Family Name: ______________________ Given Names: ______________________

Student No: ______________________

FINAL EXAM DECEMBER 2001

Department of Civil Engineering
Faculty of Applied Science and Engineering
University of Toronto

CIV 575F BUILDING SCIENCE

Examiner: K.D. Pressnail

Notes:

(i) Non-programmable calculators ONLY.

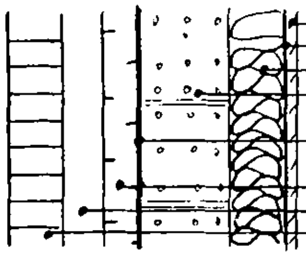
(ii) Type "B" Examination. Only the aids distributed with this exam may be used.

(iii) Make and state any reasonable assumptions.

MARKS

1. a) Calculate the quantity of heat (kWh) that would be transmitted through 1 square metre of the wall section shown during the month of January. Assume that the average indoor and outdoor conditions in January are 23°C, 35% RH, and -6°C, 80% RH respectively. Ignore the effects of the internal steel studs (not shown).

4



b) For the wall section shown in part a), calculate the temperature at the interface between the peel-and-stick membrane and the concrete block wall. The inside and outside conditions are 23°C, 35%RH and -25°C, 90% RH, respectively.

4

MARKS

1\. c) For the conditions given in part b), and assuming that condensation does not occur, calculate the vapour pressure at the interface between the peel-and-stick membrane and the concrete block wall.

4

d) Based on your calculations in parts b) and c) show whether condensation will occur at the interface between concrete block wall and the peel-and-stick membrane.

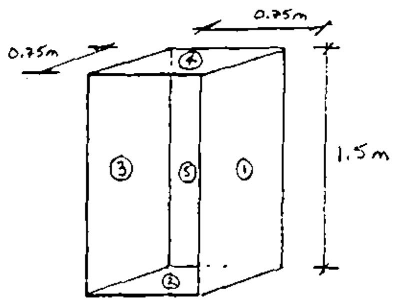
4

e) Assume that condensation DOES occur at the interface between the concrete block wall and the peel- and-stick membrane. How can this wall section be improved in order to reduce the likelihood of condensation occurring at this membrane?

4

MARKS

2. An electrically-heated guarded hot-box measures 0.75 m by 0.75 m by 1.50 m as shown. It is used to estimate the thermal resistance of a building assembly by measuring the amount of heat that is required to keep the box at a uniform, constant temperature. The "hot-box" consists of 5 sides labelled 1, 2, 3, 4, 5 and each side of the 5 sided box has a total thermal resistance (including films) of 2.0 m^2K/W. The open side is placed tightly against the inside surface of a wall element and the wall is tested for a 24 hour period. During the period of the test, the air temperature inside the hot-box is maintained at 25°C by means of an electric heater. While the test is carried out, the inside room air temperature and outside air temperature are 21°C and -10°C respectively and the wall surface temperature inside the hot-box is 23.6°C. The total electricity used during the test is found to be 0.400 kWh.



16 (a) What is your estimate of the total resistance of the wall element as determined by the guarded hot-box test?

4 (b) What is your estimate of the resistance of the inside surface film?

MARKS

3. Assume a standard atmosphere for all parts of Question 3.

2 (a) If the air temperature is 25°C and the latent heat content of the air is 20 kJ/kg dry air, what is the relative humidity?

2 (b) Air that is initially at 27°C, 70% R.H., is cooled by means of a dehumidifier to 5°C and re-heated to 22°C. Excluding the electrical energy required to run the dehumidifier, how much heat is given off by the dehumidifier if the temperature of the dehumidifier remains constant?

2 (c) Air in an adobe house in Arizona is cooled to 27°C, 70% R.H. by means of evaporative cooling. If the air initially had a R.H. of 30%, what was the original air temperature?

2 (d) What is the density of the air at 27°C, 70% R.H.?

2 (e) What is the humidity ratio (kg of water/kg dry air) of air at -20°C, 70% R.H.?

MARKS

4. **<u>CHOICE:</u>** Answer **<u>FIVE</u>** of the following **<u>SEVEN</u>** questions.

5@4

(a) Briefly discuss two reasons why "waterproof" strategies for cast-in-place basements won't work.

(b) Briefly explain how the mechanism of "capillary heat transfer" may lead to increased heat losses through wet, permeable thermal insulation.

