CAE 464/517 HVAC Systems Design
Spring 2023

January 17, 2023
HVAC Systems Drawings, Installation and Intro to Psychrometrics

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ANNOUNCEMENTS

Announcements

- ASHRAE IL Chapter Scholarship
  - Application Link: https://illinoisashrae.org/Scholarship

ASHRAE Illinois Chapter

Illinois Chapter of ASHRAE

Apply for Chapter Engineering Scholarships by January 31st

The deadline for annual Illinois Chapter ASHRAE Scholarships in 2023 is January 31st. The Chapter plans to award **up to four $1,500 scholarships** to deserving college students interested in pursuing studies in engineering, science or mathematics that are fundamental for a career in the HVAC field. **It's quick and simple to apply** for one of these scholarships. Applicants do not need to belong to an ASHRAE student chapter.

Don't let this opportunity to lower the educational expenses of the college student (and future engineer) in your life pass you by. **For additional information and application form, click here**.

Please submit your application by January 31, 2023. The Chapter plans to announce scholarship winners in the spring of 2022.

Announcements

- Do not miss this presentation!

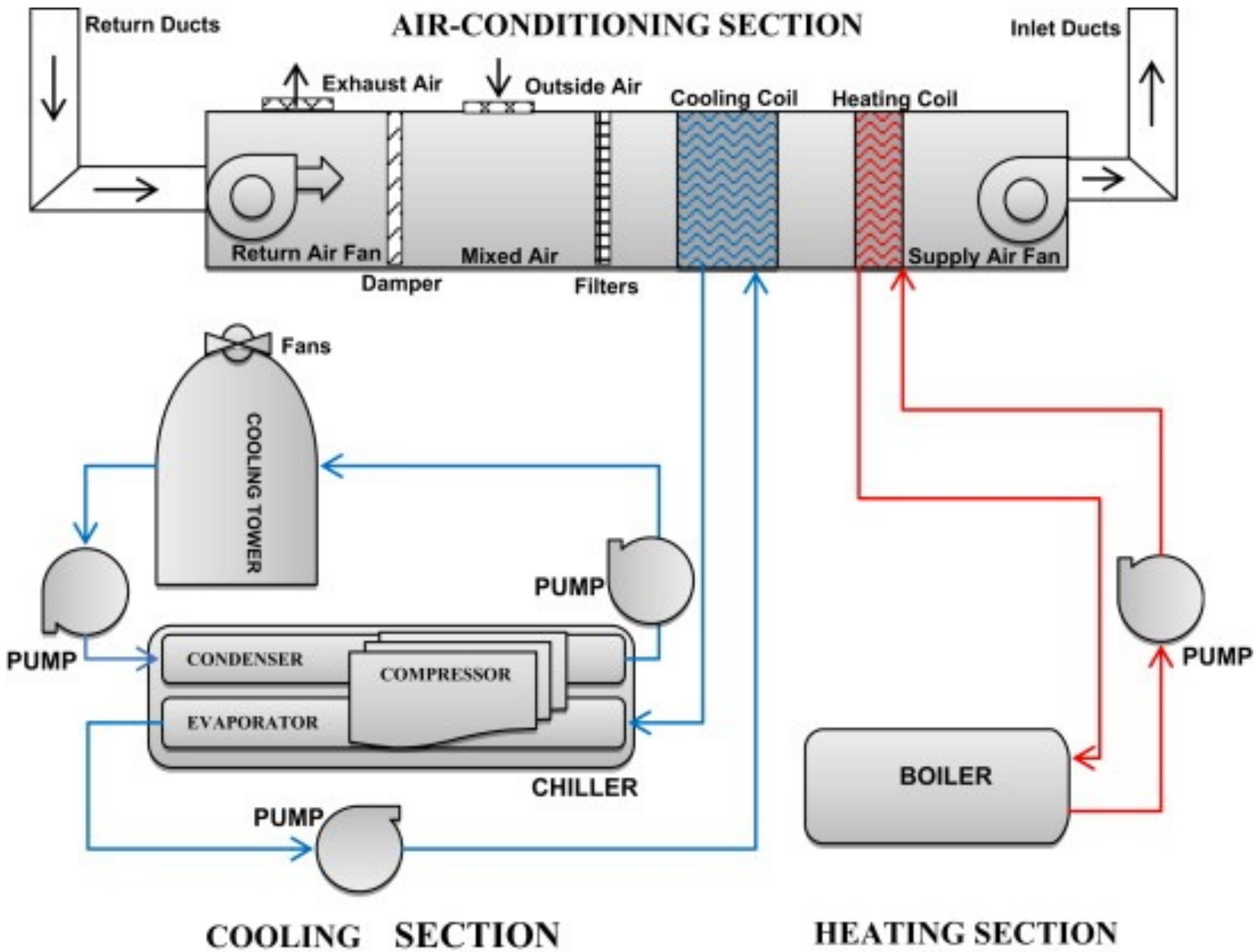
Assignment

- Assignment 1 is posted
- The assignment is due next Tuesday
- You may want to use Bluebeam

RECAP OF BUILDING HVAC SYSTEMS

Recap of Building HVAC Systems

- How many HVAC loops do you see here?



Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals

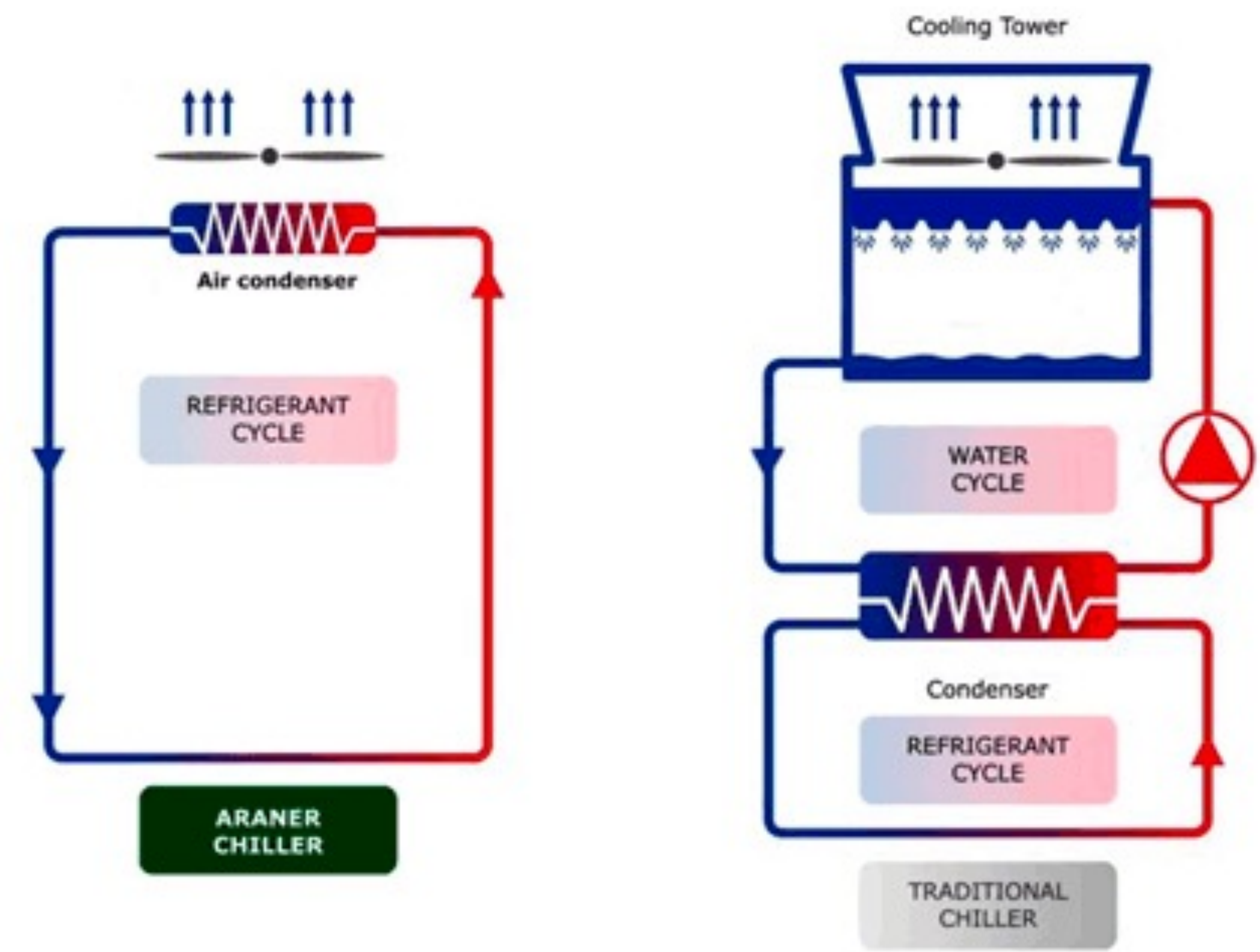
Recap of Building HVAC Systems

- The cooling is the most complex one to determine the number of loops:
  - ❑ Do we have a chilled water loop or not?
  - ❑ If it is a chilled water loop, do we have an air cooled or a water-cooled chiller?

https://theengineeringmindset.com/chiller-cooling-tower-air-handling-unit-work-together/

Recap of Building HVAC Systems

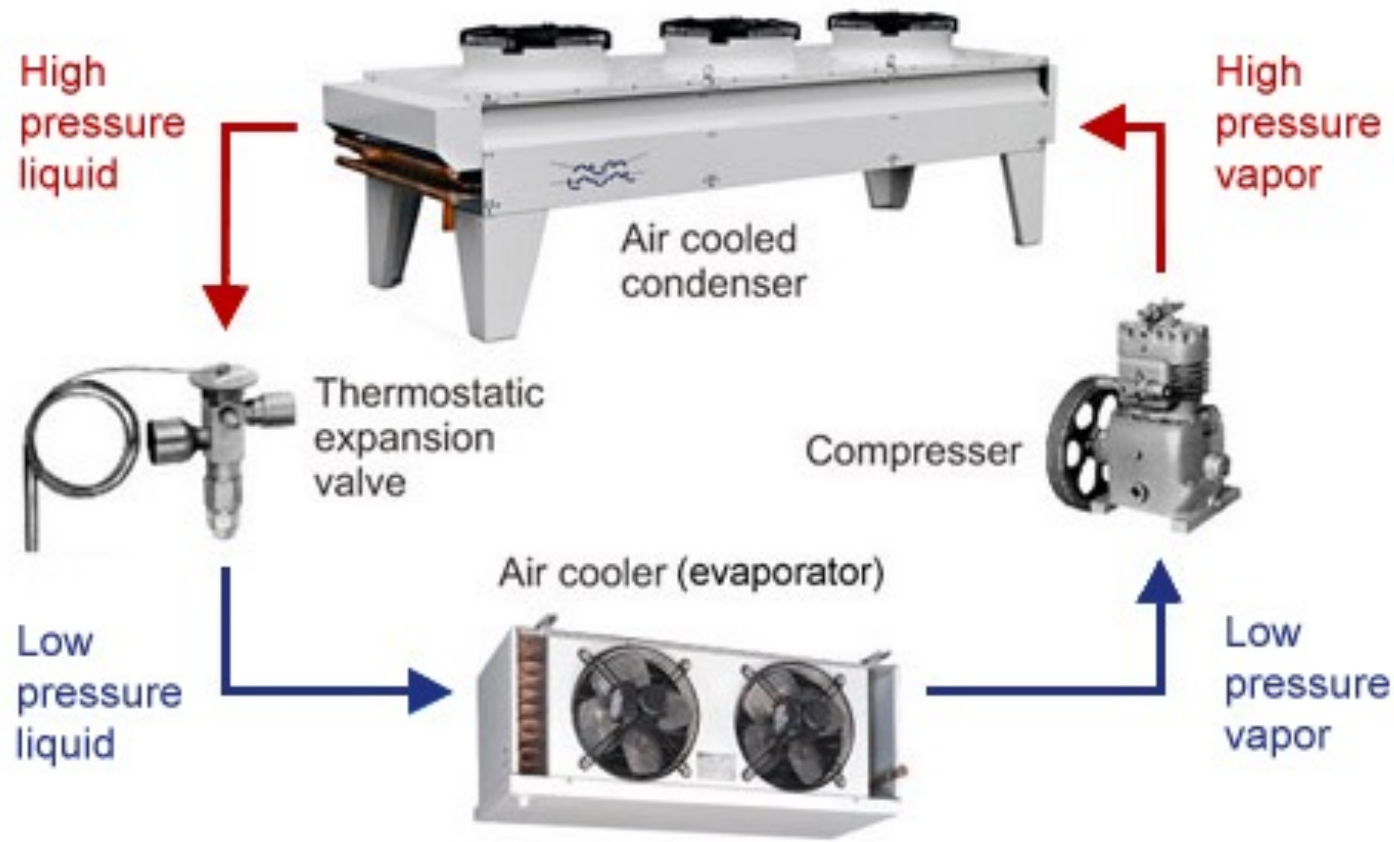
- Water cooled vs air cooled chillers



https://www.araner.com/blog/difference-between-air-cooled-and-water-cooled-chiller/

Recap of Building HVAC Systems

- How does a Direct Expansion (DX) system work?



http://coolingunitsjitsurui.blogspot.com/2017/03/dx-cooling-units.html

Recap of Building HVAC Systems

- Sometimes the heating options are simpler than cooling options (or vice versa):
  - ❑ Do we have a hydronic heating system or not?

