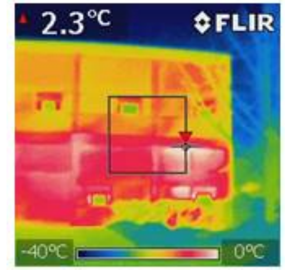
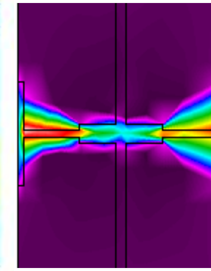
CAE 331/513
Building Science
Fall 2016





Week 6: September 27, 2016
Psychrometrics (chart and definitions)

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Exam 1 graded and returned

- Overall grade summary
  - Mean: 84%
  - Standard deviation: 11%
  - Minimum: 61%
  - Maximum: 98%

- Undergraduate average: 85%
- Graduate average: 83%

Graduate student projects

- Expectations document on BB now
  - Individual projects
  - Literature review
  - Some modeling and/or measurement
  - Conference paper and presentation

- Due dates for deliverables:
  - Tuesday, October 18: Project topic
  - Thursday, December 1: Final report and presentation in class

Graduate student projects: Topic suggestions

- Energy questions
  - Efficiency of radiant vs. central forced air heating/cooling?
  - Efficiency of different air distribution systems (e.g., overhead/UFAD)
  - Net zero energy/carbon design/operation
  - Electrical metering and power draw signatures
- HVAC systems
  - Heat pumps, geothermal, energy recovery, absorption chillers, cogeneration
- Green building rating systems
  - LEED, Green Globes, EnergyStar, Living Building, BREEAM, 189.1
- Moisture
  - Dampness, fungal growth, remediation, buffering capacity
- IAQ/IEQ
  - Thermal comfort, aerosols, ventilation, VOCs
- Other
  - Electrical, lighting, plumbing, acoustics
- Tools you can use:
  - Energy simulation, MATLAB modeling, measurements in BERG Lab

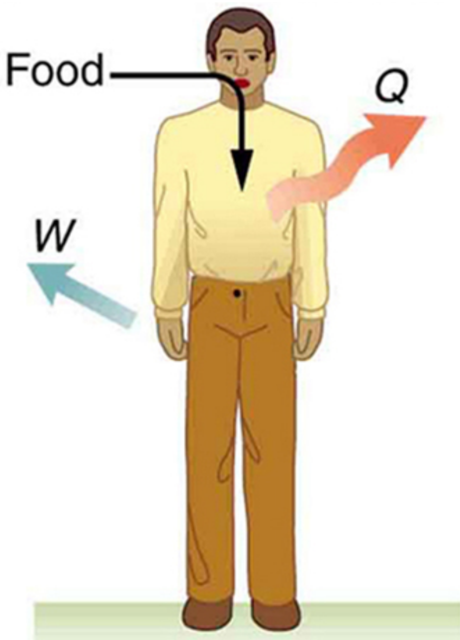
Last time (September 15)

