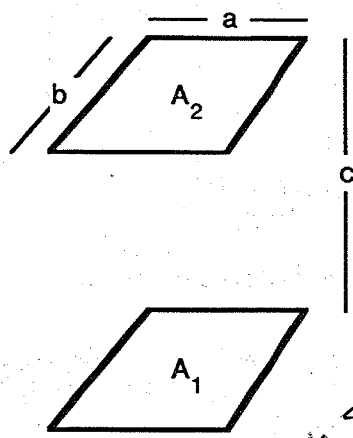
[l]L. Adams: Supporting cryogenic equipment with wood (*Chemical Engineering*, May 17, 1971).

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

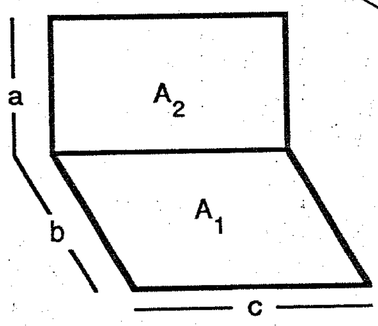
APPENDIX 3-4
ANGLE FACTORS FOR THERMAL RADIATION HEAT TRANSFER
SEVEN SIMPLE CONFIGURATIONS

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



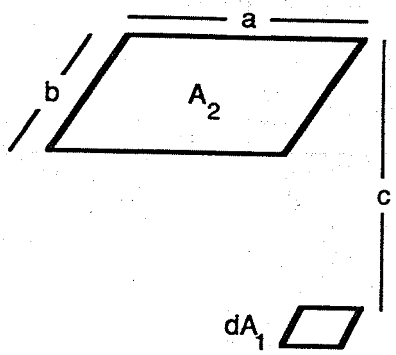
$$F_{1-2}(\pi XY/2) = \ln\left(\frac{W^2 Z^2}{1+X^2+Y^2}\right)^{1/2} + YW\tan^{-1}(Y/W) + XZ\tan^{-1}(X/Z) - Y\tan^{-1}Y - X\tan^{-1}X.$$

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



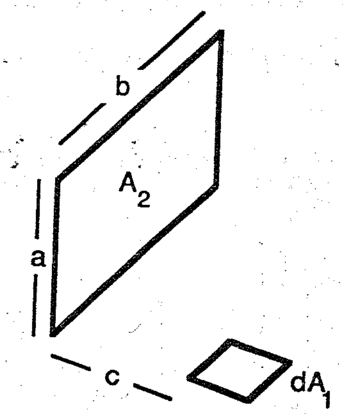
$$F_{1-2}(\pi Y) = (\tfrac{1}{4})\ln\left(\frac{(1+X^2)(1+Y^2)}{1+Z^2}\right) + (\tfrac{1}{4})Y^2\ln\left(\frac{Y^2(1+Z^2)}{(1+Y^2)Z^2}\right) + (\tfrac{1}{4})X^2\ln\left(\frac{X^2(1+Z^2)}{Z^2(1+X^2)}\right) + Y\tan^{-1}(1/Y) + X\tan^{-1}(1/X) - Z\tan^{-1}(1/Z).$$

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



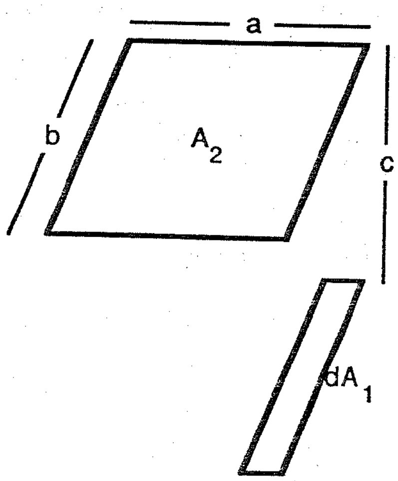
$$F_{1-2}(2\pi) = (X/W)\tan^{-1}(Y/W) + (Y/Z)\tan^{-1}(X/Z)$$

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



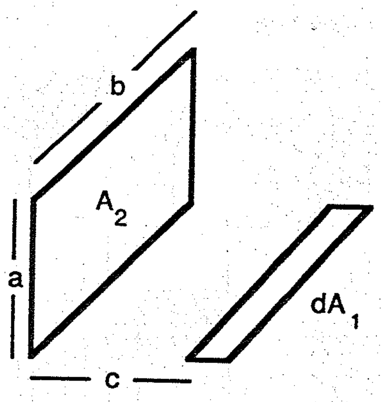
$$F_{1-2}(2\pi) = \tan^{-1}(1/Y) - ZY\tan^{-1}Z$$

