$P_T = P_w + P_a$

$PV = mRT$

R_w = 461.5 J/kg.K (for water vapour)

R_a = 287.1 J/kg.K (for air)

$P_w = \frac{P_T W}{0.622+W}$

$W = \frac{m_w}{m_a} = \frac{0.622 P_w}{P_T - P_w}$

Latent (kJ/kg) = W (2500 + 1.86T*)

Sensible (kJ/kg) = 1.005T*

$M = \frac{\overline{\mu}}{l}$

$W = M\,(P_{w1} - P_{w2})tA$

$P_w = P_{sat}$ x RH

$M_c = \frac{1}{Rv1 + Rv2 + \cdots} = \frac{1}{\frac{1}{M_1} + \frac{1}{M_2} + \ldots}$

$RH = \frac{P_w}{P_{sat}}$ x 100

$\frac{\Delta P_w}{\Delta P_{w\,Total}} = \frac{R_v}{R_{v\,Total}}$

$A = 0.2024 m^{0.425} h^{0.725}$

Energy = Power x Time

°C + 273 = K

$1m^3$ natural gas ~ 10.3kWh

$C = \frac{1}{R} = \frac{k}{l}$

$R_{tot} = R_1 + R_2 + R_3 + \cdots + R_n = \frac{1}{U}$

U= 1/R

$Q = \frac{A}{R}\Delta T t$ $q = \frac{A}{R}\Delta T$

$E_{in} = \propto I_t$

$E_{out} = \varepsilon \sigma T^4$ where $\sigma = 5.67 \times 10^{-8} W/m^2K^4$

$T = \sqrt[4]{\frac{\alpha I_t}{\varepsilon_1 \sigma + \varepsilon_2 \sigma}}$

$\frac{\Delta T_i}{\Delta T_{tot}} = \frac{R_i}{R_{tot}}$

$q_{1-2} = E \cdot \sigma A_1 (T_1^4 - T_2^4)$ *where* $E = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$

$Q = CA\left[\frac{2}{\rho}(p_1 - p_2)\right]^{1/2}$

$q/A = SHGC(I_t) - U(t_i - t_o)$

$\frac{V_z}{V_g} = \left[\frac{Z}{Z_g}\right]^{\alpha}$

$Q = C(\Delta P)^n$

$\frac{G}{G_g} = \left[\frac{Z}{Z_g}\right]^{\beta}$

$G_g = 1.35 V_g$

$t_e = t_o + \alpha\, I_t/h_o - \varepsilon\, \Delta R/h_o$

$C_p = \frac{p}{1/2 \rho V^2}$

$p_s = 0.0342 h p_t (\frac{1}{T_o} - \frac{1}{T_i})$

$\Delta p = \gamma p_s = 0.0342 \gamma h p_t \frac{\Delta T}{T_i T_o}$

γ = *thermal draft coefficient*

$\beta_{max} = 90 - \lambda + \delta$

$\gamma = \phi_s - \phi_p$

$sin\beta = cos\lambda cos\delta cos\omega + sin\lambda sin\delta$

$sin\varphi = \frac{cos\delta sin\omega}{cos\beta}$

cos θ = cos β cos γ sin Σ + sin β cos Σ

TABLE 9.7

Sol-Air Temperature Minus Air Temperature for 45°N Latitude for January 21 and July 21, degrees Celsius

January 21	N	NE	E	SE	S	SW	W	NW	Horizontal
08:00	0	2	12	15	8	0	0	0	−3
09:00	2	2	26	38	28	2	2	2	3
10:00	3	3	22	44	39	10	3	3	9
11:00	3	3	11	41	46	23	3	3	14
12:00	3	3	3	34	48	34	3	3	16
13:00	3	3	3	23	46	41	11	3	14
14:00	3	3	3	10	39	44	22	3	9
15:00	2	2	2	2	28	38	26	2	3
16:00	0	2	0	0	8	15	12	2	−3
July 21	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**	**Horizontal**
05:00	2	4	4	2	0	0	0	0	−3
06:00	7	26	29	15	2	2	2	2	3
07:00	5	30	40	26	4	4	4	4	13
08:00	5	27	41	32	6	5	5	5	24
09:00	6	18	37	35	13	6	6	6	32
10:00	6	9	28	33	19	7	6	6	39
11:00	7	7	15	27	24	9	7	7	43
12:00	7	7	8	18	26	18	8	7	44
13:00	7	7	7	9	24	27	15	7	1
14:00	6	6	6	7	19	33	28	9	2
15:00	6	6	6	6	13	35	37	18	3
16:00	5	5	5	5	6	32	41	27	4
17:00	5	4	4	4	4	26	40	30	5
18:00	7	2	2	2	2	15	29	26	6
19:00	2	0	0	0	0	2	4	4	7

Note: These values are for dark-coloured walls for which $\alpha/h_o = 0.053$. For light-coloured surfaces, divide values by 2.