(c) Briefly state and explain the factors that you would consider when choosing a glass for a new, single-glazed greenhouse.

(d) Briefly explain why maintaining 23°C, 50% R.H. in an adobe house museum such as the Helliwell House, may lead to damage of the heritage building.

MARKS

4. <u>CHOICE:</u> CONTINUED

5@4

(e) Briefly explain 2 ways in which the likelihood of sun-driven moisture problems can be greatly reduced.

(f) In July, briefly explain why the solar heat gain factor for a building in Bracebridge, Ontario (45°N) is greater for an east facing window at 9:00 A.M. than for the same window facing south at 12:00 P.M.

(g) "Flat roof designs using built up layers of tar and roofing felts have a vapour retarding membrane on the "cold side". Explain this statement and the possible consequences.

MARKS

5. (a) Estimate the wind velocity (m/s) 2.4 m above the ground when the hourly airport data shows that the winds are from the north at 28 km/h measured 10 m above the ground. The house where the wind speed is required is located in suburban Mississauga and the outside air temperature and relative humidity are -10°C and 90% respectively.

5

(b) Using the velocity determined in part a) as the <u>average</u> wind velocity, calculate the net resulting force due to wind on a 4.8 m x 10 m north facing wall. The average wind pressure co-efficient for the north facing wall is +0.4.

5

(c) Assume that there is no mechanical ventilation and the effects of stack action are negligible. Given the conditions in part a), estimate the air flow rate through a 1 cm x 10 cm opening that is located 2.4 m above the ground. The opening is located on a south facing wall and the wind pressure co-efficient is -0.85. The indoor air temperature and relative humidity are 23°C, 30% respectively. State the direction of air movement.

5

(d) Briefly describe why condensation often appears on the inside of the outer second-storey storm windows, while the outer storm windows on the first floor remain clear.

5

MARKS

6. The crawl-space beneath the Summer Kitchen of "This Old Farmhouse" measures 4 m x 5 m in plan and contains saturated soil covered with 100 mm of 20 mmφ crushed stone. The effective permeance of the stone layer is 4000 ng/Pa·s·m². The soil and crushed stone layer are at a temperature of 16°C. The air temperature in the 1.2 m crawl-space is 8°C. Assume that the air temperature inside the crawl-space remains constant. The outside air temperature and relative humidity are 0°C and 100% respectively.

(a) How much outside ventilation air (L/s) must be brought into the crawl-space if the relative humidity of the air space is to be maintained at 70%.

7

(b) How can the need for ventilation be greatly reduced?

3

1

All the best!
K.D

$$T = 273 + 15 - 0.0065\,h \qquad (\mathrm{K})$$

$$\rho = 1.225\,(1 - 22.6 \times 10^{-6}\,h)^{4.256} \qquad (\mathrm{kg/m^3})$$

$$p = 101\,300\,(1 - 22.6 \times 10^{-6}\,h)^{5.256} \qquad (\mathrm{Pa})$$

$R_v = 461.5$ J/(kg · K) (for water vapour)

$R_a = 287.1$ J/(kg · K) (for air)

$$pV = wR_aT$$

$$p_t = p_a + p_v$$

$$p_v = \frac{p_t W}{0.622 + W}$$

$$rh = \frac{p_v}{p_{vs}} \times 100$$

TABLE 4.1

Emittances and Absorptances for Some Surfaces
(From *ASHRAE Handbook 1981 Fundamentals*, Table 3, p. 2.8) [4.1]

Surface	Fraction of blackbody radiation at 10 to 38°C	540°C	Absorptivity for solar radiation
1. Small hole in an enclosure	0.97–0.99	0.97–0.99	0.97–0.99
2. Black, nonmetallic surfaces	0.90–0.98	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	0.75–0.90	0.65–0.80
4. Yellow and buff building materials	0.85–0.95	0.70–0.85	0.50–0.70
5. White or light cream surfaces	0.85–0.95	0.60–0.75	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	0.30–0.50	0.40–0.65
9. Polished brass, copper	0.02–0.05	0.05–0.15	0.30–0.50
10. Highly polished tin, aluminum, nickel, chrome	0.02–0.04	0.05–0.10	0.10–0.40

$$W = \epsilon W_b = \epsilon \sigma T^4 \qquad F_E = \frac{1}{1/\epsilon_1 + 1/\epsilon_2 - 1}$$

$$q_1 = W_1 A_1 = \sigma A_1 T_1^4$$

$$h = \frac{2\gamma}{g\rho r}$$

$$W = \bar{\mu} A\theta \frac{(p_1 - p_2)}{\ell} \qquad M_c = \frac{1}{R_c} = \frac{1}{R_1 + R_2} \qquad M = \frac{\bar{\mu}}{\ell}$$

$$W = MA\theta(p_1 - p_2)$$

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 [illegible] kg/m²	[illegible]		