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



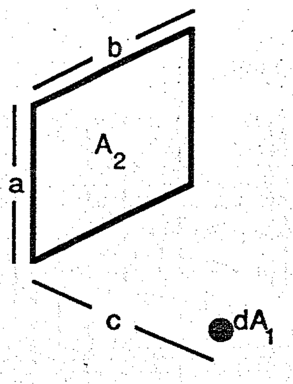
$$F_{1-2}(\pi X) = W\tan^{-1}(Y/W) - \tan^{-1}Y + (XY/Z)\tan^{-1}(X/Z)$$

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 $\emptyset = 90°$,

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

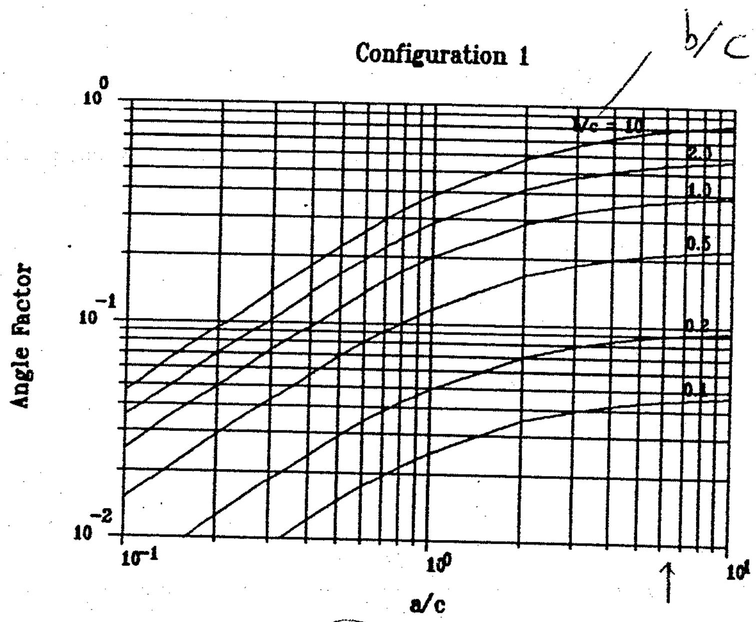
$$\lim_{x\to\infty} F_{1-2} = (1/4\pi)\tan^{-1}(y)$$

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

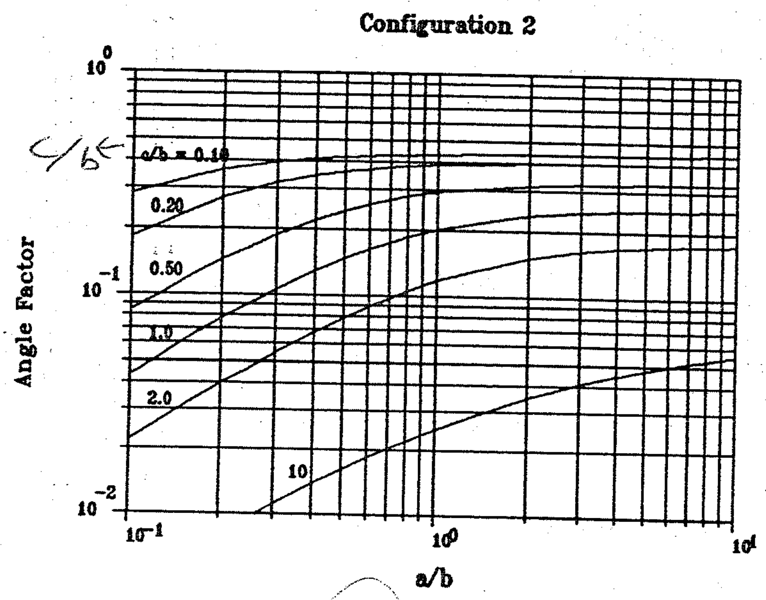
Note: angle factors for more complex configurations can be built using the above. For example, the angle factor from a small animal in a barn to the ceiling of the barn can be built using four applications of configuration 3 above. The ceiling is divided into four quadrants, intersecting above the location 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.