Credits: Akram Ali, Chris Riley

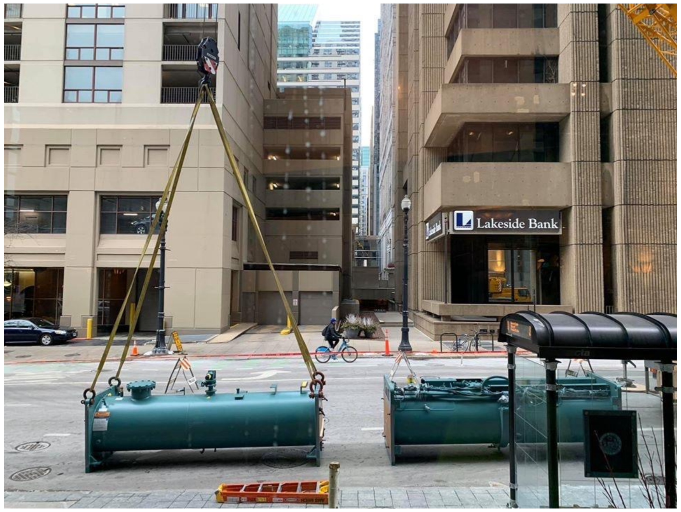
Recap of Building HVAC Systems

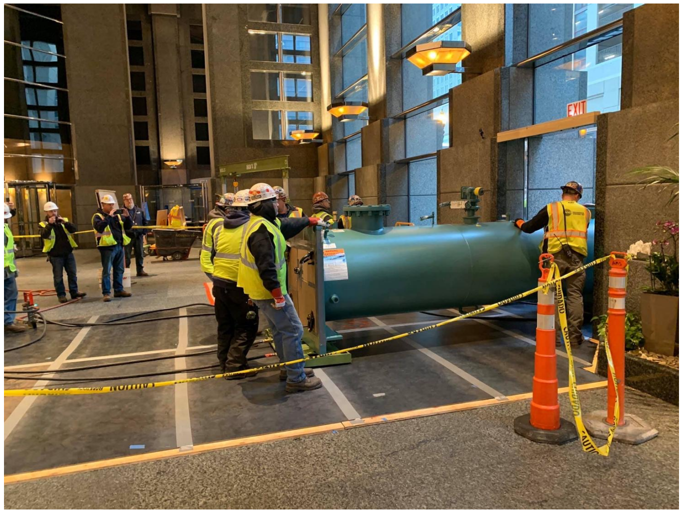
- I would recommend working on this assignment. Assume we have:
  1. Only resistance electric heat(s), what type of HVAC systems can we have?
  2. Only direct expansion component(s), what type of HVAC system can we have?
  3. An all air system. Can you provide an example? What are the heating and cooling energy sources?
  4. An all water system. Can you provide an example? What are the heating and cooling energy sources?
  5. Can you provide an example of a system that has
     - No loop
     - 1 loop
     - 2 loops
     - 3 loops
     - 4 loops
     - 5 loops

EXAMPLES OF HVAC SYSTEMS INSTALLATION

Examples of HVAC System Installation

- An example of a chiller installation/replacement
  - ❑ Six 1,000 ton chiller
  - ❑ Install on the 16th floor

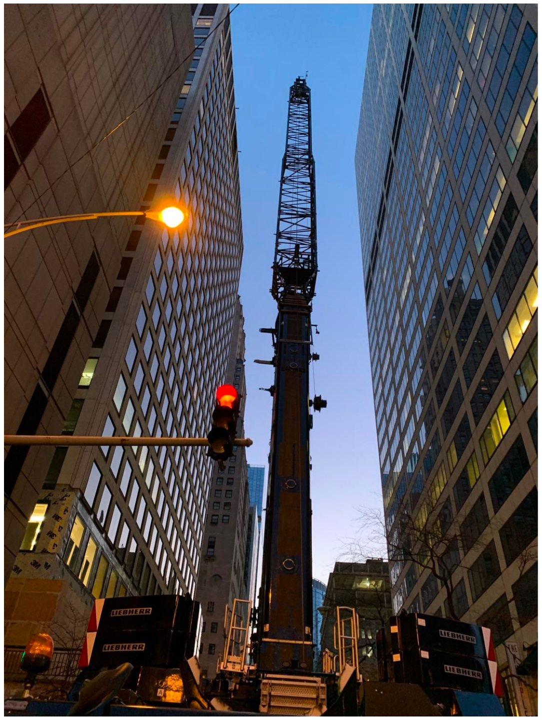




Credits: AMS Mechanical

Examples of HVAC System Installation

- An example of a chiller installation



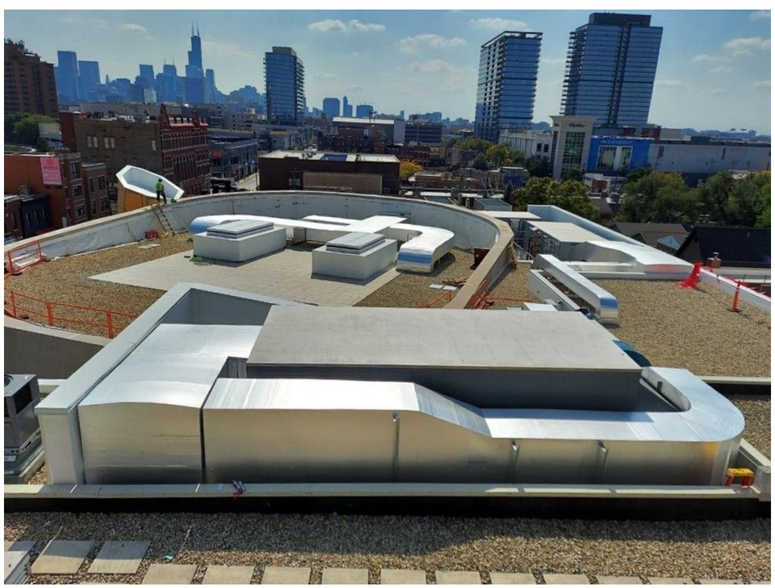
Credits: State Mechanical Services

Examples of HVAC System Installation

- To put this in perspective, we can look at some data sheets:
  - https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/water-cooled/centrifugal-liquid/CTV-PRC007M-EN_09152015.pdf
  - https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/equipment/chillers/water-cooled/Agility/HDWA-PRC001B-EN_07022020.pdf

Examples of HVAC System Installation

- An example of a ductwork installation (~50,000 ft^2 expansion)



Credit: Westside Mechanical Group

Examples of HVAC System Installation

- An example of a DOAS unit and two condensing units' installation

Credits: Westside Mechanical Group

Examples of HVAC System Installation

- An example of installing 36 new rooftop units via helicopter for a new warehouse center in the Chicago suburbs

Credits: EMCOR Services Team Mechanical

PSYCHROMETRICS
(CAE 208, CAE 331, MMAE 320)

Psychrometrics

- Psychrometrics:
  - Focuses on the properties of mixtures of dry air and water vapor
  - Is a required basics for the fundamentals of HVAC processes
  - Assumes ideal air gas assumptions since the partial pressure of water vapor is very small

(See Chapter 1 and 2 of the Handbook)

Psychrometrics

- Barometric or total pressure
  - The pressure measured with a barometer
  - The sum of the partial pressure of the dry air and the partial pressure of the water vapor
  - Water vapor is usually in the form of superheated steam at low partial pressure and temperature

Psychrometrics

- Gibbs-Dalton's (Law of Partial Pressures)
  - ❑ The amount of water vapor contained in the air may vary from zero (totally dry) to a maximum determined by the temperature and pressure of the mixture
  - ❑ The total pressure p_{tot} of moist air for a mixture of perfect gases is equal to the individual contributions of dry air and water vapor

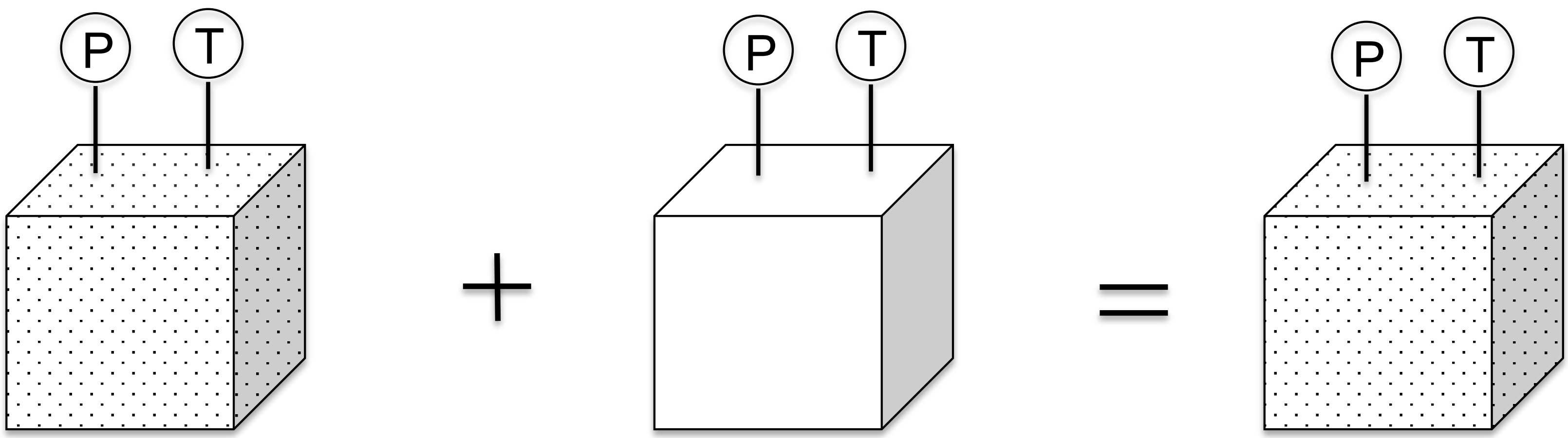
$$p_{tot} = p_a + p_{vap}$$

p_a: Partial pressure of dry air

p_{vap}: Partial pressure of water vapor

Psychrometrics

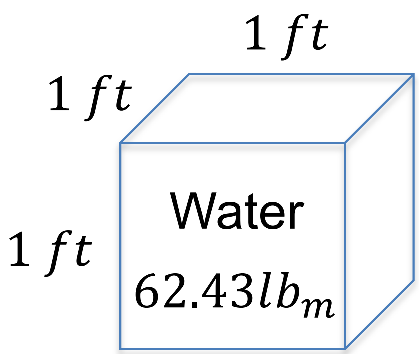
- Moist air:
  - ❑ Atmospheric air is a mixture of “dry air and gases” and “water vapor”



Dry Air	**Water Vapor**	**Moist Air**
T = 75 °F	T = 75 °F	T = 75 °F
m_a = 1 lb	m_a = 0 lb	m_a = 1 lb
m_w = 0 lb	m_w = 0.0092 lb	m_w = 0.0092 lb
p_a = 14.482 psia	p_a = 0 psia	p_a = 14.482 psia
p_w = 0 psia	p_w = 0.215 psia	p_w = 0.215 psia
$p_{mixture}$ = 14.482 psia	$p_{mixture}$ = 0.215 psia	$p_{mixture}$ = 14.697 psia

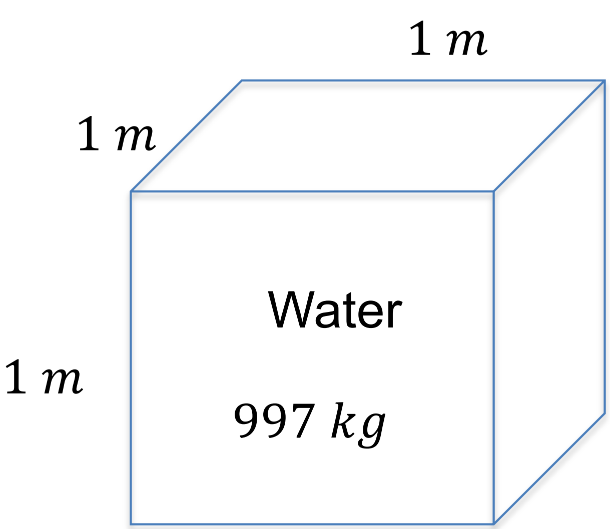
Psychrometrics

- How much is the density of water in IP and SI units?



