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## **APPENDIX B**

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# **PSYCHROMETRIC CHART, TABLES OF PROPERTIES, AND I-P UNITS TO SI UNITS CONVERSION**

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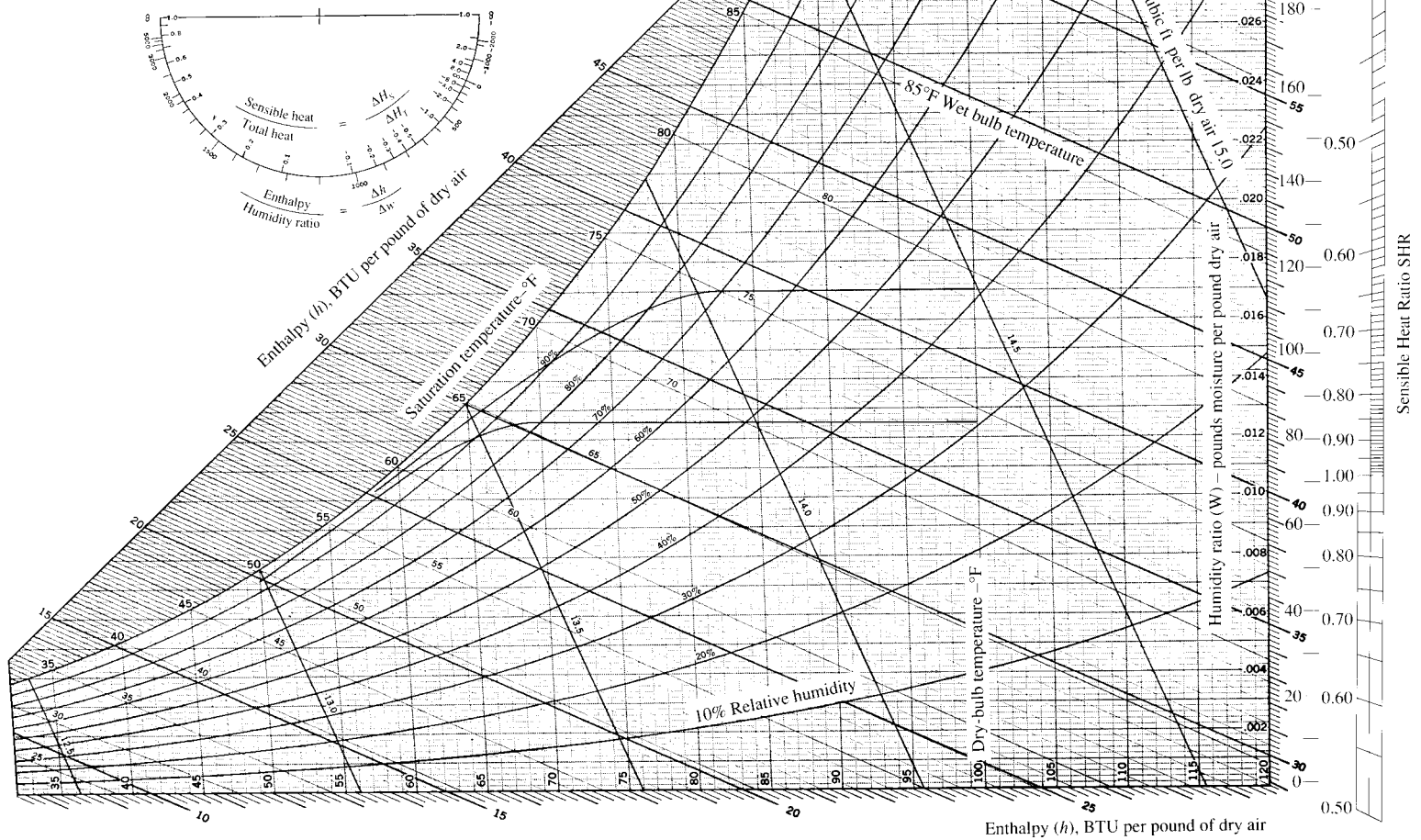
## ASHRAE Psychrometric Chart No. 1

Normal temperature

Barometric pressure 29.921 inches of mercury

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**FIGURE B.1** Psychrometric chart. Based on ASHRAE Psychrometric Chart No. 1. Reprinted with permission from ASHRAE Inc. Sensible heat ratio (SHR), humidity ratio scale in grains/lb, and two cooling and dehumidifying curves were added by author.