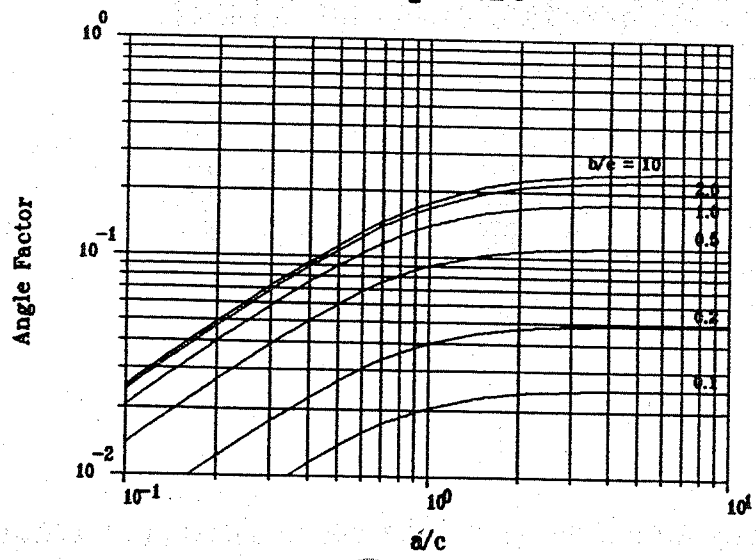


Angle factors for configuration 1, for b/c of 10, 2, 1, 0.5, 0.2 and 0.1 (top to bottom).



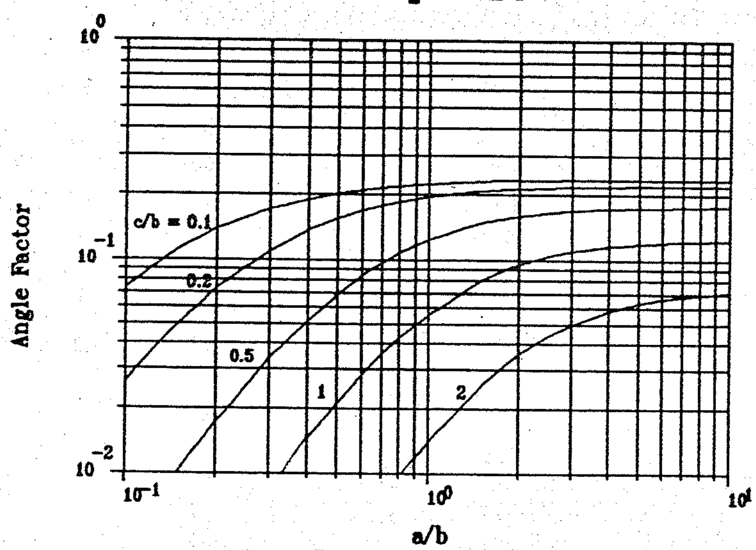
Angle factors for configuration 2, for c/b of 0.1, 0.2, 0.5, 1, 2, and 10 (top to bottom).

Configuration 3

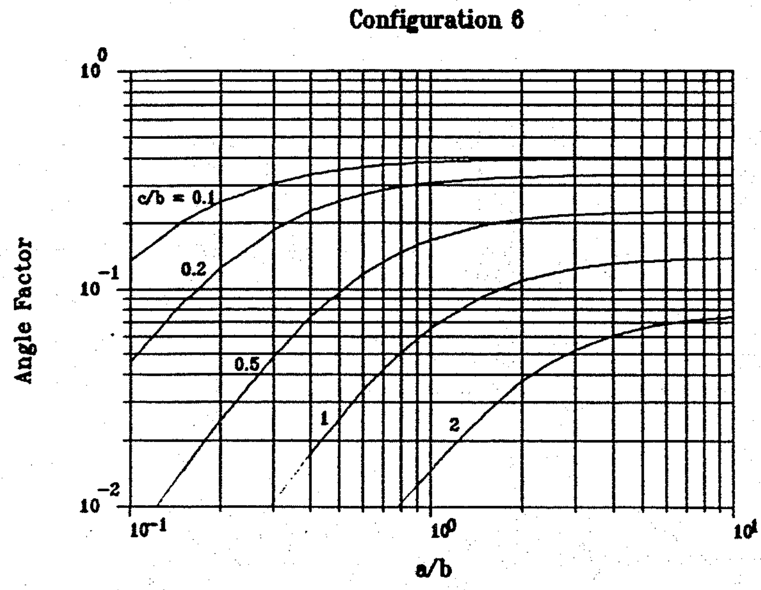


Angle factors for configuration 3, for b/c of 10, 2, 1, 0.5, 0.2 and 0.1 (top to bottom).