$$\rho = 62.43\,\frac{lb_m}{ft^2}$$

$$\rho = 62.43\,\frac{lb_m}{ft^2} \times \frac{ft^2}{144\ in^2} = 0.434\,\frac{lb_m}{in^2}$$



$$\rho = 997\,\frac{kg}{m^3}$$

Psychrometrics

- Ideal Gas
  - ❑ Atmospheric air behaves such as an ideal gas

$$P\,V = n\,\bar{R}\,T$$

$$n = \frac{m}{M} \qquad \frac{kg}{kg/kmol}$$

$$n = \frac{m}{M} \qquad \frac{kg}{kg/kmol}$$

$$\bar{R} = 1545\,\frac{ft - lbf}{lb - mol - R}$$

$$\bar{R} = 8.3145\,\frac{kNm}{kmol - K}$$

$$P\,V = n\,R\,T$$

$$P\,v = m\,R\,T$$

Psychrometrics

- Ideal Gas
  - ❑ Atmospheric air behaves like a perfect gas

$$Pv = m\,R\,T$$

R_{air}: 53.3 $\frac{lb}{ft^2}$

R_{water}: 85.8 $\frac{lb}{ft^2}$

$T = \mathrm{T(F)} + 460$

R_{air}: 0.287 $\frac{kNm}{kg-K}$

R_{water}: 0.461$\frac{kNm}{kg-K}$

$T = \mathrm{T(C)} + 273.15$

Psychrometrics

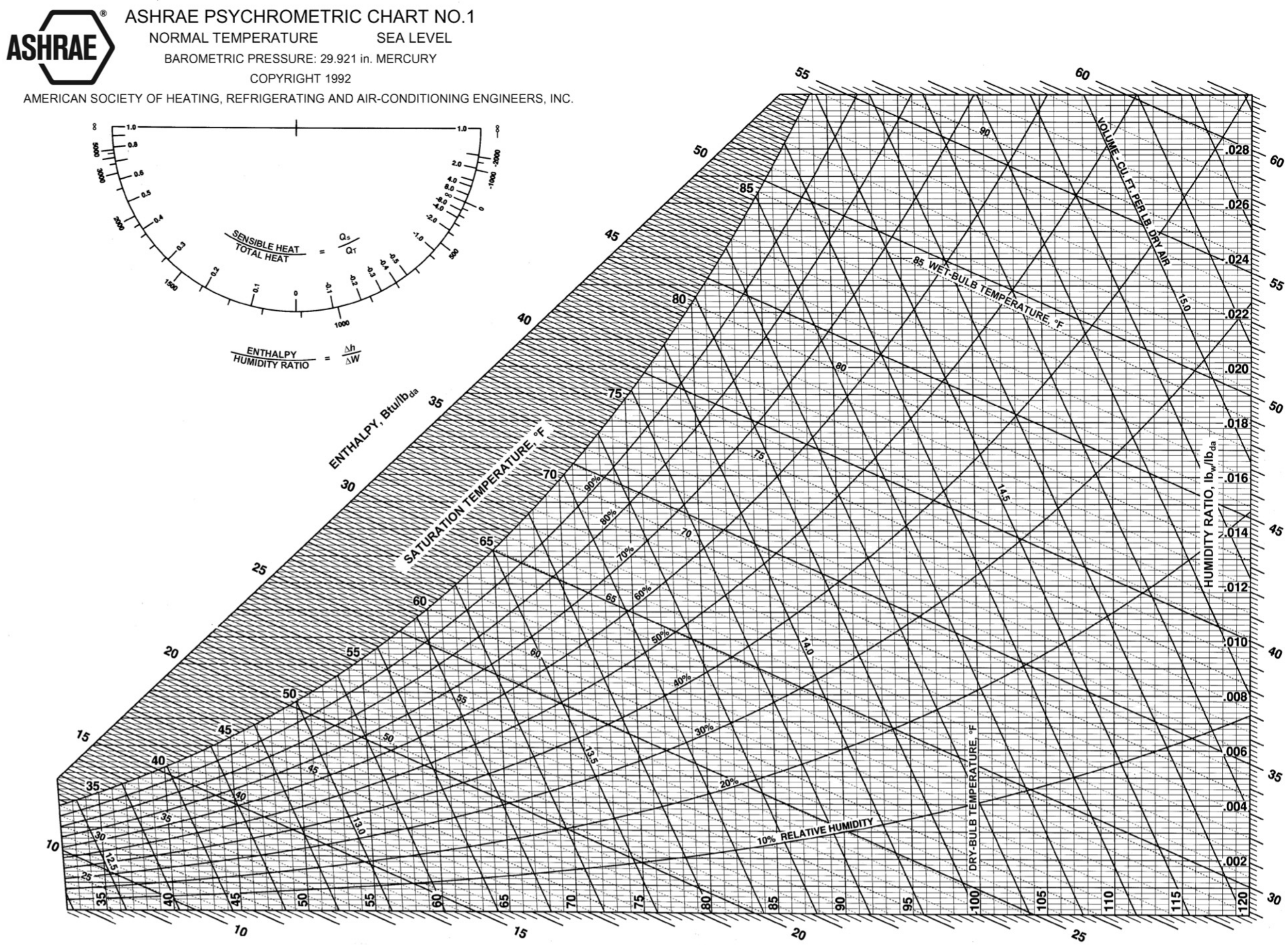
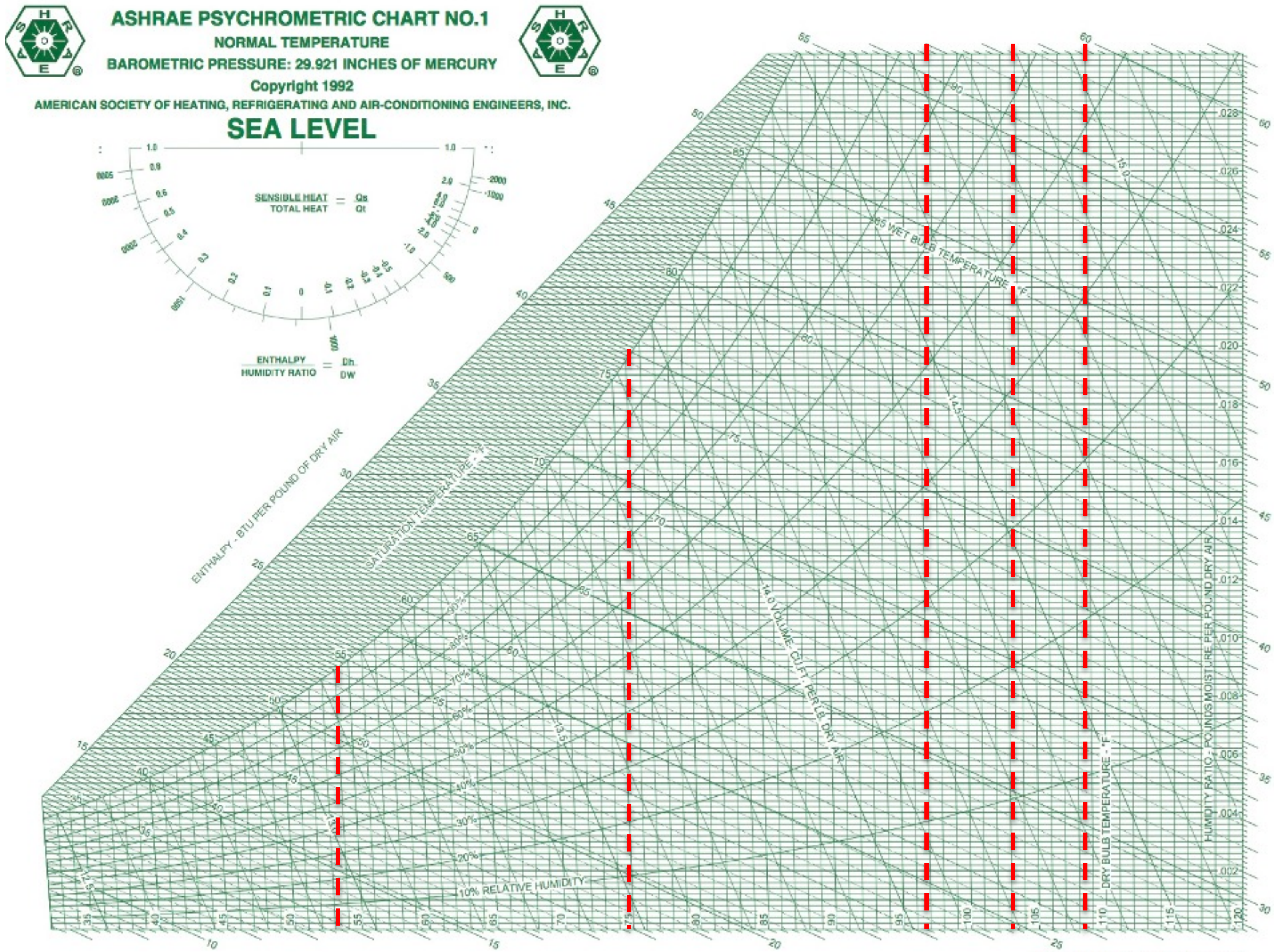


Fig. 1 ASHRAE Psychrometric Chart No. 1

See Fig. 1 of Chapter 1 (Page 1.15) – Version 2017

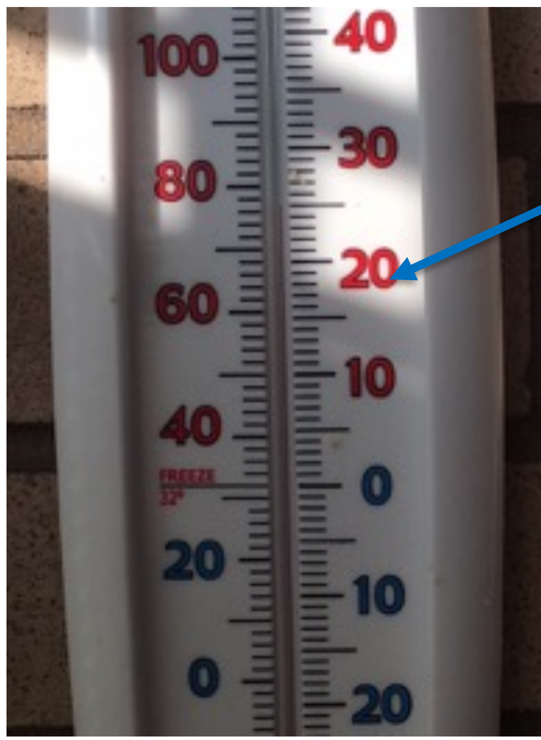
Psychrometrics

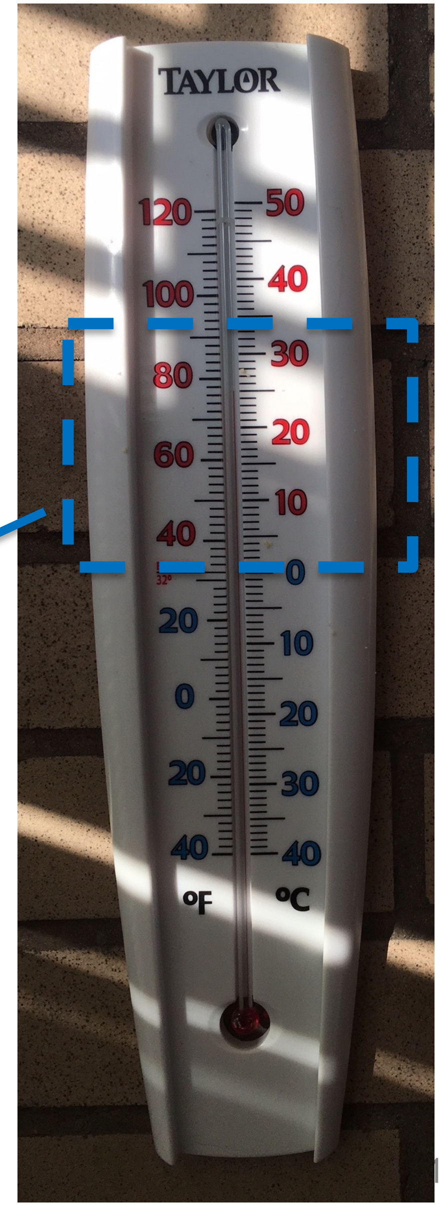


Psychrometrics

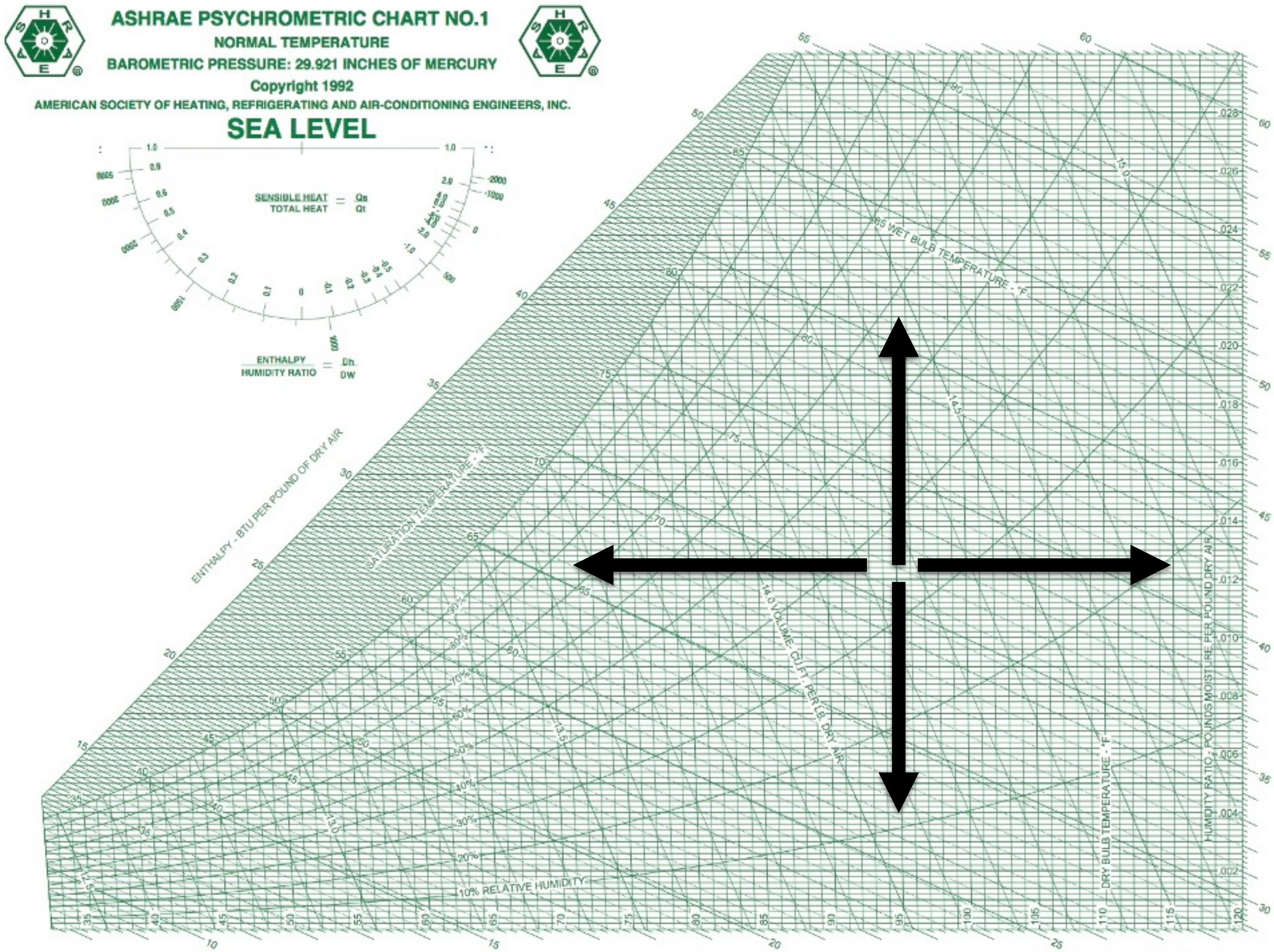
- Dry bulb temperature:
  - Known as DBT or T_{db}
  - Measured with a dry-bulb thermometer
  - Measures the level of heat intensity of a substance
  - Represents the sensible heat and changes in sensible heat levels
  - Does not take into account the latent heat aspect
  - Room thermostats usually measures this in an occupied space