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	Over water	Temp., °C	Pressure, Pa Over ice	Over water	Temp., °C	Press., kPa	Temp., °C	Press., kPa
−50	3.935	6.409	−22	85.02	105.4	5	0.8719	33	5.031
−49	4.449	7.124	−21	93.70	115.0	6	0.9347	34	5.320
−48	5.026	7.975	−20	103.2	125.4	7	1.001	35	5.624
−47	5.671	8.918	−19	113.5	136.6	8	1.072	36	5.942
−46	6.393	9.961	−18	124.8	148.8	9	1.147	37	6.276
−45	7.198	11.11	−17	137.1	161.9	10	1.227	38	6.626
−44	8.097	12.39	−16	150.6	176.0	11	1.312	39	6.993
−43	9.098	13.79	−15	165.2	191.2	12	1.402	40	7.378
−42	10.21	15.34	−14	181.1	207.6	13	1.497	41	7.780
−41	11.45	17.04	−13	198.4	225.2	14	1.598	42	8.202
−40	12.83	18.91	−12	217.2	244.1	15	1.704	43	8.642
−39	14.36	20.97	−11	237.6	264.4	16	1.817	44	9.103
−38	16.06	23.23	−10	259.7	286.3	17	1.937	45	9.586
−37	17.94	25.71	−9	283.7	309.7	18	2.063	46	10.09
−36	20.02	28.42	−8	309.7	334.8	19	2.196	47	10.62
−35	22.33	31.39	−7	337.9	361.8	20	2.337	48	11.17
−34	24.88	34.63	−6	368.5	390.6	21	2.486	49	11.74
−33	27.69	38.18	−5	401.5	421.5	22	2.643	50	12.33
−32	30.79	42.05	−4	437.2	454.5	23	2.809	51	12.96
−31	34.21	46.28	−3	475.7	489.8	24	2.983	52	13.61
−30	37.98	50.88	−2	517.3	527.5	25	3.167	53	14.29
−29	42.13	55.89	−1	562.3	567.8	26	3.361	54	15.00
−28	46.69	61.39	0	610.8	610.8	27	3.565	55	15.74
				Triple point					
−27	51.70	67.27	+0.01	of water		28	3.780	56	16.51
−26	57.20	73.71	1	—	656.6	29	4.006	57	17.31
−25	63.23	80.70	2	—	705.5	30	4.243	58	19.15
−24	69.85	88.27	3	—	757.5	31	4.493	59	19.02
−23	77.09	96.49	4	—	812.9	32	4.755	60	19.92

Material (For unit thickness of 1 metre)	Permeability ng/(Pa · s · m) dry cup	wet cup	Other
Concrete 1:2:4 mix		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 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/m²	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	—

All values from [5.18] converted to SI unit.
1 ng/(Pa · s · m²) = 1 × 10⁻¹² kg/(N · s) [illegible]

2

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)

$$C = k/t \quad (\mathrm{W/(m^2 \cdot K)})$$

$$R_{total} = \frac{1}{C} + R_1 + R_2 + R_3 \ldots + R_n$$

$$R = \frac{1}{C} = \frac{t}{k} \quad (\mathrm{m^2 \cdot K/W})$$

ion through one square metre of a

$$\frac{q}{A} = U(t_i - t_o) \quad (\mathrm{W/m^2}) \qquad Q = \frac{A}{R}\,(\mathrm{D.D.})$$

$$\frac{p}{\rho g} + \frac{V^2}{2g} + z = \text{a constant} \qquad Q = CA\left[\frac{2}{\rho}(p_1 - p_2)\right]^{1/2}$$

3

TABLE 8.3

Effective Emissivities of Air Spaces
(From *ASHRAE Handbook 1981 Fundamentals*, Table 2, Section B, p. 23.13) [8.1]