**TABLE B.1** Thermodynamic Properties of Moist Air (at Atmospheric Pressure 14.696 psia) and Water

Temp $T$ , °F	Humidity ratio $w_s$ $\text{lb}_w/\text{lb}_{da}$	Volume, $\text{ft}^3/\text{lb dry air}$			Enthalpy, $\text{Btu/lb dry air}$			Saturated water vapor		Enthalpy, Btu/lb		
		$v_a$ $v_{as}$ $v_s$			$h_a$ $h_{as}$ $h_s$			Absolute pressure $p$		Sat. water liq. $h_f$	Evap. $h_{ig}/h_{fg}$	Sat. water vapor $h_g$
								psi	in. Hg.			
32	0.003790	12.389	0.075	12.464	7.687	4.073	11.760	0.08865	0.18049	− 0.02	1075.15	1075.14
33	0.003947	12.414	0.079	12.492	7.927	4.243	12.170	0.09229	0.18791	0.99	1074.59	1075.58
34	0.004109	12.439	0.082	12.521	8.167	4.420	12.587	0.09607	0.19559	2.00	1074.02	1076.01
35	0.004277	12.464	0.085	12.550	8.408	4.603	13.010	0.09998	0.20355	3.00	1073.45	1076.45
36	0.004452	12.490	0.089	12.579	8.648	4.793	13.441	0.10403	0.21180	4.01	1072.88	1076.89
37	0.004633	12.515	0.093	12.608	8.888	4.990	13.878	0.10822	0.22035	5.02	1072.32	1077.33
38	0.004820	12.540	0.097	12.637	9.128	5.194	14.322	0.11257	0.22919	6.02	1071.75	1077.77
39	0.005014	12.566	0.101	12.667	9.369	5.405	14.773	0.11707	0.23835	7.03	1071.18	1078.21
40	0.005216	12.591	0.105	12.696	9.609	5.624	15.233	0.12172	0.24783	8.03	1070.62	1078.65
41	0.005424	12.616	0.110	12.726	9.849	5.851	15.700	0.12654	0.25765	9.04	1070.05	1079.09
42	0.005640	12.641	0.114	12.756	10.089	6.086	16.175	0.13153	0.26780	10.04	1069.48	1079.52
43	0.005863	12.667	0.119	12.786	10.330	6.330	16.660	0.13669	0.27831	11.04	1068.92	1079.96
44	0.006094	12.692	0.124	12.816	10.570	6.582	17.152	0.14203	0.28918	12.05	1068.35	1080.40
45	0.006334	12.717	0.129	12.8946	10.810	6.843	17.653	0.14755	0.30042	13.05	1067.79	1080.84
46	0.006581	12.743	0.134	12.877	11.050	7.114	18.164	0.15326	0.31205	14.05	1067.22	1081.28
47	0.006838	12.768	0.140	12.908	11.291	7.394	18.685	0.15917	0.32407	15.06	1066.66	1081.71
48	0.007103	12.793	0.146	12.939	11.531	7.684	19.215	0.16527	0.33650	16.06	1066.09	1082.15
49	0.007378	12.818	0.152	12.970	11.771	7.984	19.756	0.17158	0.34935	17.06	1065.53	1082.59
50	0.007661	12.844	0.158	13.001	12.012	8.295	20.306	0.17811	0.36263	18.06	1064.96	1083.03
51	0.007955	12.869	0.164	13.033	12.252	8.616	20.868	0.18484	0.37635	19.06	1064.40	1083.46
52	0.008259	12.894	0.171	13.065	12.492	8.949	21.441	0.19181	0.39054	20.07	1063.83	1083.90
53	0.008573	12.920	0.178	13.097	12.732	9.293	22.025	0.19900	0.40518	21.07	1063.27	1084.34
54	0.008897	12.945	0.185	13.129	12.973	9.648	22.621	0.20643	0.42031	22.07	1062.71	1084.77
55	0.009233	12.970	0.192	13.162	13.213	10.016	23.229	0.21410	0.43592	23.07	1062.14	1085.21
56	0.009580	12.995	0.200	13.195	13.453	10.397	23.850	0.22202	0.45204	24.07	1061.58	1085.65
57	0.009938	13.021	0.207	13.228	13.694	10.790	24.484	0.23020	0.46869	25.07	1061.01	1086.08
58	0.010309	13.046	0.216	13.262	13.934	11.197	25.131	0.23864	0.48588	26.07	1060.45	1086.52
59	0.010692	13.071	0.224	13.295	14.174	11.618	25.792	0.24735	0.50362	27.07	1059.89	1086.96
60	0.011087	13.096	0.233	13.329	14.415	12.052	26.467	0.25635	0.52192	28.07	1059.32	1087.39
61	0.011496	13.122	0.242	13.364	14.655	12.502	27.157	0.26562	0.54081	29.07	1058.76	1087.83
62	0.011919	13.147	0.251	13.398	14.895	12.966	27.862	0.27519	0.56029	30.07	1058.19	1088.27
63	0.012355	13.172	0.261	13.433	15.135	13.446	28.582	0.28506	0.58039	31.07	1057.63	1088.70