Psychrometrics

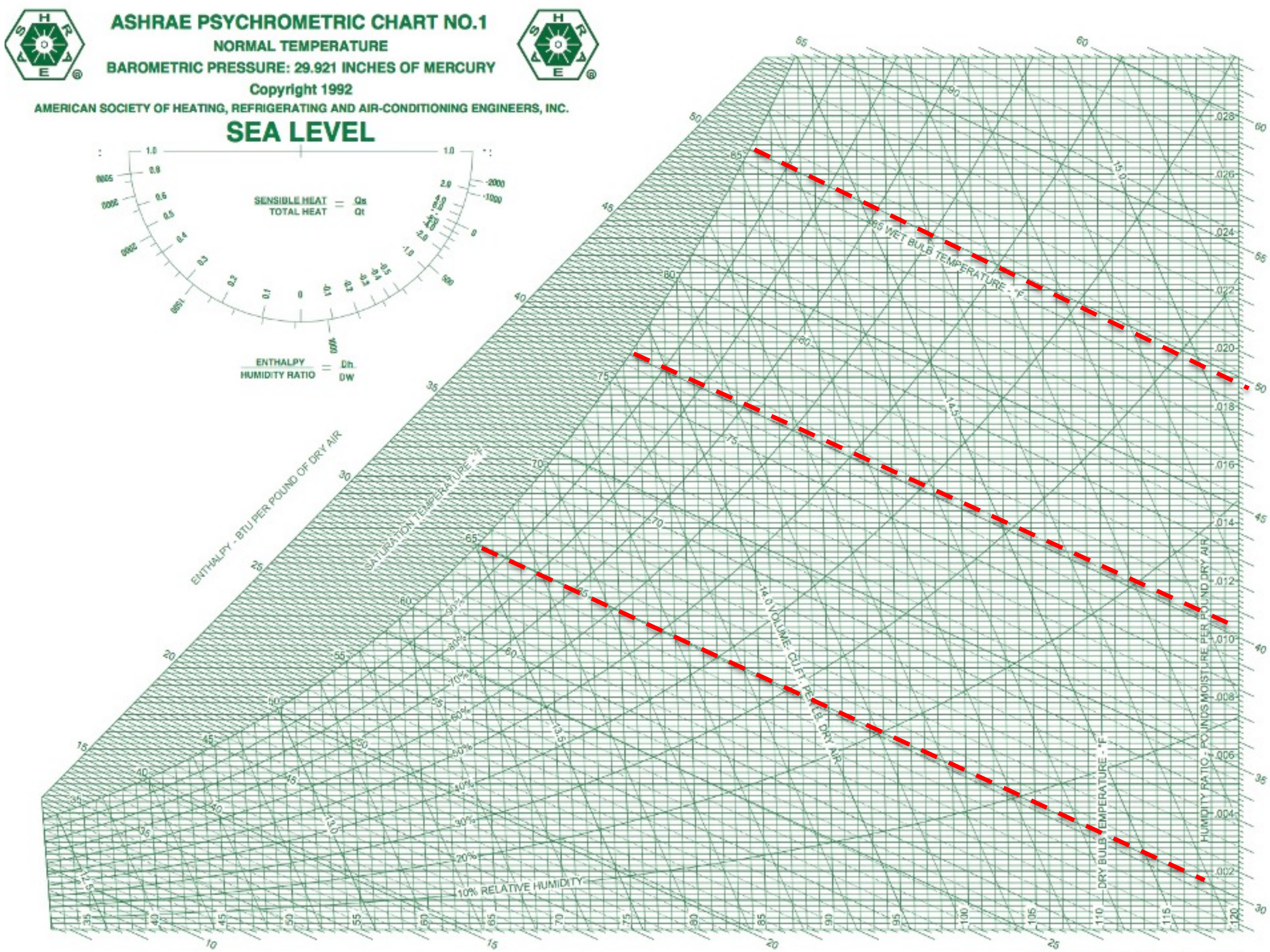




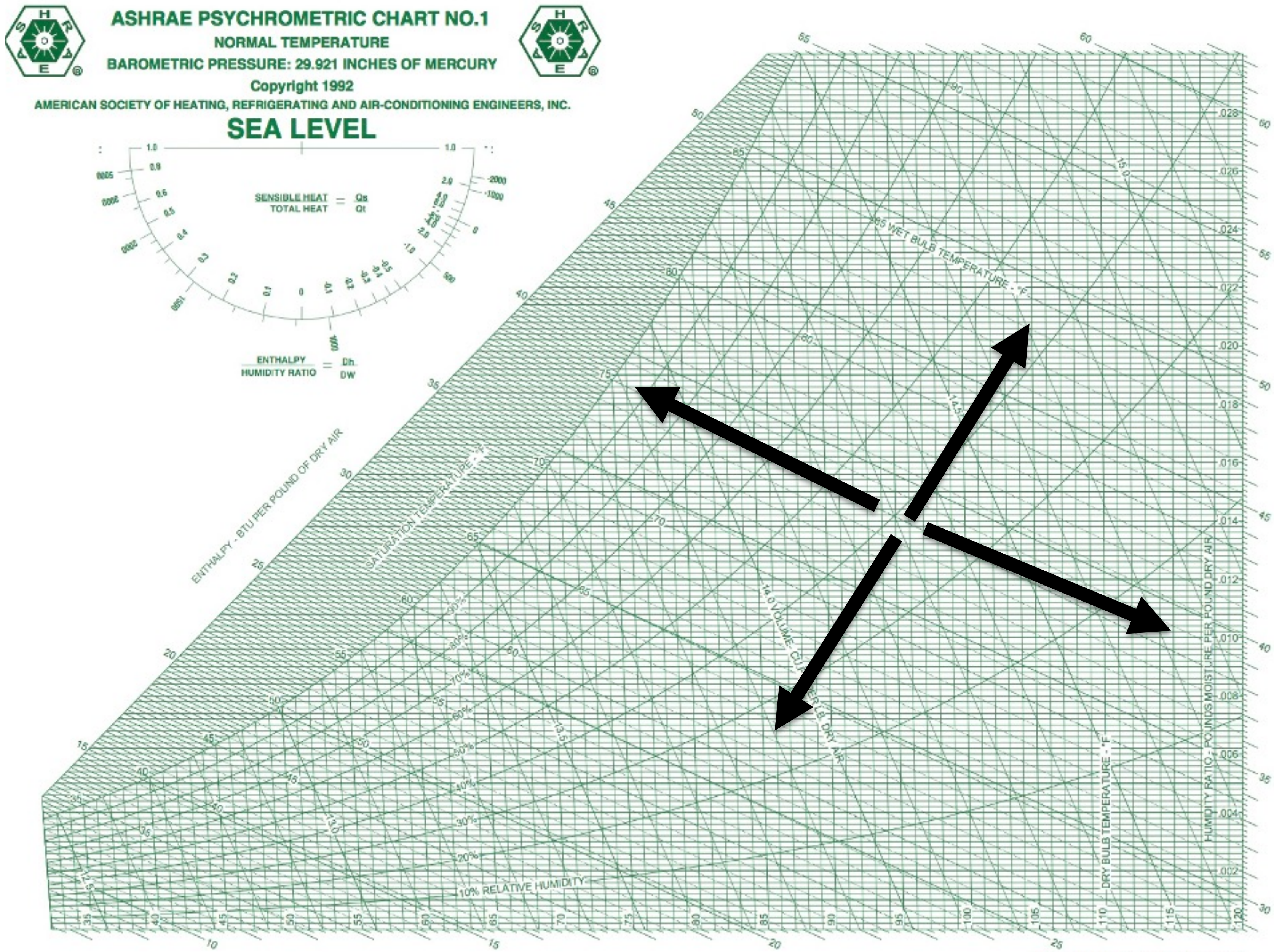
Psychrometrics



Psychrometrics

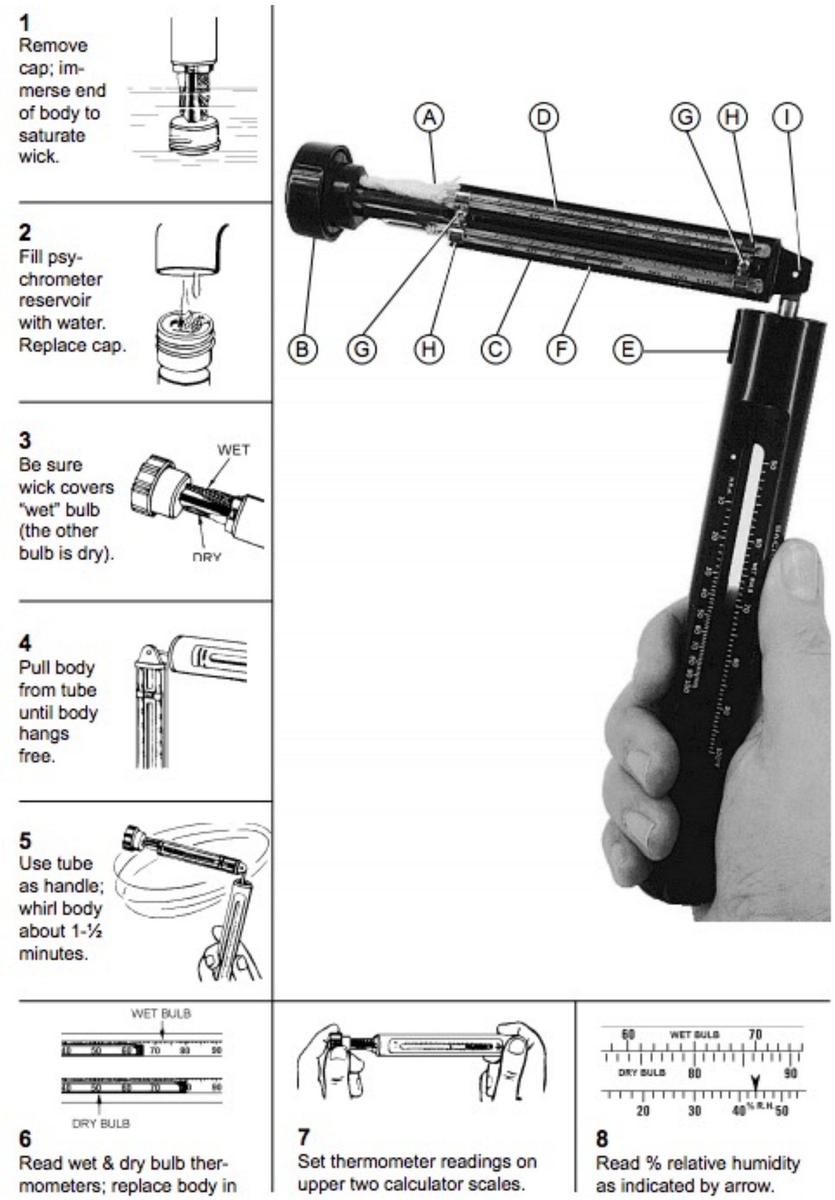


Psychrometrics

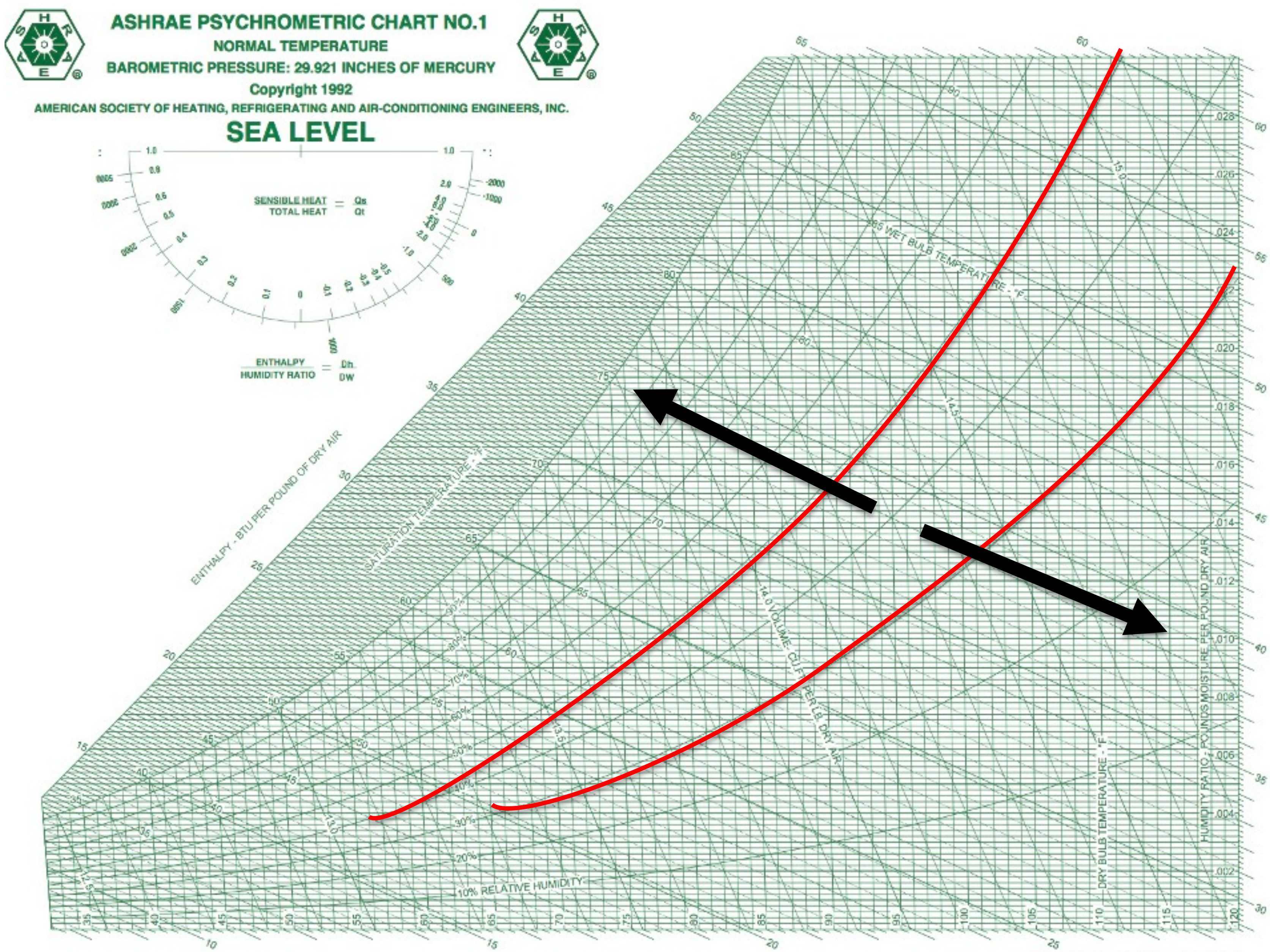


Psychrometrics

- Wet bulb temperature:
  - Is known as WBT or T_{wb}
  - Can be measured with a wet-bulb thermometer
  - Moisture content of the air affects temperature
  - Takes the latent heat aspect into account
  - The humidity of the air affects evaporation and temperature reading
  - Approximates adiabatic saturation process



Psychrometrics



Psychrometrics

- Relative humidity:
  - Is known as RH or ϕ
  - The ratio of mole fraction of the vapor in the mixture to the mole fraction of vapor in a saturated mixture at the same temperature and pressure