			E, effective	
Surface	Reflectivity, %	ϵ average	$\epsilon_1 = 0.90$, $\epsilon_2 = \epsilon$	$\epsilon_1 = \epsilon_2 = \epsilon$
Aluminum foil, bright	92-97	0.05	0.05	0.03
Aluminum sheet	80-95	0.12	0.12	0.06
Polished aluminum paper	75-84	0.20	0.20	0.11
Steel, galvanized, bright	70-80	0.25	0.24	0.15
Aluminum paint	30-70	0.50	0.47	0.35
Building materials	5-15	0.90	0.82	0.82

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]

		Air space		Thickness			
				19 mm		92 mm	
Position	Direction of flow	Mean temp., °C	Temp. diff., K	$E = 0.03$	$E = 0.82$	$E = 0.03$	$E = 0.82$
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

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

$q_s = SC \times SHGF + U(t_o - t_i)$

Transmittance and U-Values for Some Glazing Units
(From Stephenson, D.G., Canadian Building Digest 101, Table 1, DBR/NRCC, 1968) [9.6]

	Transmittance without shades		*U*-values W/(m² · K)	
Type of Window	Light	Solar heat	No shade	Curtain or blind
Single glazing				
Clear sheet glass	0.90	0.80	5.7	4.5
Regular plate glass	0.87	0.77	5.7	4.5
Heat-absorbing plate	0.50	0.45	5.7	4.5
Double glazing				
Regular plate / Air space / Regular plate	0.77	0.60	3.4	2.8
Heat-absorbing plate / Air space / Regular plate	0.45	0.35	3.4	2.8
Regular plate-reflective / Air space / Regular plate	0.35	0.16	1.7	—

Note: Clear sheet 1/8 in. (3 mm) thick. Plate glass 1/4 in. (6 mm) thick. Air space 1/2 in. (12.5 mm) thick.

Shading Coefficients for Some Glazing Units
(From Stephenson, D.G., Canadian Building Digest 101, Table 1, DBR/NRCC, 1968) [9.6]

	Shading coefficient			
	No shade	With curtain		With venetian blind
Type of Window		Min.	Max.	
Single glazing				
Clear sheet glass	1.00	0.45	0.65	0.55
Regular plate glass	0.95	0.45	0.65	0.55
Heat-absorbing plate	0.70	0.40	0.50	0.47
Double glazing				
Regular plate / Air space / Regular plate	0.83	0.40	0.60	0.50
Heat-absorbing plate / Air space / Regular plate	0.55	0.33	0.43	0.36
Regular plate-reflective / Air space / Regular plate	0.25	—	—	—

TABLE 8.2

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

		Surface emissivity		
Position of surface	Direction of flow	$\epsilon = 0.90$	$\epsilon = 0.20$	$\epsilon = 0.05$
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	—	—

$$t_e = t_o + \alpha I_t/h_o - \epsilon \Delta R/h_o.$$

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.

$$\frac{V_z}{V_g} = \left[\frac{Z}{Z_g}\right]^{\alpha}. \qquad \frac{G_z}{G_g} = \left[\frac{Z}{Z_g}\right]^{\beta}$$

$$G_g = 1.35\ V_g$$

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

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

$$Q = CA\,[(2/\rho)(\Delta p)]^{1/2}$$

where Q = flow rate in m³/s. C, the orifice coefficient, is commonly taken as 0.60.

$$p_s = g\,\frac{hp_t}{R_a}\left(\frac{1}{T_o} - \frac{1}{T_i}\right)$$

$$= 0.0342\ hp_t\left(\frac{1}{T_o} - \frac{1}{T_i}\right). \qquad \text{(Pa)}$$

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

$$H_s = Q\rho c_p(t_i - t_o) \qquad \text{(W)}$$

where H_s = heat required, W
Q = rate of air flow, L/s
ρ = mass density of air, kg/m³
c_p = specific heat of air, kJ/kg · K
t_o, t_i are outdoor and indoor temperatures, °C

For ρ = 1.20 kg/m³ and c_p for air = 1.005 kJ/kg

$$H_s = 1.21\ Q(t_i - t_o) \qquad \text{(W)}$$

$$H_\ell = Q\rho(W_i - W_o)h_{fg}$$

where H_ℓ = heat required, W
Q = air flow rate, L/s
W_i = humidity ratio, kg/kg of dry indoor air
W_o = humidity ratio, kg/kg of dry outdoor air
h_{fg} = latent heat of evaporation of water, kJ/kg

For air density ρ = 1.20 kg/m³ and h_{fg} = 2465 kJ/kg

$$H_\ell = 3000\ Q(W_i - W_o)$$

All the best!