TABLE B.1 (Continued)

Temp $T, ^\circ\text{F}$	Humidity ratio $w_v$ , $\text{lb}_w/\text{lb}_{da}$	Volume, $\text{ft}^3/\text{lb dry air}$			Enthalpy, $\text{Btu}/\text{lb dry air}$			Saturated water vapor		Enthalpy, $\text{Btu}/\text{lb}$		
		$v_a$ $v_{as}$ $v_s$			$h_a$ $h_{as}$ $h_s$			Absolute pressure $p$		Sat. water liq. $h_f$	Evap. $h_{fg}/h_{fg}$	Sat. water vapor $h_g$
								psi	in. Hg.			
64	0.012805	13.198	0.271	13.468	15.376	13.942	29.318	0.29524	0.60112	32.07	1057.07	1089.14
65	0.013270	13.223	0.281	13.504	15.616	14.454	30.071	0.30574	0.62249	33.07	1056.50	1089.57
66	0.013750	13.248	0.292	13.540	15.856	14.983	30.840	0.31656	0.64452	34.07	1055.94	1090.01
67	0.014246	13.273	0.303	13.577	16.097	15.530	31.626	0.32772	0.66724	35.07	1055.37	1090.44
68	0.014758	13.299	0.315	13.613	16.337	16.094	32.431	0.33921	0.69065	36.07	1054.81	1090.88
69	0.015286	13.324	0.326	13.650	16.577	16.677	33.254	0.35107	0.71478	37.07	1054.24	1091.31
70	0.015832	13.349	0.339	13.688	16.818	17.279	34.097	0.36328	0.73964	38.07	1053.68	1091.75
71	0.016395	13.375	0.351	13.726	17.058	17.901	34.959	0.37586	0.76526	39.07	1053.11	1092.18
72	0.016976	13.400	0.365	13.764	17.299	18.543	35.841	0.38882	0.79164	40.07	1052.55	1092.61
73	0.017575	13.425	0.378	13.803	17.539	19.204	36.743	0.40217	0.81883	41.07	1051.98	1093.05
74	0.018194	13.450	0.392	13.843	17.779	19.889	37.668	0.41592	0.84682	42.06	1051.42	1093.48
75	0.018833	13.476	0.407	13.882	18.020	20.595	38.615	0.43008	0.87564	43.06	1050.85	1093.92
76	0.019491	13.501	0.422	13.923	18.260	21.323	39.583	0.44465	0.90532	44.06	1050.29	1094.35
77	0.020170	13.526	0.437	13.963	18.500	22.075	40.576	0.45966	0.93587	45.06	1049.72	1094.78
78	0.020871	13.551	0.453	14.005	18.741	22.851	41.592	0.47510	0.96732	46.06	1049.16	1095.22
79	0.021594	13.577	0.470	14.046	18.981	23.652	42.633	0.49100	0.99968	47.06	1048.59	1095.65
80	0.022340	13.602	0.487	14.089	19.222	24.479	43.701	0.50736	1.03298	48.06	1048.03	1096.08
81	0.023109	13.627	0.505	14.132	19.462	25.332	44.794	0.52419	1.06725	49.06	1047.46	1096.51
82	0.023902	13.653	0.523	14.175	19.702	26.211	45.913	0.54150	1.10250	50.05	1046.89	1096.95
83	0.024720	13.678	0.542	14.220	19.943	27.120	47.062	0.55931	1.13877	51.05	1046.33	1097.38
84	0.025563	13.703	0.561	14.264	20.183	28.055	48.238	0.57763	1.17606	52.05	1045.76	1097.81
85	0.026433	13.728	0.581	14.310	20.424	29.021	49.445	0.59647	1.21442	53.05	1045.19	1098.24
86	0.027329	13.754	0.602	14.356	20.664	30.017	50.681	0.61584	1.25385	54.05	1044.63	1098.67
87	0.028254	13.779	0.624	14.403	20.905	31.045	51.949	0.63575	1.29440	55.05	1055.06	1099.11
88	0.029208	13.804	0.646	14.450	21.145	32.105	53.250	0.65622	1.33608	56.05	1043.49	1099.54
89	0.030189	13.829	0.669	14.498	21.385	33.197	54.582	0.67726	1.37892	57.04	1042.92	1099.97
90	0.031203	13.855	0.692	14.547	21.626	34.325	55.951	0.69889	1.42295	58.04	1042.36	1100.40
91	0.032247	13.880	0.717	14.597	21.866	35.489	57.355	0.72111	1.46820	59.04	1041.79	1100.83
92	0.033323	13.905	0.742	14.647	22.107	36.687	58.794	0.74394	1.51468	60.04	1041.22	1101.26
93	0.034433	13.930	0.768	14.699	22.347	37.924	60.271	0.76740	1.56244	61.04	1040.65	1101.69
94	0.035577	13.956	0.795	14.751	22.588	39.199	61.787	0.79150	1.61151	62.04	1040.08	1102.12
95	0.036757	13.981	0.823	14.804	22.828	40.515	63.343	0.81625	1.66189	63.03	1039.51	1102.55