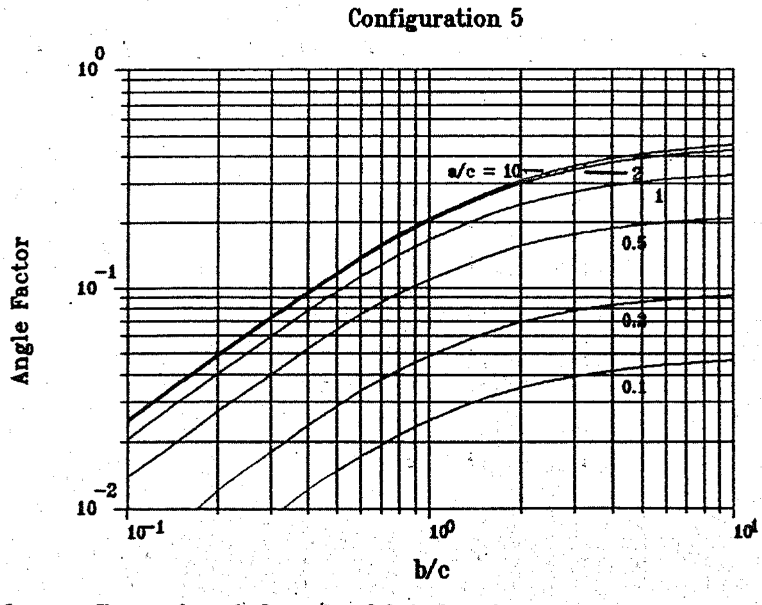
Configuration 4



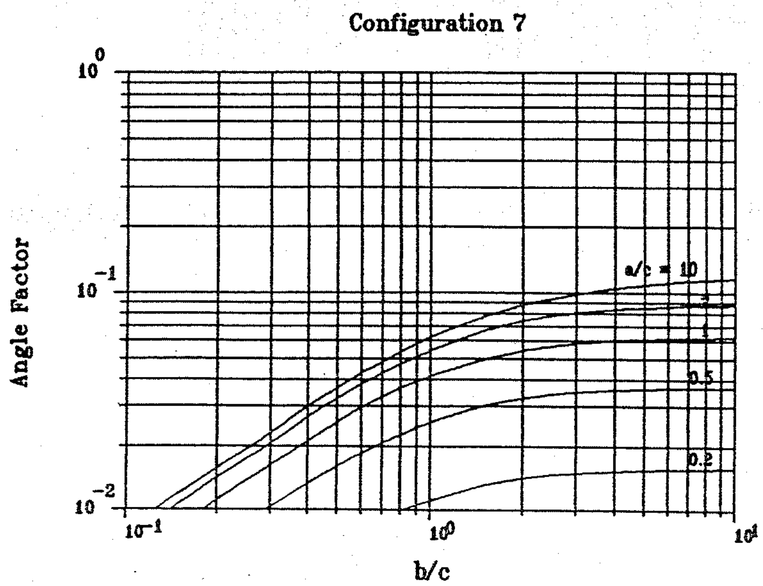
Angle factors for configuration 4, for c/b of 0.1, 0.2, 0.5, 1 and 2 (top to bottom). Factors for c/b of 10 are less than 0.01.



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



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.



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] 0.03	0.05	0.2	0.5	0.82	19.1-mm Air Space[c] Value of E[d,e] 0.03	0.05	0.2	0.5	0.82
		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
Horiz.	Up ↑	-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
		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
45° Slope	Up ↗	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
		-45.5	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
		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
Vertical	Horiz. →	-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
		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
45° Slope	Down ↘	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
		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
Horiz.	Down ↓	-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] 0.03	0.05	0.2	0.5	0.82	88.9 mm Air Space[c] Value of E[d,e] 0.03	0.05	0.2	0.5	0.82
		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
Horiz	Up ↑	-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
		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
45° Slope	Up ↗	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
		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
Vertical	Horiz. →	-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
		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
45° Slope	Down ↘	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
		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
Horiz.	Down ↓	-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