K.D.

Carrier

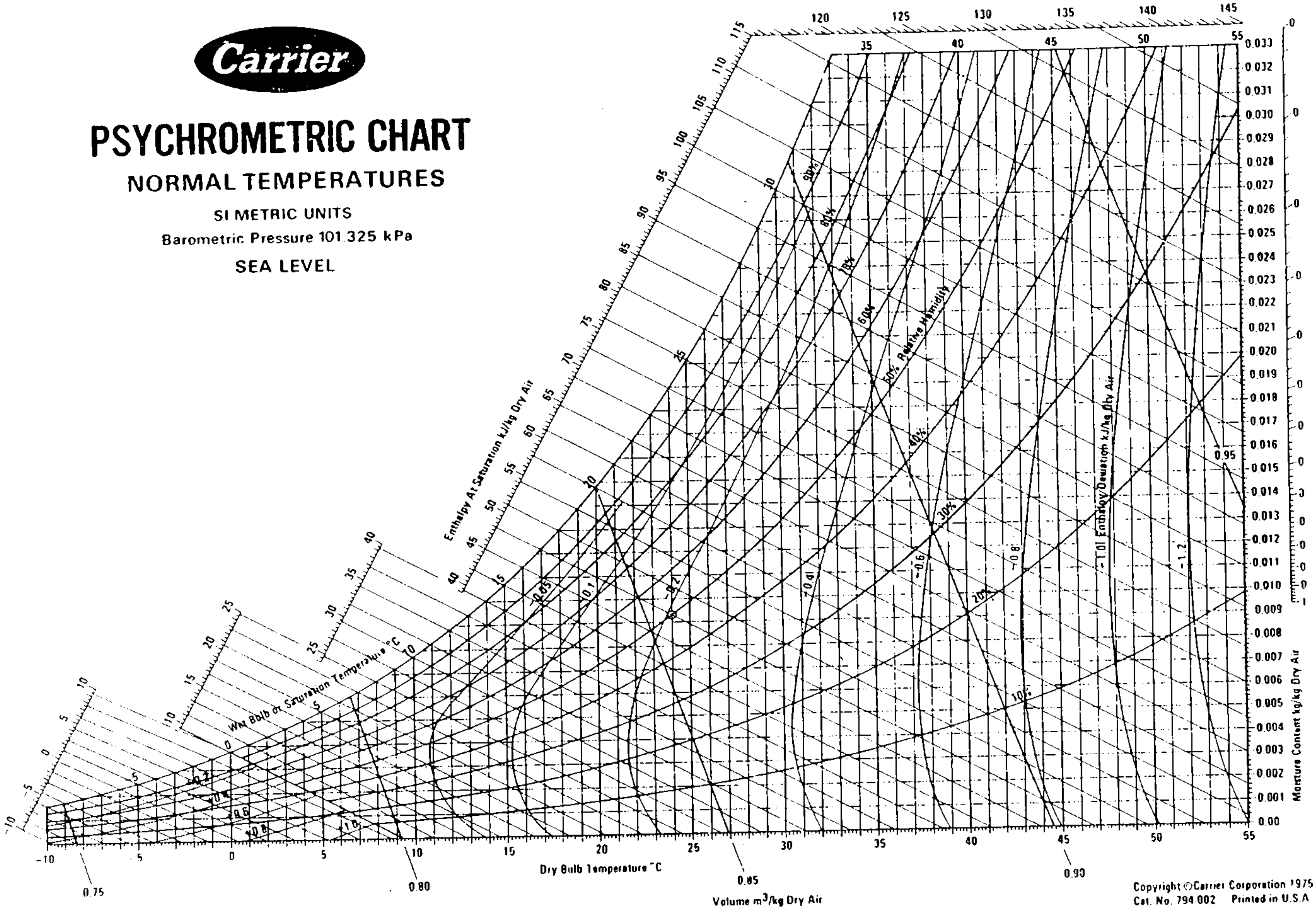
PSYCHROMETRIC CHART

NORMAL TEMPERATURES

SI METRIC UNITS

Barometric Pressure 101.325 kPa

SEA LEVEL



Below 0°C Properties and Enthalpy Deviation Lines Are For Ice