TABLE 9.5

Solar Heat-Gain Factors, W/m², for 45°N Latitude

(From Stephenson, D.G., *Tables of solar altitude, azimuth intensity and heat gain factors*, NRCC 9528, 1967) [**9.3**]

January 21	North	East	South	West	Horizontal
08:00	8	199	137	8	17
09:00	29	422	454	29	111
10:00	42	358	646	42	222
11:00	50	177	756	50	299
12:00	53	57	792	57	326
13:00	50	50	756	177	299
14:00	42	42	646	358	222
15:00	29	29	454	422	111
16:00	8	8	137	199	17
Daily totals, W • h/m²	312	1346	4798	1346	1628
July 21	**North**	**East**	**South**	**West**	**Horizontal**
05:00	32	71	5	5	9
06:00	117	472	38	38	119
07:00	83	651	68	63	286
08:00	87	679	107	82	454
09:00	97	606	209	97	595
10:00	107	457	318	107	704
11:00	114	252	394	114	772
12:00	116	126	420	126	795
13:00	114	114	394	252	772
14:00	107	107	318	457	704
15:00	97	97	209	606	595
16:00	87	82	107	679	454
17:00	83	63	68	651	286
18:00	117	38	38	472	119
19:00	32	5	5	71	9
Daily totals, W • h/m²	1360	3785	2700	3785	6664

TABLE 10.1

Values of Gradient Height and Power Law Exponents for Wind Profiles

(From Aynsley, R.M., Melbourne, W., and Vickery, B.J., *Architectural aerodynamics*, London: Applied Science Publishers Ltd., 1977, Table 3.1, p. 89) [**10.1**]

Terrain category and description	Gradient height Z_g m	Mean speed exponent α	Gust-speed exponent β
1. Open sea, ice, tundra, desert	250	0.11	0.07
2. Open country with low scrub or scattered trees	300	0.15	0.09
3. Suburban areas, small towns, well-wooded areas	400	0.25	0.14
4. Numerous tall buildings, city centres, well-developed industrial areas	500	0.36	0.20

TABLE 5.1

Water-Vapour Pressures at Saturation at Various Temperatures over Plane Surfaces of Pure Water and Pure Ice

Temp., °C	Pressure, Pa Over ice	Temp., °C	Pressure, Pa Over ice	Temp., °C	Press., kPa	Temp., °C	Press., kPa
−50	3.935	−22	85.02	5	0.8719	33	5.031
−49	4.449	−21	93.70	6	0.9347	34	5.320
−48	5.026	−20	103.2	7	1.001	35	5.624
−47	5.671	−19	113.5	8	1.072	36	5.942
−46	6.393	−18	124.8	9	1.147	37	6.276
−45	7.198	−17	137.1	10	1.227	38	6.626
−44	8.097	−16	150.6	11	1.312	39	6.993
−43	9.098	−15	165.2	12	1.402	40	7.378
−42	10.21	−14	181.1	13	1.497	41	7.780
−41	11.45	−13	198.4	14	1.598	42	8.202
−40	12.83	−12	217.2	15	1.704	43	8.642
−39	14.36	−11	237.6	16	1.817	44	9.103
−38	16.06	−10	259.7	17	1.937	45	9.586
−37	17.94	−9	283.7	18	2.063	46	10.09
−36	20.02	−8	309.7	19	2.196	47	10.62
−35	22.33	−7	337.9	20	2.337	48	11.17
−34	24.88	−6	368.5	21	2.486	49	11.74
−33	27.69	−5	401.5	22	2.643	50	12.33
−32	30.79	−4	437.2	23	2.809	51	12.96
−31	34.21	−3	475.7	24	2.983	52	13.61
−30	37.98	−2	517.3	25	3.167	53	14.29
−29	42.13	−1	562.3	26	3.361	54	15.00
−28	46.69	0	610.8	27	3.565	55	15.74
		Triple point					
−27	51.70	+0.01	of water	28	3.780	56	16.51
−26	57.20	1	656.6	29	4.006	57	17.31
−25	63.23	2	705.5	30	4.243	58	19.15
−24	69.85	3	757.5	31	4.493	59	19.02
−23	77.09	4	812.9	32	4.755	60	19.92