Abridged from ASHRAE Handbook 1997, Fundamentals. Reprinted with permission.

**TABLE B.2** Physical Properties of Air (at Atmospheric Pressure 14.696 psia)

Temp. <i>T</i> , °F	$\rho$ , lb <sub>m</sub> /ft <sup>3</sup>	$c_p$ , Btu/lb <sub>m</sub> · °F	$\mu \times 10^5$ , lb <sub>m</sub> /ft · s	$\nu \times 10^3$ , ft <sup>2</sup> /s	$k$ , Btu/h · ft · °F	$\alpha$ , ft <sup>2</sup> /h	Pr	$\beta \times 10^3$ , 1/°F	$g\beta\rho^2/\mu^2$ , 1/°F <sup>3</sup> · ft <sup>3</sup>
0	0.0862	0.240	1.09	0.126	0.0132	0.639	0.721	2.18	$4.39 \times 10^6$
30	0.0810	0.240	1.15	0.142	0.0139	0.714	0.716	2.04	3.28
60	0.0764	0.240	1.21	0.159	0.0146	0.798	0.711	1.92	2.48
80	0.0735	0.240	1.24	0.169	0.0152	0.855	0.708	1.85	2.09
100	0.0710	0.240	1.28	0.181	0.0156	0.919	0.703	1.79	1.76
150	0.0651	0.241	1.36	0.209	0.0167	1.06	0.698	1.64	1.22
200	0.0602	0.241	1.45	0.241	0.0179	1.24	0.694	1.52	0.840
250	0.0559	0.242	1.53	0.274	0.0191	1.42	0.690	1.41	0.607
300	0.0523	0.243	1.60	0.306	0.0203	1.60	0.686	1.32	0.454
400	0.0462	0.245	1.74	0.377	0.0225	2.00	0.681	1.16	0.264
500	0.0413	0.247	1.87	0.453	0.0246	2.41	0.680	1.04	0.163
600	0.0374	0.251	2.00	0.535	0.0270	2.88	0.680	0.944	$79.4 \times 10^3$
800	0.0315	0.257	2.24	0.711	0.0303	3.75	0.684	0.794	50.6
1000	0.0272	0.263	2.46	0.906	0.0337	4.72	0.689	0.685	27.0
1500	0.0203	0.277	2.92	1.44	0.0408	7.27	0.705	0.510	7.96

Source: *Fundamentals of Momentum Heat and Mass Transfer*, Welty et al., 1976. John Wiley & Sons. Reprinted with permission.