  - Expressed as a percentage

Psychrometrics

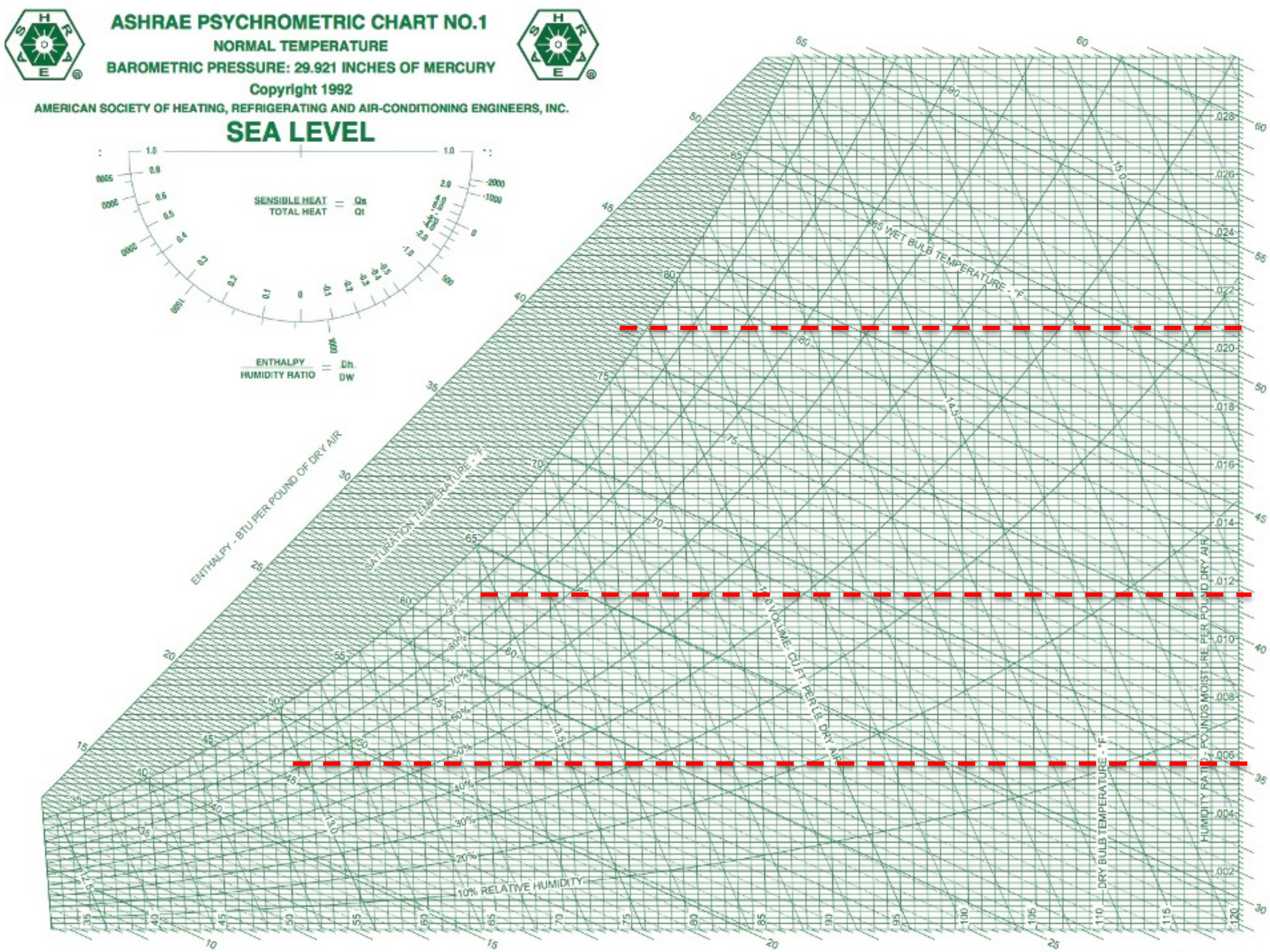
- Relative Humidity:

$$\phi = \frac{p_{vap}}{p_{sat}}$$

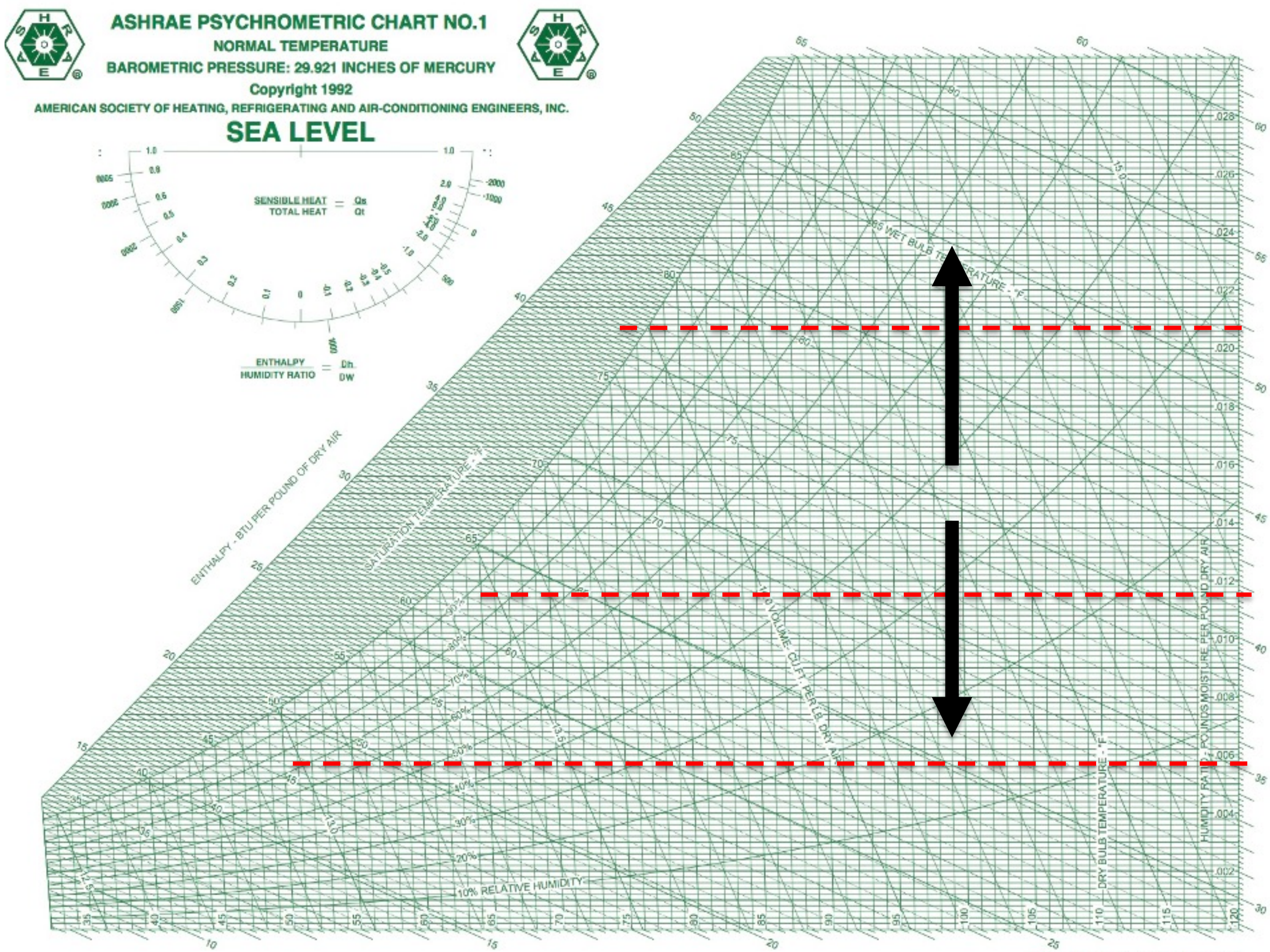
  - ❑ Ideal gas and knowing $T_{db} = T_{sat}$

$$\phi = \frac{RT_{db}/v_{vap}}{RT_{db}/v_{sat}} = \frac{v_{sat}}{v_{vap}}$$

Psychrometrics



Psychrometrics



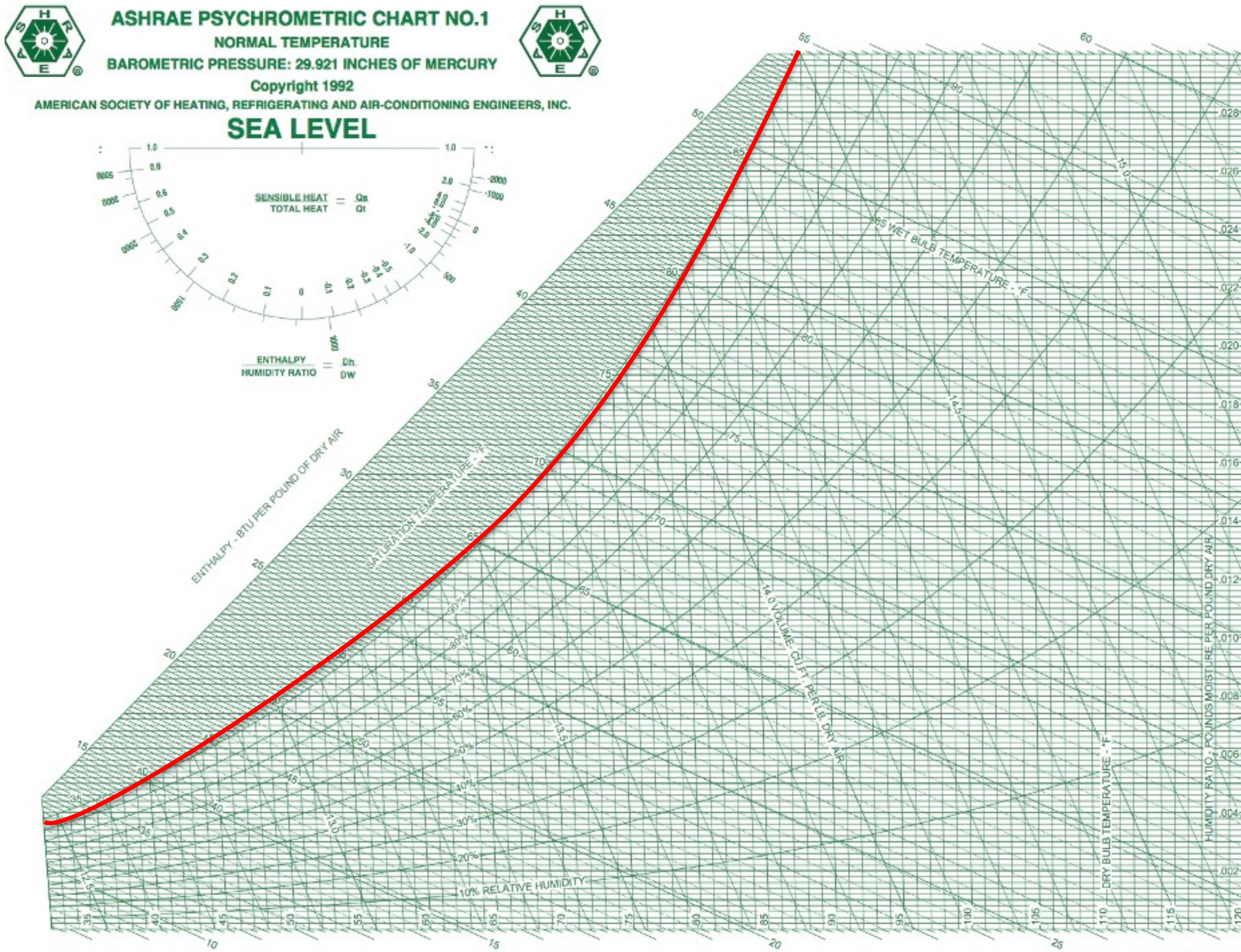
Humidity Ratio

- Humidity ratio (W): The ratio of the mass (m_v) of the water vapor to the mass (m_a) of the dry air in the mixture:

$$W = \frac{mass\ of\ water\ vapor}{mass\ of\ dry\ air} = \frac{m_w}{m_a}$$

- ❑ m_w unit: lb_m (kg) of the water vapor or grains
- ❑ m_a unit: lb_m (kg) dry air
- ❑ grains: One drop of water
- ❑ 7000 grains = 1 lb