TABLE 4.1

Emittances and Absorptances for Some Surfaces

(From *ASHRAE Handbook 1981 Fundamentals*, Table 3, p. 2.8) [**4.1**]

Surface	Emissivity 10 to 38°C	Absorptivity for solar radiation
1. Small hole in an enclosure	0.97–0.99	0.97–0.99
2. Black, nonmetallic surfaces	0.90–0.98	0.85–0.98
3. Red brick and tile, stone and concrete, rusted iron and dark paints	0.85–0.95	0.65–0.80
4. Yellow and buff building materials	0.85–0.95	0.50–0.70
5. White or light cream surfaces	0.85–0.95	0.30–0.50
6. Glass	0.90–0.95	transparent (8% reflected)
7. Bright aluminum paint	0.40–0.60	0.30–0.50
8. Dull brass, copper, aluminum, polished iron	0.20–0.30	0.40–0.65
9. Polished brass, copper	0.02–0.05	0.30–0.50
10. Highly polished tin, aluminum, nickel, chrome	0.02–0.04	0.10–0.40

Material (For unit thickness of 1 metre)	Permeability ng/(Pa • s • m) dry cup	wet cup	Other
Concrete 1:2:4 min		4.7	
Wood, sugar pine			0.58
Mineral wool, unprotected		170	1011.5
Expanded polystyrene—bead	3–8.5		

Material	Permeance ng/(Pa • s • m²) dry cup	wet cup	other
Brick masonry, 10 cm	—	—	46
Concrete block, 20 cm, cored, limestone aggregate	—	—	138
Tile masonry, glazed, 10 cm	—	—	7
Asbestos cement board, 5 mm	31	—	—
Plaster on wood lath	—	630	—
Plaster on plain gypsum lath on studs	—	—	1150
Gypsum wallboard, 9.5 mm, plain	—	—	2870
Hardboard, 3 mm, tempered	—	—	290
Plywood, douglas fir, exterior glue, 6.5 mm	—	—	40
Enamels, 2 coats on smooth plaster	—	—	29–86
Primers, sealers, 2 coats on insulation board	—	—	52–120
Various primers, 2 coats + 1 coat flat oil paint on plaster	—	—	92–172
Flat paint, 2 coats on insulation board	—	—	230
Water emulsion, 2 coats on insulation board	—	—	1720 to 4900
Exterior paint, 3 coats white lead and oil on wood siding	17–57	—	—
Styrene butadiene latex coating 0.62 kg/m²	630	—	—
Polyvinyl acetate latex coating 1.25 kg/m²	320	—	—

Material	Permeance ng/(Pa • s • m²) dry cup 50–0%	wet cup 100–50%	inverted wet cup
Foamed polyurethane insulation 25 mm			
28 kg/m³	75	75	—
31 kg/m³	63	63	—
Foamed polystyrene insulation 25 mm			
Extruded 29 kg/m³	92	92	—
Extruded 35 kg/m³	44	42	—
Polyethylene film			
0.05 mm	9	8	—
0.10 mm	5	4	—
0.15 mm	3	2	—
Nylon film 0.025 mm	39	40	—
Vinyl film 0.05 mm	19	19	—
Cellulose acetate film 0.25 mm	270	640	—
Waxed building paper			
medium weight	5	9	—
heavy weight	6	51	—
Asphalt-saturated sheathing paper			
0.75 kg/m² (15 lb)	270	480	725
1.25 kg/m² (25 lb)	190	370	—
heavy weight	47	360	500
Asphalt-saturated roofing felt 0.75 kg/m³	110	680	910
Tar-infused sheathing paper .	375	1770	4050
Asphalt-infused sheathing paper	365	1080	2400
Asphalt-coated building paper	47	63	115
Perforated asphalt-coated sheathing paper	630	800	860
Structural clay tile 6 mm		660	—
Vitreous ceramic tile 9 mm	0.6	23	—
Fibreboard, untreated 12.5 mm	2470	2520	—
Fibreboard, sheathing grade 12.5 mm	1720	1780	—
Asbestos cement board	285	480	—