**TABLE B.3** Physical Properties of Water (at Atmospheric Pressure 14.696 psia)

<i>T</i> , °F	$\rho$ , lb <sub>m</sub> /ft <sup>3</sup>	$c_p$ , Btu/lb <sub>m</sub> · °F	$\mu \times 10^3$ , lb <sub>m</sub> /ft · s	$\nu \times 10^5$ , ft <sup>2</sup> /s	$k$ , Btu/ft · °F	$\alpha$ , ft <sup>2</sup> /h	Pr	$\beta \times 10^3$ , 1/°F	$g\beta\rho^2/\mu^2$ , 1/°F <sup>3</sup> · ft <sup>3</sup>
32	62.4	1.01	1.20	1.93	0.319	5.06	13.7	− 0.350	
60	62.3	1.00	0.760	1.22	0.340	5.45	8.07	0.800	17.2
80	62.2	0.999	0.578	0.929	0.353	5.67	5.89	1.30	48.3
100	62.1	0.999	0.458	0.736	0.364	5.87	4.51	1.80	107
150	61.3	1.00	0.290	0.474	0.383	6.26	2.72	2.80	403
200	60.1	1.01	0.206	0.342	0.392	6.46	1.91	3.70	1010
250	58.9	1.02	0.160	0.272	0.395	6.60	1.49	4.70	2045
300	57.3	1.03	0.130	0.227	0.395	6.70	1.22	5.60	3510
400	53.6	1.08	0.0930	0.174	0.382	6.58	0.950	7.80	8350
500	49.0	1.19	0.0700	0.143	0.349	5.98	0.859	11.0	17350
600	42.4	1.51	0.0579	0.137	0.293	4.58	1.07	17.5	30300

Source: *Fundamental of Momentum Heat and Mass Transfer*, Welty et al., 1976 John Wiley & Sons. Reprinted with permission.

**TABLE B.4** Conversion of Inch-Pound (I-P) Units to International System of Units (SI)

Unit	Equivalents	Unit	Equivalents
atm	= 14.696 lb <sub>f</sub> /in <sup>2</sup>	Btu/h · cfm	= 06209 W · s/L
	= 33.91 ft of water	Btu/h · ft	= 0.961 W/m
	= 29.92 in. Hg.	Btu/h · ft <sup>2</sup>	= 3.155 W/m <sup>2</sup>
	= 1.013 bars	Btu/h · ft <sup>2</sup> · °F	= 5.678 W/m <sup>2</sup> · °C
	= 101,325 Pa	Btu · in./h · ft <sup>2</sup> · °F	= 0.1442 W/m · °C
Btu (British thermal unit)	= 778 ft · lb <sub>f</sub>	Btu/lb	= 2.326 kJ/kg
	= 1055 J	Btu/lb · °F	= 4.187 kJ/kg · °C
	= 252 cal	Btu/lb · ft	= 7.63 kJ/kg · m
Btu · ft/h · ft <sup>2</sup> · °F	= 1.731 W/m · °C	Btu/yr · ft <sup>2</sup>	= 0.000293 kWh/yr · ft <sup>2</sup>
Btu/h	= 0.293 W	clo (clothing insulation)	= 0.155 m <sup>2</sup> · °C/W

TABLE B.4 Conversion of Inch-Pound (I-P) Units to International System of Units (SI) (Continued)