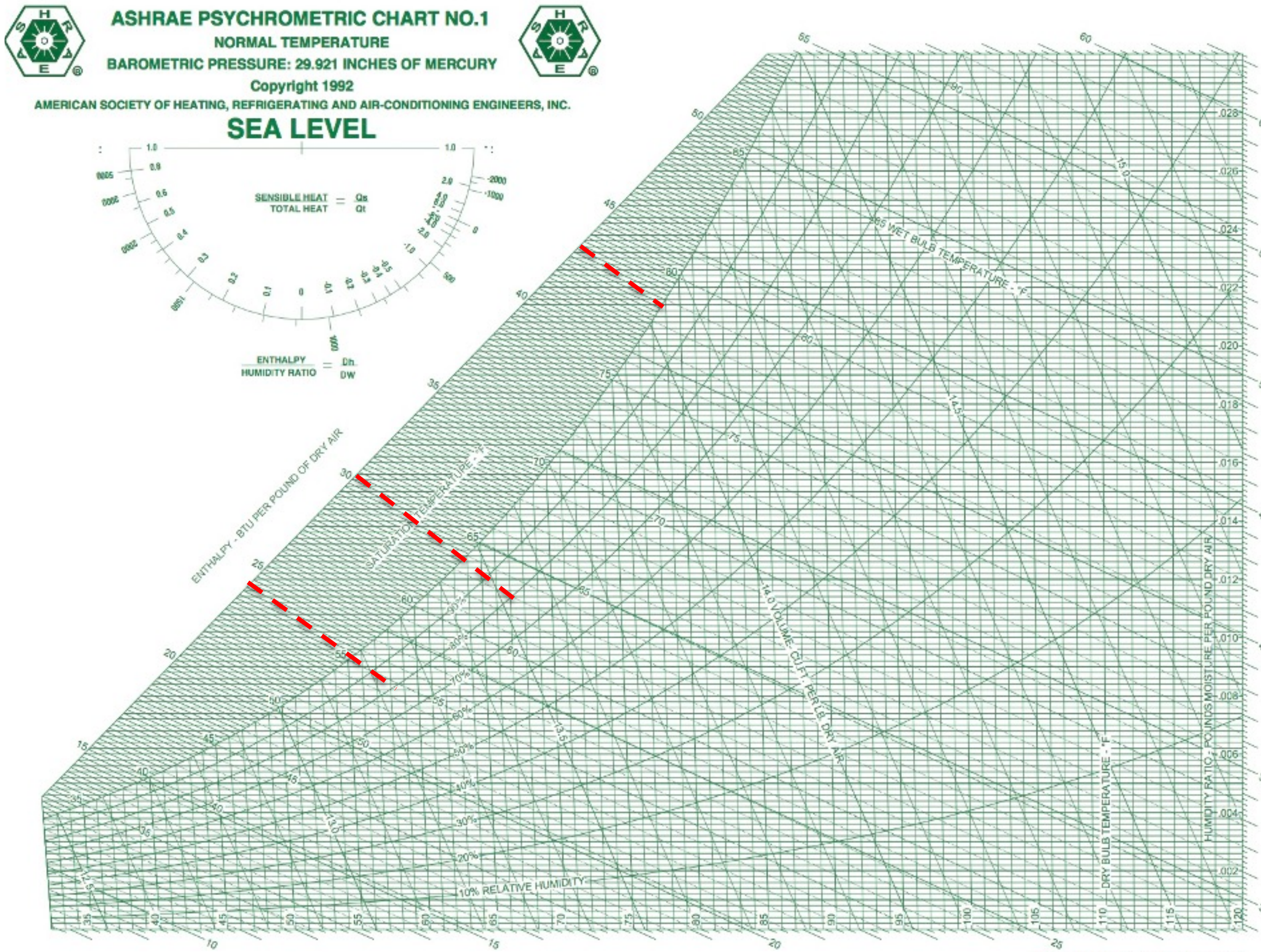
Psychrometrics



Psychrometrics

- Dew point temperature:
  - Known as DPT or T_{dp}
  - The temperature at which the water vapor in the moist air would begin to condense if the moist air were cooled at constant pressure when $P_v = P_s$
  - When a surface reaches the dew point temperature of air, condensation begins
  - Condensation of water from air on the outside of a cold glass of water during summer
  - The dry bulb temperature tells us the amount of water vapor air can hold at a maximum (vapor capacity) of air

Psychrometrics



Psychrometrics

- Enthalpy

  - The enthalpy of the dry air in terms of the specific heat and temperature is given as:

$$h_a = c_{p,da}(T - T_{ref,a})$$

  - The enthalpy of the water vapor is given in terms of the specific heat of water vapor and temperature by:

$$h_{wv} = c_{p,wv}\left(T - T_{ref,wv}\right) + h_{fg,ref}$$

Psychrometrics

- Enthalpy (IP Unit)
  - Enthalpy of moist air is given as:

$$h_a = h_{da} + W h_{wv}$$

$$h_a = c_{p,da} T_{db} + W\left(h_{g,wv} + c_{pw} T_{db}\right)$$

$$h_a = 0.24\, T_{db} + W(1061 + 0.444\, T_{db})$$

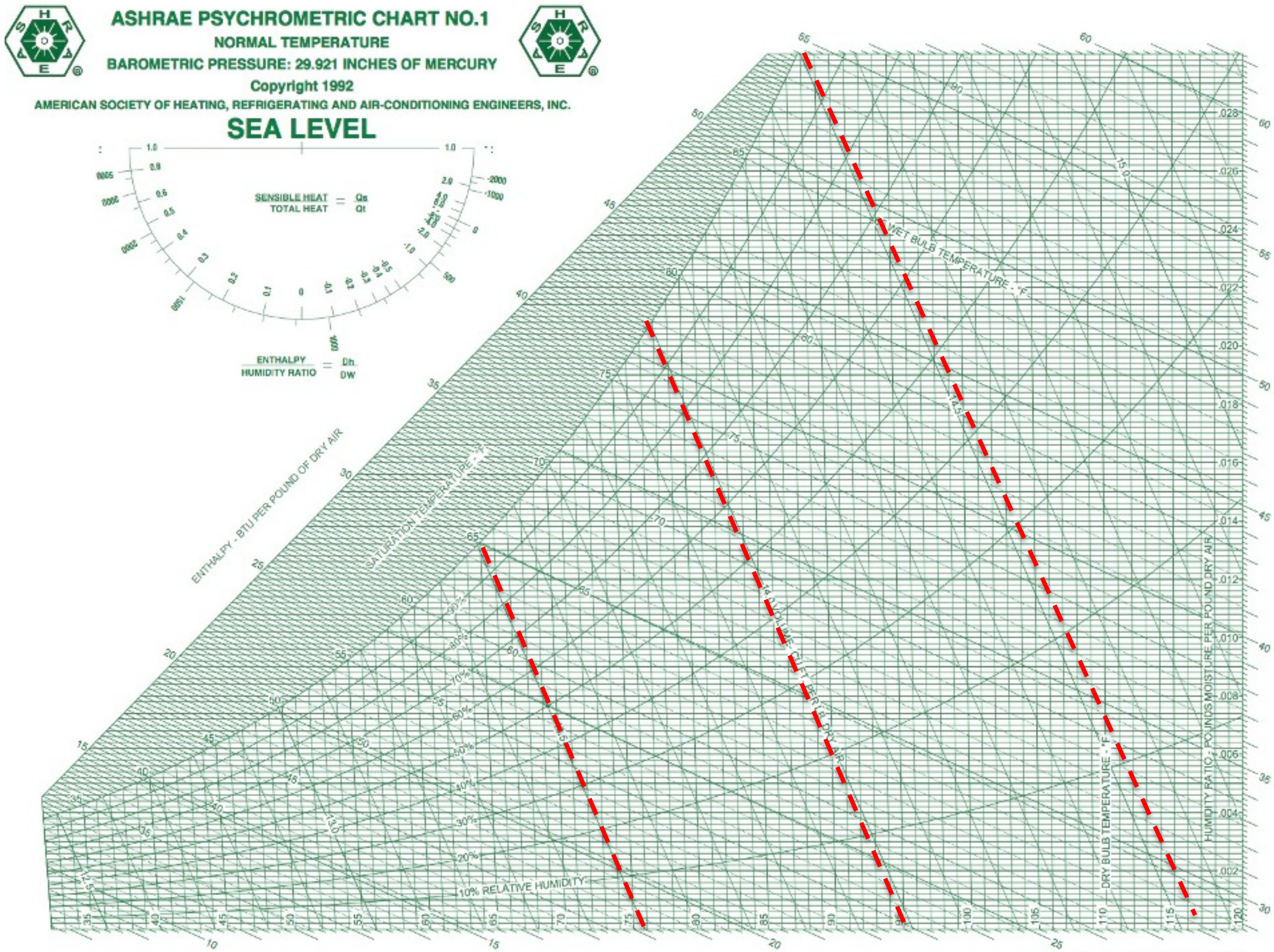
  - $h_{g,wv}$ specific enthalpy of saturated water vapor at 0 F and equals to 1061

Psychrometrics

- Enthalpy (IP Unit)
  - Enthalpy of moist air is given as:

$h_a = 0.24\, T_{db} + W(1061 + 0.444\, T_{db})$	IP
$h_a = 1.006\, T_{db} + W(2501 + 1.86\, T_{db})$	SI

Psychrometrics



Psychrometrics

- Psychrometrics properties:

Description	Symbol	Unit (IP)	Unit (SI)
Specific enthalpy	h	Btu/lb_m	kJ/kg
Specific volume	v	$ft^3//lb_m$	m^3/kg
Humidity ratio	W	lb_v/lb_{da}	kg_v/kg_{da}
Water vapor pressure	p_w	psia	Pa
Relative Humidity	RH	%	%

Psychrometrics

- Thermodynamic properties of moist air
- See Table 2 of Chapter 1

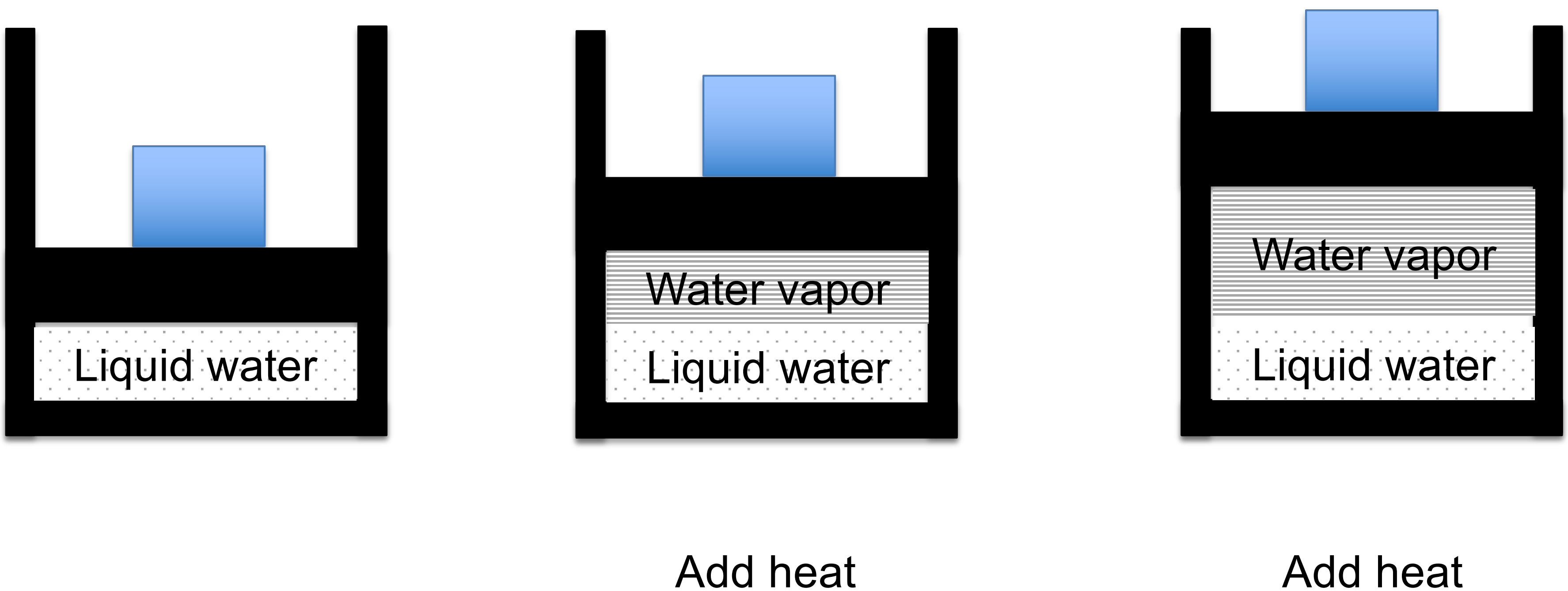
Table 2 Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 14.696 psia (*Continued*)