TABLE 8.1

Thermal Conductivities and Conductances of Building and Insulating Materials

(From *ASHRAE Handbook 1981 Fundamentals*, Table 3A, p. 23.14–23.17) **[8.1]**

Material	ρ kg/m³	k W/(m • K)	C W/(m² • K)
Building board			
Asbestos cement board	1920	0.58	—
Gypsum or plaster board, 9.5 mm	800	—	16.6
Gypsum or plaster board, 12.5 mm	800	—	12.5
Plywood	545	0.115	—
Insulating board, regular	290	0.055	—
Hardboard, medium density	800	0.105	—
Particle board, low density	590	0.078	—
Particle board, medium density	800	0.136	—
Particle board, high density	1000	0.170	—
Building paper			
Building paper	—	—	95
Vapour barrier, plastic film	—		negligible
Insulating blankets and batts			
Mineral fibre 50–68 mm	5–32		0.81
(rock, slag, or glass) 75–88 mm	5–32		0.52
89–162 mm	5–32		0.30
Insulating boards and slabs			
Cellular glass	136	0.555	—
Glass fibre, organic bonded	65–145	0.036	—
Expanded polystyrene			
extruded, cut cell surface	29	0.036	—
extruded, smooth skin surface	35	0.029	—
extruded, smooth skin surface	56	0.027	—
Molded beads	16	0.040	—
Expanded polyurethane			
R-11 expanded	24	0.023	—
Mineral fibre, resin binder	240	0.042	—
Wood fibreboard, interior finish	240	0.050	—
Insulating materials loose fill			
Cellulose insulation (milled paper)	37–50	0.039–0.046	—
Sawdust or shavings	128–240	0.065	—
Mineral fibre (rock, slag, or glass)			
approximately 95–127 mm	10–32	—	0.52
approximately 165–222 mm	10–32	—	0.30
approximately 190–254 mm	10–32	—	0.26
approximately 260–350 mm	10–32	—	0.19
Vermiculite, expanded	110–130	0.068	—
	65–95	0.064	—
Roof insulation			
Various types supplied in thicknesses to provide the rated conductance			
Masonry materials			
Cement mortar	1860	0.72	—
Lightweight concretes	1920	0.75	—
(Various aggregates)	1600	0.52	—
	1280	0.36	—
	960	0.25	—
	640	0.17	—
	480	0.13	—
	320	0.10	—
Dense concrete, dry	2250	1.32	—
Dense concrete, not dry	2250	1.82	—
Stucco	1860	0.72	—
Masonry units			
Brick, common	1920	0.72	—
Brick, face	2080	1.32	—
Clay tile, hollow:			
1 cell 100 mm	—	—	5.0
2 cells 200 mm	—	—	3.0
3 cells 300 mm	—	—	2.3
Concrete blocks, 3 oval core:			
Sand and gravel aggregate 200 mm	—	—	5.0
Lightweight aggregate 200 mm	—	—	2.9
Concrete blocks, rectangular core:			
Sand and gravel 2 core 200 mm	—	—	5.6
Same with insulation-filled cores	—	—	2.9
Lightweight aggregate 2 core 200 mm	—	—	2.6
Same with insulation-filled cores	—	—	1.1
Plastering materials			
Cement plaster, sand aggregate	1860	0.72	—
Gypsum plaster, light aggregate	720	0.23	—
Gypsum plaster, sand aggregate	1680	0.81	—
Gypsum plaster, vermiculite aggregate	720	0.25	—
Roofing			
Asphalt shingles	—	—	12.5
Built-up roofing 9.5 mm	—	—	17
Wood shingles	—	—	6.0
Siding materials			
Asbestos cement shingles	—	—	25
Wood shingles	—	—	6.7
Wood siding, bevel, 13 × 200 mm	—	—	7.0
Wood siding, bevel, 19 × 250 mm	—	—	5.4
Wood plywood 9.5 mm	—	—	10.0
Metal siding, hollow backed over board sheathing	—	—	9.0
Architectural glass	—	—	50
Wood			
Maple, oak, and similar hardwoods	720	0.16	—
Fir, pine, and similar softwoods	510	0.12	—
Metals			
Aluminum	2 740	220	—
Brass, yellow	8 300	120	—
Copper	8 900	390	—
Lead	11 300	35	—
Nickel	8 890	60	—
Steel, mild	7 830	45	—
Miscellaneous			
Glass, soda lime	2470	1.0	—
Air, still	1.2	0.025	—
Water, still	1000	0.60	—