Unit	Equivalents	Unit	Equivalents
clo	= 0.88 h · ft <sup>2</sup> · °F/Btu	kW/ton	= [3.516/(kW/ton)] COP <sub>ref</sub>
ft <sup>3</sup> /lb	= 0.0624 m <sup>3</sup> /kg	L	= 0.001 m <sup>3</sup>
cfm (cubic foot per minute)	= 7.481 gpm		= 0.0353 ft <sup>3</sup>
	= 0.4719 L/s	lb <sub>f</sub>	= 4.45 N
	= 0.02832 m <sup>3</sup> /min	lb/Btu	= 0.4786 kg/kJ
cfm/ft	= 1.548 L/s · m	lb · °F/Btu	= 0.2659 kg · °C/kJ
cfm/ft <sup>2</sup>	= 5.078 L/s · m <sup>2</sup>	lb <sub>f</sub> /ft <sup>2</sup>	= 0.0069 lb <sub>f</sub> /in <sup>2</sup>
	= 18.2 m <sup>3</sup> /h · m <sup>2</sup>		= 4.88 kg/m <sup>2</sup>
cfm/ton <sub>ref</sub>	= 0.1342 L/s · k W <sub>ref</sub>	lb/ft <sup>3</sup>	= 16.0 kg/m <sup>3</sup>
\$/ft <sup>2</sup>	= 10.76 \$/m <sup>2</sup>	lb/ft · h	= 0.413 mPa · s
°F	= (°F − 32)/(1.8)°C	lb <sub>f</sub> /ft · s	= 1490 mPa · s
fc	= 10.76 lx	lb/h	= 0.126 g/s
fpm	= 0.01136 mi/h	lb/h · ft <sup>2</sup>	= 4.88 kg/h · m <sup>2</sup>
	= 0.00508 m/s	lb/lb	= 1.0 kg/kg
ft	= 0.3048 m	lb (mass)	= 7000 gr
	= 304.8 mm		= 16 oz
ft <sup>2</sup>	= 144 in. <sup>2</sup>		= 0.4536 kg
	= 0.0929 m <sup>2</sup>	lb of water	= 0.01602 ft <sup>3</sup>
ft <sup>3</sup>	= 0.748 gal		= 0.12 gal
ft · lb <sub>f</sub>	= 1.356 J	L/s	= 2.119 cfm
ft · lb <sub>f</sub> /min	= 0.0226 W		= 15.85 gpm
ft/s, fps	= 0.3048 m/s	m	= 1.094 yard
ft <sup>2</sup> /s(kinematic viscosity)	= 92,900 mm <sup>2</sup> /s		= 3.281 ft
ft WC	= 0.4334 lb <sub>f</sub> /in <sup>2</sup>		= 39.37 in.
	= 2.99 kPa	met	= 58.2 W/m <sup>2</sup>
gal	= 0.1337 ft <sup>3</sup>		= 18.46 Btu/h · ft <sup>2</sup>
	= 8.35 lb of water	mg	= 0.01543 gr
	= 3.785 L	mil	= 0.001 in.
gpm (U.S)	= 0.0631 L/s		= 25.4 μm
gpm/ton <sub>ref</sub>	= 0.0179 L/s · kW	mi	= 5280 ft
h · °F/Btu	= 1.911 °C/W		= 1.61 km
h · ft <sup>2</sup> · °F/Btu	= 0.176 m <sup>2</sup> · °C/W	mi/h	= 88 fpm
hp	= 33,000 ft · lb <sub>f</sub> /min		= 0.44 m/s
	= 550 ft · lb <sub>f</sub> /s	mm	= 0.03937 in.
	= 0.746 kW	mm Hg	= 133.3 Pa
hp (boiler)	= 33,476 Btu/h	μg	= 1 × 10 <sup>−6</sup> g
	= 9808 W	μm	= 1 × 10 <sup>−6</sup> m
in. (inch)	= 25.4 mm		= 3.94 × 10 <sup>−5</sup> in.
in. Hg (mercury)	= 0.4912 lb <sub>f</sub> /in. <sup>2</sup>	oz	= 0.0625 lb
	= 3.3 kPa		= 28.35 g
in. WC (water column)	= 0.0361 lb <sub>f</sub> /in. <sup>2</sup>	Pa (pascal)	= 1 N/m <sup>2</sup>
	= 5.20 lb <sub>f</sub> /ft <sup>2</sup>	pint	= 28.37 in. <sup>3</sup>
	= 248.6 Pa		= 0.4732 L
in. WC/(cfm) <sup>2</sup>	= 5.27 × 10 <sup>5</sup> Pa · s/m <sup>6</sup>	ppm (mass)	= 1 mg/kg
in. WG (water gauge)	= 248.6 Pa + 1 atm	psia (absolute)	= 2.307 ft water abs.
J (joule)	= 9.48 × 10 <sup>−4</sup> Btu		= 703.1 kg/m <sup>2</sup> abs.
kBtu/ft <sup>2</sup> · yr	= 3.153 kWh/m <sup>2</sup> · yr		= 6.895 kPa abs.
kg	= 2.2046 lb	psig (gauge)	= 1 lb <sub>f</sub> /in. <sup>2</sup> + 1 atm
km	= 3281 ft	quad (quadrillion)	= 1 × 10 <sup>15</sup> Btu
	= 0.6214 mi		= 1.055 EJ
kW	= 3413 Btu/h	qt (quart)	= 57.75 in. <sup>3</sup>
	= 1.341 hp		= 0.9461 L
kWh	= 3413 Btu	rad (radian)	= 57.3°

**TABLE B.4** Conversion of Inch-Pound (I-P) Units to International System of Units (SI)    *(Continued)*

Unit	Equivalents	Unit	Equivalents
rpm	= 1 r/min	ton (metric)	= 1000 kg
therm	= 100,000 Btu	ton <sub>ref</sub> (refrigeration)	= 12,000 Btu/h
	= 105.5 MJ		= 3.516 kW
ton · h	= 12,000 Btu	ton (short)	= 2000 lb
	= 3.516 kWh	torr	= 1 mm Hg
ton (long)	= 2240 lb	W	= 3.413 Btu/h
	= 1016 kg		

Most of the conversion equivalents are based on values in *ASHRAE Handbook 1997, Fundamentals*.