Temp., °F	Humidity Ratio	Specific Volume, ft^3/lb$_{da}$			Specific Enthalpy, Btu/lb$_{da}$			Specific Entropy, Btu/lb$_{da}\cdot$°F		Temp., °F
t	W_s, lb$_w$/lb$_{da}$	v_{da}	v_{as}	v_s	h_{da}	h_{as}	h_s	s_{da}	s_s	t
60	0.011087	13.096	0.233	13.329	14.415	12.052	26.467	0.02947	0.05389	60
61	0.011496	13.122	0.242	13.364	14.655	12.502	27.157	0.02994	0.05522	61
62	0.011919	13.147	0.251	13.398	14.895	12.966	27.862	0.03040	0.05657	62
63	0.012355	13.172	0.261	13.433	15.135	13.446	28.582	0.03086	0.05795	63
64	0.012805	13.198	0.271	13.468	15.376	13.942	29.318	0.03132	0.05936	64
65	0.013270	13.223	0.281	13.504	15.616	14.454	30.071	0.03178	0.06080	65
66	0.013750	13.248	0.292	13.540	15.856	14.983	30.840	0.03223	0.06226	66
67	0.014246	13.273	0.303	13.577	16.097	15.530	31.626	0.03269	0.06376	67
68	0.014758	13.299	0.315	13.613	16.337	16.094	32.431	0.03315	0.06529	68
69	0.015286	13.324	0.326	13.650	16.577	16.677	33.254	0.03360	0.06685	69
70	0.015832	13.349	0.339	13.688	16.818	17.279	34.097	0.03406	0.06844	70
71	0.016395	13.375	0.351	13.726	17.058	17.901	34.959	0.03451	0.07007	71
72	0.016976	13.400	0.365	13.764	17.299	18.543	35.841	0.03496	0.07173	72
73	0.017575	13.425	0.378	13.803	17.539	19.204	36.743	0.03541	0.07343	73
74	0.018194	13.450	0.392	13.843	17.779	19.889	37.668	0.03586	0.07516	74
75	0.018833	13.476	0.407	13.882	18.020	20.595	38.615	0.03631	0.07694	75
76	0.019491	13.501	0.422	13.923	18.260	21.323	39.583	0.03676	0.07875	76
77	0.020170	13.526	0.437	13.963	18.500	22.075	40.576	0.03721	0.08060	77
78	0.020871	13.551	0.453	14.005	18.741	22.851	41.592	0.03766	0.08250	78
79	0.021594	13.577	0.470	14.046	18.981	23.652	42.633	0.03811	0.08444	79

- Additional tables in Chapter 30

P-H, T-S DIAGRAMS
(CAE 208, CAE 331, MMAE 320)

Properties of A Pure Substance



Class Activity

- Define:
  - ❑ Saturation pressure
  - ❑ Saturation temperature
  - ❑ Saturated liquid
  - ❑ Saturated vapor
  - ❑ Superheated vapor
  - ❑ Sub-cooled liquid (or compressed air)
  - ❑ Quality

Properties of A Pure Substance

Refrigerant 718 (Water/Steam) Properties of Saturated Liquid and Saturated Vapor

Temp.,* °F	Pressure, psia	Density, lb/ft³ Liquid	Volume, ft³/lb Vapor	Enthalpy, Btu/lb		Entropy, Btu/lb·°F		Specific Heat c_p, Btu/lb·°F		c_p/c_v	Vel. of Sound, ft/s		Viscosity, lb_m/ft·h		Thermal Cond., Btu/h·ft·°F		Surface Tension, dyne/cm	Temp.,* °F
				Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor		
32.02[a]	0.089	62.42	3299.7	0.00	1075.92	0.0000	2.1882	1.0086	0.4504	1.3285	4601	1342	4.333	0.0223	0.3244	0.00987	75.65	32.02
40	0.122	62.42	2443.3	8.04	1079.42	0.0162	2.1604	1.0055	0.4514	1.3282	4670	1352	3.738	0.0226	0.3293	0.01001	75.02	40
50	0.178	62.41	1702.8	18.08	1083.79	0.0361	2.1271	1.0028	0.4528	1.3278	4748	1365	3.159	0.0229	0.3353	0.01019	74.22	50
60	0.256	62.36	1206.0	28.10	1088.15	0.0556	2.0954	1.0010	0.4543	1.3275	4815	1378	2.712	0.0232	0.3413	0.01038	73.40	60
70	0.363	62.30	867.11	38.10	1092.50	0.0746	2.0653	0.9999	0.4558	1.3273	4874	1391	2.359	0.0236	0.3471	0.01058	72.57	70
80	0.507	62.21	632.38	48.10	1096.83	0.0933	2.0366	0.9993	0.4574	1.3272	4924	1403	2.074	0.0240	0.3527	0.01079	71.71	80
90	0.699	62.11	467.40	58.09	1101.15	0.1117	2.0093	0.9990	0.4591	1.3271	4967	1416	1.841	0.0244	0.3579	0.01101	70.84	90
100	0.951	61.99	349.84	68.08	1105.44	0.1297	1.9832	0.9989	0.4609	1.3272	5003	1428	1.648	0.0248	0.3628	0.01124	69.96	100
110	1.277	61.86	264.97	78.07	1109.71	0.1474	1.9583	0.9991	0.4628	1.3273	5033	1440	1.486	0.0252	0.3672	0.01148	69.05	110
120	1.695	61.71	202.95	88.06	1113.95	0.1648	1.9346	0.9993	0.4648	1.3276	5056	1452	1.348	0.0256	0.3713	0.01172	68.13	120
130	2.226	61.55	157.09	98.06	1118.17	0.1819	1.9118	0.9997	0.4671	1.3280	5075	1463	1.230	0.0260	0.3750	0.01198	67.19	130
140	2.893	61.38	122.82	108.06	1122.35	0.1987	1.8901	1.0003	0.4696	1.3285	5088	1475	1.128	0.0265	0.3783	0.01225	66.24	140
150	3.723	61.19	96.930	118.07	1126.49	0.2152	1.8693	1.0009	0.4723	1.3291	5097	1486	1.040	0.0269	0.3813	0.01253	65.27	150
160	4.747	61.00	77.184	128.08	1130.59	0.2315	1.8493	1.0016	0.4753	1.3299	5101	1497	0.962	0.0273	0.3839	0.01282	64.28	160
170	6.000	60.79	61.980	138.11	1134.65	0.2476	1.8302	1.0025	0.4787	1.3309	5101	1508	0.894	0.0278	0.3862	0.01312	63.28	170
180	7.520	60.58	50.169	148.14	1138.65	0.2634	1.8118	1.0035	0.4824	1.3320	5098	1518	0.834	0.0282	0.3881	0.01343	62.26	180
190	9.350	60.35	40.916	158.19	1142.60	0.2789	1.7942	1.0046	0.4865	1.3333	5090	1528	0.780	0.0287	0.3898	0.01375	61.23	190
200	11.538	60.12	33.609	168.24	1146.48	0.2943	1.7772	1.0059	0.4911	1.3348	5080	1538	0.732	0.0291	0.3912	0.01409	60.19	200
210	14.136	59.88	27.794	178.31	1150.30	0.3094	1.7609	1.0073	0.4961	1.3366	5066	1547	0.690	0.0296	0.3924	0.01444	59.13	210
211.95[b]	14.696	59.83	26.802	180.28	1151.04	0.3124	1.7578	1.0076	0.4971	1.3369	5063	1549	0.682	0.0297	0.3926	0.01451	58.92	211.95
220	17.201	59.63	23.133	188.40	1154.05	0.3244	1.7451	1.0088	0.5016	1.3386	5049	1557	0.651	0.0300	0.3934	0.01480	58.05	220
230	20.795	59.37	19.371	198.51	1157.72	0.3391	1.7299	1.0106	0.5077	1.3408	5029	1565	0.616	0.0305	0.3941	0.01517	56.96	230
240	24.986	59.10	16.314	208.63	1161.31	0.3537	1.7153	1.0125	0.5145	1.3434	5007	1574	0.585	0.0310	0.3947	0.01556	55.86	240
250	29.844	58.82	13.815	218.78	1164.81	0.3680	1.7011	1.0147	0.5218	1.3464	4981	1582	0.556	0.0314	0.3951	0.01596	54.74	250
260	35.447	58.53	11.759	228.95	1168.21	0.3823	1.6874	1.0170	0.5299	1.3496	4953	1590	0.530	0.0319	0.3953	0.01638	53.62	260
270	41.878	58.24	10.058	239.14	1171.52	0.3963	1.6741	1.0196	0.5387	1.3533	4923	1597	0.506	0.0324	0.3953	0.01680	52.47	270
280	49.222	57.94	8.6431	249.37	1174.71	0.4102	1.6612	1.0224	0.5483	1.3574	4890	1604	0.484	0.0328	0.3952	0.01725	51.32	280
290	57.574	57.63	7.4600	259.62	1177.79	0.4239	1.6487	1.0254	0.5586	1.3620	4855	1611	0.464	0.0333	0.3949	0.01770	50.16	290
300	67.029	57.31	6.4658	269.91	1180.75	0.4375	1.6365	1.0287	0.5698	1.3671	4817	1617	0.445	0.0338	0.3944	0.01817	48.98	300
310	77.691	56.99	5.6263	280.23	1183.58	0.4510	1.6246	1.0323	0.5818	1.3727	4777	1623	0.428	0.0342	0.3939	0.01866	47.79	310
320	89.667	56.65	4.9142	290.60	1186.28	0.4643	1.6131	1.0362	0.5947	1.3790	4735	1628	0.412	0.0347	0.3931	0.01916	46.59	320
330	103.07	56.31	4.3075	301.00	1188.84	0.4775	1.6018	1.0404	0.6085	1.3858	4691	1633	0.397	0.0351	0.3923	0.01967	45.38	330
340	118.02	55.95	3.7884	311.45	1191.25	0.4906	1.5908	1.0449	0.6231	1.3934	4644	1638	0.383	0.0356	0.3912	0.02020	44.16	340
350	134.63	55.59	3.3425	321.95	1193.51	0.5036	1.5800	1.0497	0.6386	1.4018	4596	1642	0.370	0.0361	0.3901	0.02074	42.93	350
360	153.03	55.22	2.9580	332.50	1195.61	0.5164	1.5694	1.0550	0.6551	1.4109	4546	1645	0.358	0.0365	0.3888	0.02130	41.69	360
370	173.36	54.85	2.6252	343.11	1197.54	0.5292	1.5591	1.0606	0.6725	1.4210	4493	1648	0.347	0.0370	0.3873	0.02187	40.45	370
380	195.74	54.46	2.3361	353.77	1199.29	0.5419	1.5489	1.0666	0.6910	1.4320	4438	1651	0.337	0.0375	0.3857	0.02246	39.19	380
390	220.33	54.06	2.0841	364.50	1200.86	0.5545	1.5388	1.0732	0.7105	1.4441	4382	1653	0.327	0.0379	0.3839	0.02307	37.93	390
400	247.26	53.65	1.8638	375.30	1202.24	0.5670	1.5290	1.0802	0.7311	1.4573	4323	1655	0.318	0.0384	0.3819	0.02369	36.66	400
410	276.68	53.23	1.6706	386.17	1203.42	0.5795	1.5192	1.0878	0.7529	1.4718	4263	1656	0.309	0.0389	0.3798	0.02433	35.38	410
420	308.76	52.80	1.5006	397.12	1204.38	0.5919	1.5096	1.0959	0.7761	1.4876	4200	1656	0.300	0.0393	0.3776	0.02499	34.10	420
430	343.64	52.36	1.3505	408.15	1205.13	0.6042	1.5000	1.1047	0.8007	1.5050	4136	1656	0.292	0.0398	0.3751	0.02568	32.81	430
440	381.48	51.91	1.2177	419.27	1205.64	0.6165	1.4906	1.1143	0.8268	1.5240	4069	1655	0.285	0.0403	0.3725	0.02638	31.51	440
450	422.46	51.45	1.0999	430.49	1205.91	0.6287	1.4811	1.1246	0.8547	1.5448	4000	1654	0.278	0.0407	0.3696	0.02711	30.22	450
460	466.75	50.97	0.9951	441.81	1205.93	0.6409	1.4718	1.1358	0.8846	1.5678	3930	1652	0.271	0.0412	0.3666	0.02786	28.92	460
470	514.52	50.48	0.9015	453.24	1205.68	0.6531	1.4625	1.1479	0.9167	1.5930	3857	1650	0.264	0.0417	0.3633	0.02865	27.61	470
480	565.95	49.98	0.8179	464.78	1205.13	0.6652	1.4531	1.1612	0.9513	1.6208	3782	1647	0.258	0.0422	0.3599	0.02947	26.30	480
490	621.23	49.46	0.7429	476.46	1204.29	0.6774	1.4438	1.1757	0.9888	1.6515	3706	1643	0.252	0.0427	0.3562	0.03033	25.00	490
500	680.55	48.92	0.6756	488.27	1203.13	0.6895	1.4344	1.1916	1.0295	1.6856	3626	1638	0.246	0.0432	0.3522	0.03124	23.69	500
510	744.11	48.37	0.6149	500.23	1201.62	0.7017	1.4250	1.2091	1.0741	1.7235	3545	1632	0.240	0.0438	0.3481	0.03220	22.38	510
520	812.10	47.80	0.5601	512.35	1199.75	0.7138	1.4155	1.2285	1.1231	1.7658	3461	1626	0.235	0.0443	0.3436	0.03323	21.08	520
530	884.74	47.20	0.5105	524.65	1197.49	0.7260	1.4059	1.2500	1.1772	1.8133	3375	1619	0.229	0.0449	0.3389	0.03434	19.77	530
540	962.24	46.59	0.4655	537.14	1194.80	0.7383	1.3962	1.2740	1.2374	1.8667	3286	1611	0.224	0.0455	0.3340	0.03554	18.47	540
550	1044.8	45.95	0.4247	549.84	1191.66	0.7506	1.3863	1.3011	1.3048	1.9274	3195	1601	0.219	0.0461	0.3288	0.03685	17.18	550
560	1132.7	45.29	0.3874	562.77	1188.02	0.7630	1.3762	1.3317	1.3810	1.9966	3101	1591	0.214	0.0467	0.3233	0.03830	15.89	560
570	1226.2	44.60	0.3534	575.97	1183.83	0.7755	1.3658	1.3668	1.4677	2.0763	3003	1580	0.209	0.0474	0.3177	0.03992	14.61	570
580	1325.5	43.88	0.3223	589.44	1179.04	0.7881	1.3552	1.4072	1.5675	2.1687	2903	1567	0.204	0.0481	0.3118	0.04175	13.35	580
590	1430.8	43.12	0.2937	603.25	1173.59	0.8009	1.3443	1.4543	1.6838	2.2772	2799	1553	0.199	0.0489	0.3057	0.04385	12.09	590
600	1542.5	42.32	0.2674	617.42	1167.39	0.8139	1.3329	1.5100	1.8210	2.4061	2691	1537	0.194	0.0497	0.2995	0.04627	10.85	600
610	1660.9	41.47	0.2431	632.02	1160.34	0.8271	1.3210	1.5769	1.9855	2.5615	2580	1520	0.189	0.0506	0.2931	0.04912	9.62	610
620	1786.2	40.57	0.2206	647.11	1152.31	0.8406	1.3085	1.6588	2.1869	2.7524	2463	1501	0.183	0.0516	0.2867	0.05252	8.42	620
630	1918.9	39.61	0.1997	662.79	1143.14	0.8545	1.2953	1.7618	2.4392	2.9922	2341	1480	0.178	0.0527	0.2801	0.05664	7.23	630
640	2059.3	38.57	0.1802	679.19	1132.60	0.8689	1.2812	1.8958	2.7654	3.3023	2213	1456	0.173	0.0540	0.2735	0.06174	6.08	640
650	2207.8	37.42	0.1618	696.48	1120.40	0.8839	1.2659	2.0791	3.2045	3.7194	2076	1430	0.167	0.0555	0.2668	0.06819	4.96	650
660	2364.9	36.15	0.1444	714.96	1106.08	0.8997	1.2491	2.3480	3.8305	4.3113	1928	1399	0.161	0.0572	0.2600	0.07660	3.88	660
670	2531.2	34.69	0.1277	735.12	1088.91	0.9169	1.2301	2.7832	4.8020	5.2224	1762	1363	0.154	0.0594	0.2531	0.08808	2.84	670
680	2707.3	32.94	0.1113	757.89	1067.56	0.9361	1.2078	3.5861	6.5383	6.8275	1574	1320	0.146	0.0622	0.2461	0.10495	1.88	680
690	2894.0	30.69	0.0946	785.02	1039.02	0.9589	1.1798	5.3920	10.639	10.516	1365	1263	0.136	0.0663	0.2404	0.13393	1.00	690
700	3093.0	27.28	0.0748	823.00	991.66	0.9907	1.1361	15.579	32.942	29.223	1119	1162	0.122	0.0740	0.2547	0.21590	0.26	700
705.10[c]	3200.1	20.10	0.0497	896.67	896.67	1.0533	1.0533	∞	∞	∞	0	0	—	—	∞	∞	0.00	705.10