Metric conversions for heat transfer

U or C	Btu/(ft² • hr • °F) × 5.678 = W/(m² • K)
k-ft	Btu/(ft • hr • °F) × 1.730 = W/(m • K)
k-in.	Btu • in./(ft² • hr • °F) × 0.1442 = W/(m • K)
Heat flow	Btu/(ft² • hr) × 3.155 = W/m²

Specific weight, lb/ft³ × 16.02 = kg/m³ (mass density).

TABLE 8.2

Surface Conductances for Air W/(m² · K)
(From *ASHRAE Handbook 1981 Fundamentals*, Table 1, p. 23.12) [8.1]

Position of surface	Direction of flow	Surface emissivity ε = 0.90	ε = 0.20	ε = 0.05
Still air				
Horizontal	upward	9.3	5.2	4.3
Sloping 45°	upward	9.1	5.0	4.1
Vertical	horizontal	8.3	4.2	3.4
Sloping 45°	downward	7.5	3.4	2.6
Horizontal	downward	6.1	2.1	1.25
Moving air (any position)				
24 km/h, for winter	any	34	—	—
12 km/h, for summer	any	23	—	—

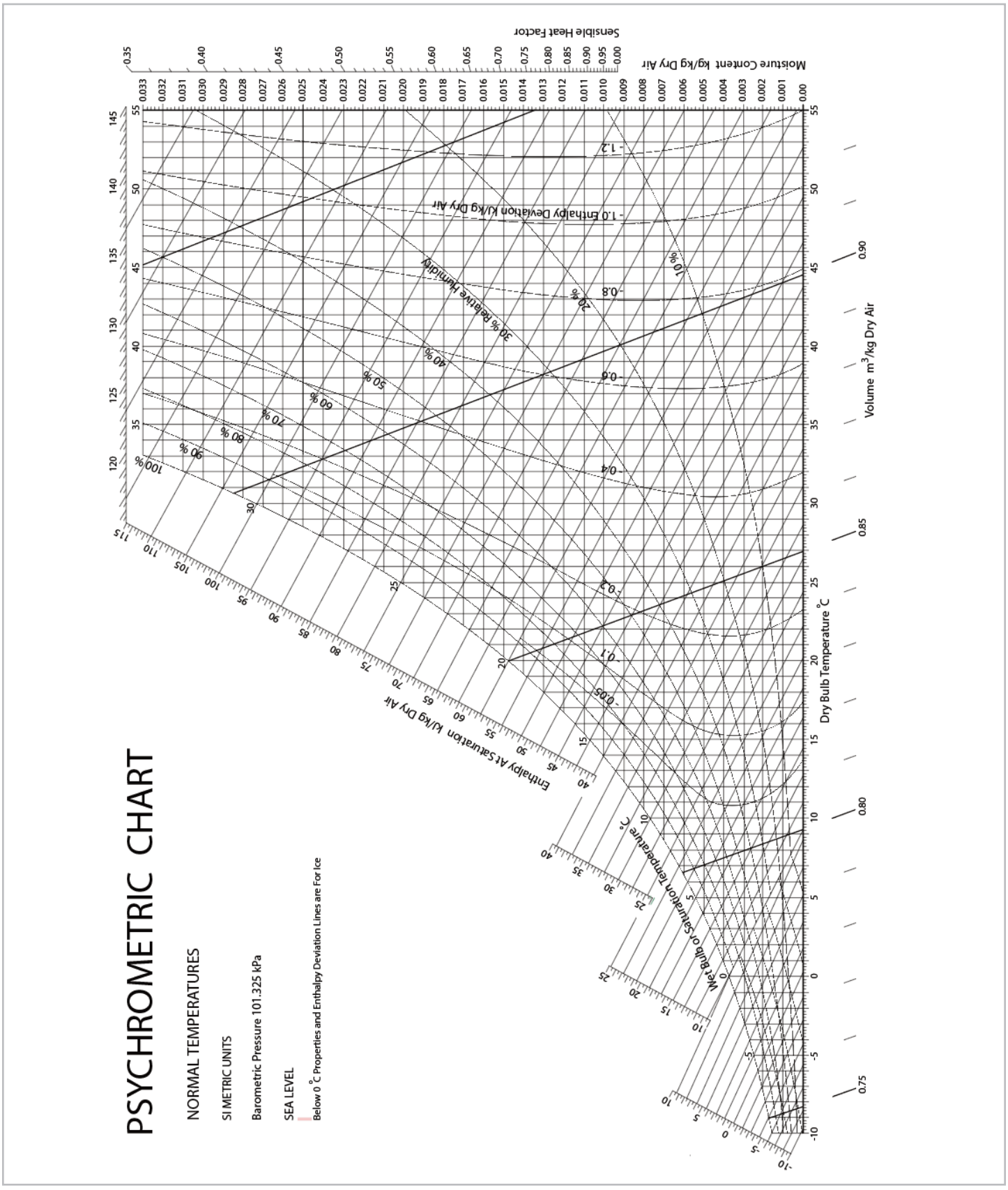
Table 2 Emissivity of Various Surfaces and Effective Emittances of Facing Air Spaces[a]