*Temperatures on ITS-90 scale [a]Triple point [b]Normal boiling point [c]Critical point

Properties of A Pure Substance

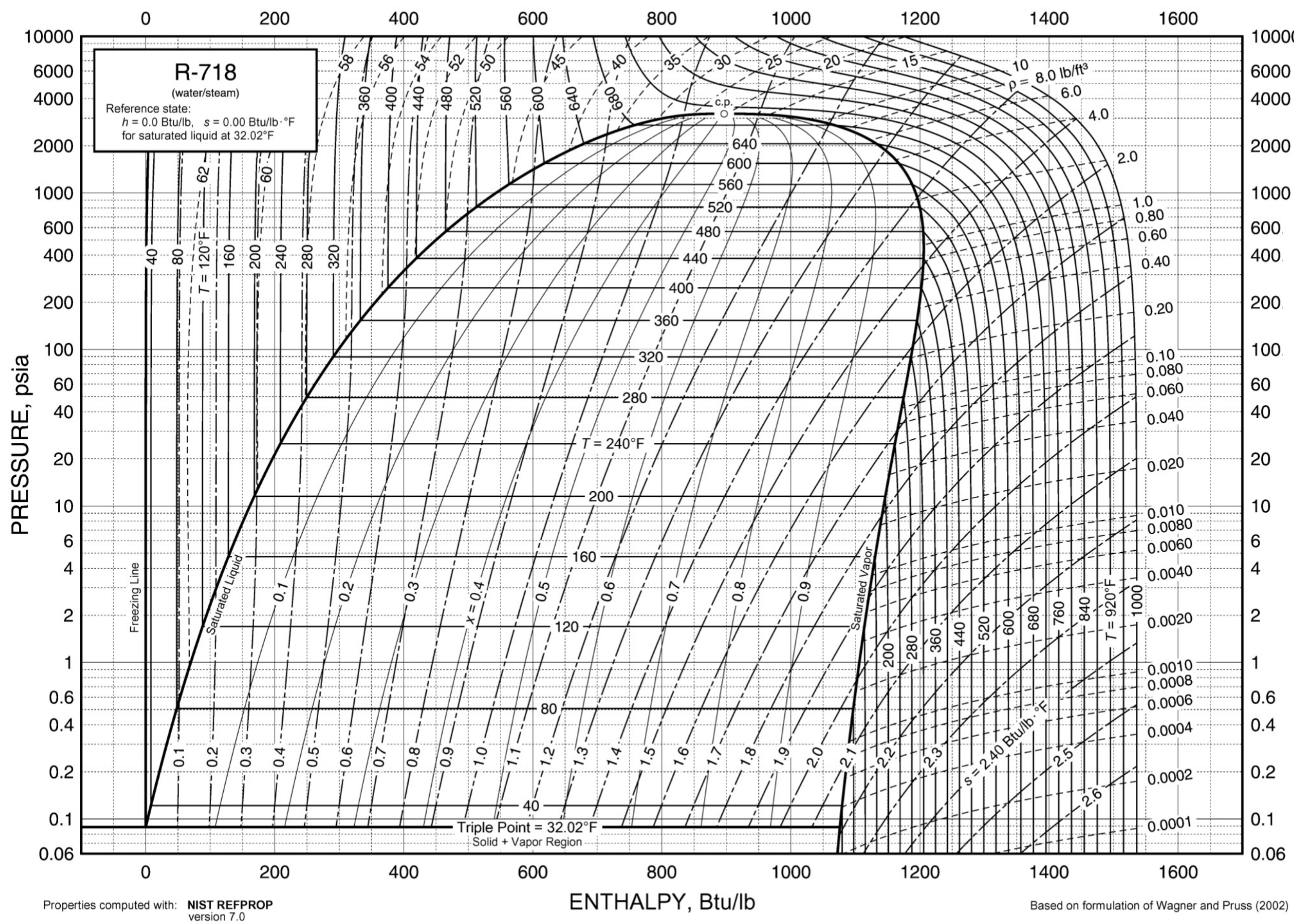
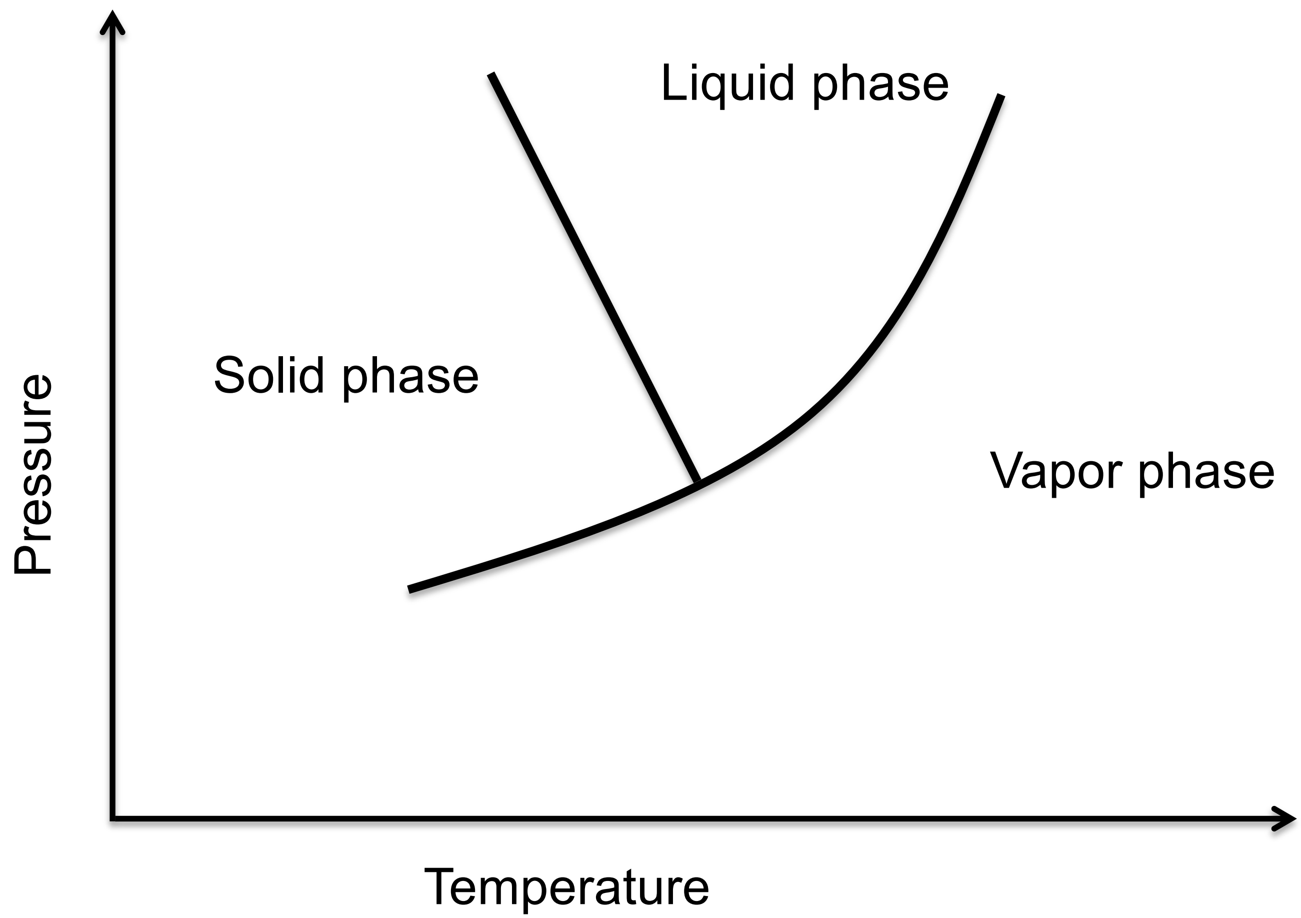


Fig. 20 Pressure-Enthalpy Diagram for Refrigerant 718 (Water/Steam)

Properties of A Pure Substance



Vapor-pressure curve

CLASS ACTIVITY

Class Activity

Example: A closed vessel contains 0.1 ft^3 of saturated liquid and 0.9 ft^3 of saturated vapor R-134a in equilibrium at 90 F.

1. Determine the percent vapor on a mass basis.
2. Calculate the quality of the mixture

Class Activity

Solution: (From Page 30.16 and 30.17 – Version 2017)

$$V_{liquid} = m_{liquid} v_f$$

$$m_{liquid} = \frac{V_{liquid}}{v_f} = \frac{0.1}{\frac{1}{73.58}} = 7.358\ lbm$$

$$V_{vapor} = m_{vapor} v_g$$

$$m_{vapor} = \frac{V_{vapor}}{v_g} = \frac{0.9}{0.3999} = 2.250\ lbm$$

Class Activity

Solution: (From Page 30.16 and 30.17)

$$m = m_{liquid} + m_{vapor} = 7.\ 358\ + 2.250$$ =9.608 lbm

$$x = \frac{m_{vapor}}{m} = \frac{2.250}{9.608} = 0.234\ lbm$$