Surface	Average Emissivity ε	Effective Emittance ε_{eff} of Air Space: One Surface's Emittance ε; Other, 0.9	Effective Emittance ε_{eff} of Air Space: Both Surfaces' Emittance ε
Aluminum foil, bright	0.05	0.05	0.03
Aluminum foil, with condensate just visible (>0.5 g/m²)	0.30[b]	0.29	—
Aluminum foil, with condensate clearly visible (>2.0 g/m²)	0.70[b]	0.65	—
Aluminum sheet	0.12	0.12	0.06
Aluminum-coated paper, polished	0.20	0.20	0.11
Brass, nonoxidized	0.04	0.038	0.02
Copper, black oxidized	0.74	0.41	0.59
Copper, polished	0.04	0.038	0.02
Iron and steel, polished	0.2	0.16	0.11
Iron and steel, oxidized	0.58	0.35	0.41
Lead, oxidized	0.27	0.21	0.16
Nickel, nonoxidized	0.06	0.056	0.03
Silver, polished	0.03	0.029	0.015
Steel, galvanized, bright	0.25	0.24	0.15
Tin, nonoxidized	0.05	0.047	0.026
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

TABLE 8.4

Thermal Conductances of Plane Air Spaces, W/(m² · K)
(From *ASHRAE Handbook 1981 Fundamentals*, Table 2, p. 23.12, 23.13) [8.1]

Position	Direction of flow	Air space: Mean temp., °C	Air space: Temp. diff., K	Thickness: 19 mm, E = 0.03	19 mm, E = 0.82	92 mm, E = 0.03	92 mm, E = 0.82
Horizontal	Up	30	5	2.4	7.5	1.9	7.0
		10	20	3.3	7.0	2.7	6.6
		−20	10	3.1	6.1	2.5	5.6
45°	Up	30	5	1.9	7.0	1.8	6.9
		10	20	2.8	6.8	2.4	6.5
		−20	10	2.6	5.6	2.3	5.3
Vertical	Horizontal	30	5	1.6	6.8	1.5	6.6
		10	20	1.9	5.9	2.0	6.1
		−20	10	1.8	4.8	1.9	4.9
45°	Down	30	5	1.6	6.8	1.2	6.3
		10	20	1.6	5.6	1.6	5.6
		−20	10	1.5	4.5	1.5	4.4
Horizontal	Down	30	—	1.6	6.8	0.56	5.7
		10	—	1.5	5.6	0.51	4.6
		−20	—	1.3	4.3	0.45	3.5


PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Below 0 °C Properties and Enthalpy Deviation Lines are For Ice
Sensible Heat Factor
Moisture Content kg/kg Dry Air
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Dry Bulb Temperature °C
Volume m³/kg Dry Air
- 1.2
- 1.0 Enthalpy Deviation kJ/kg Dry Air
- 0.8
- 0.6
- 0.4
- 0.3
- 0.2
- 0.1
- 0.05
10 %
20 %
30 % Relative Humidity
40 %
50 %
60 %
70 %
80 %
90 %
100 %