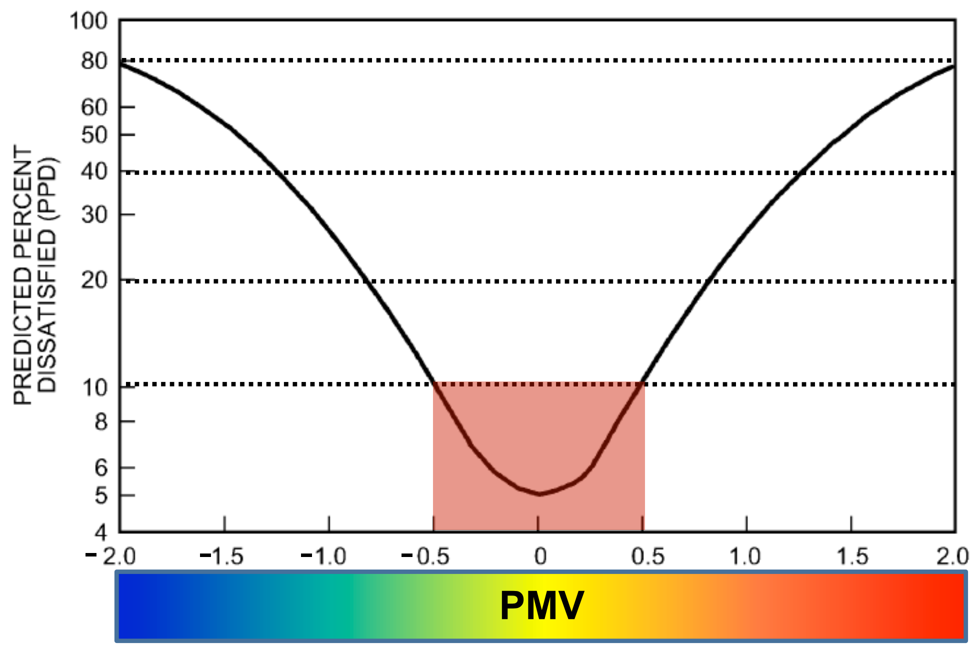
- Human thermal comfort

$$A_D = 0.202 m^{0.425} l^{0.725}$$

$$\dot{Q} = M A_{skin}$$

A_D = DuBois surface area, m^2
m = mass, kg
l = height, m





$$1 \text{ met} = 18.4 \frac{\text{Btu}}{\text{h} \cdot \text{ft}^2} = 58 \frac{\text{W}}{\text{m}^2}$$

-3	-2	-1	0	+1	+2	+3
cold	cool	slightly cool	neutral	slightly warm	warm	hot

ASHRAE comfort zone

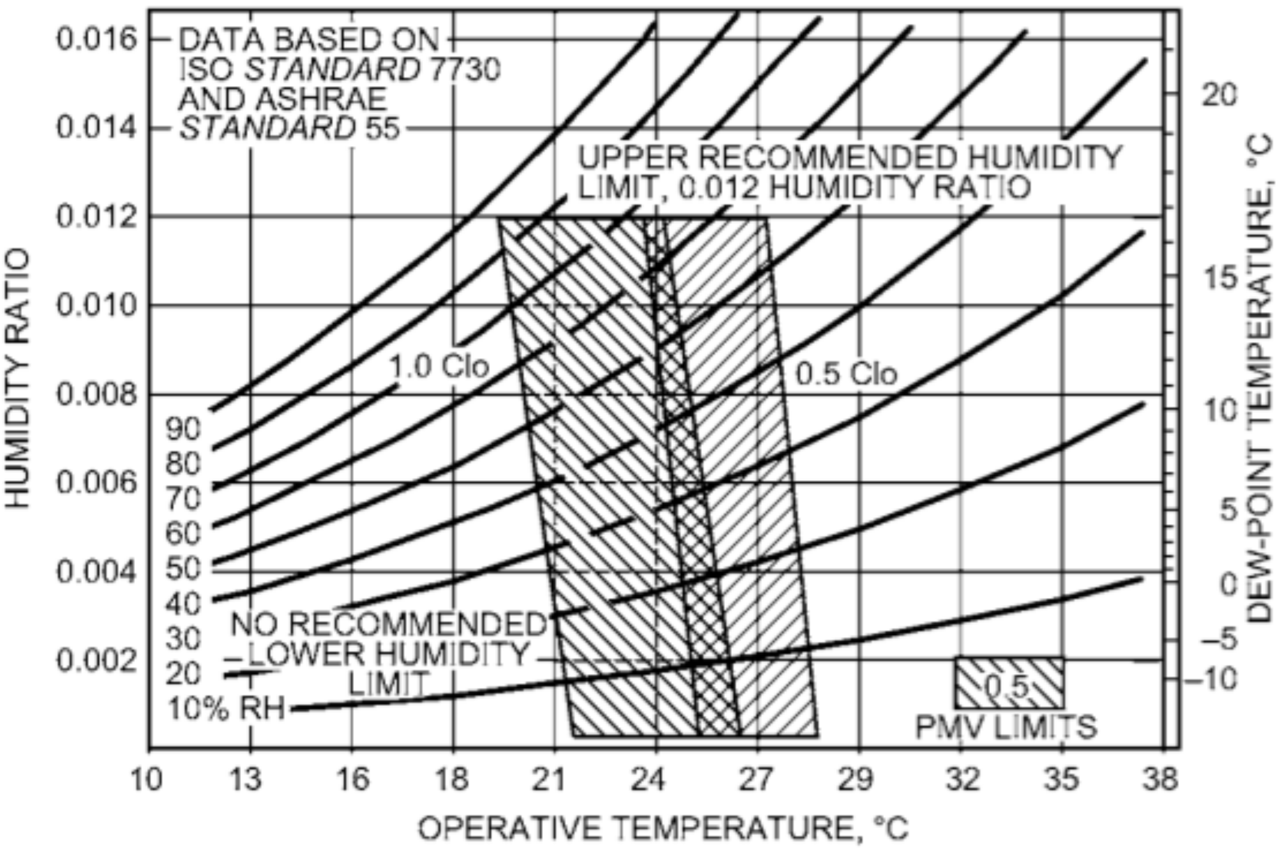


Fig. 5 ASHRAE Summer and Winter Comfort Zones
[Acceptable ranges of operative temperature and humidity with air speed ≤ 0.2 m/s for people wearing 1.0 and 0.5 clo clothing during primarily sedentary activity (≤1.1 met)].

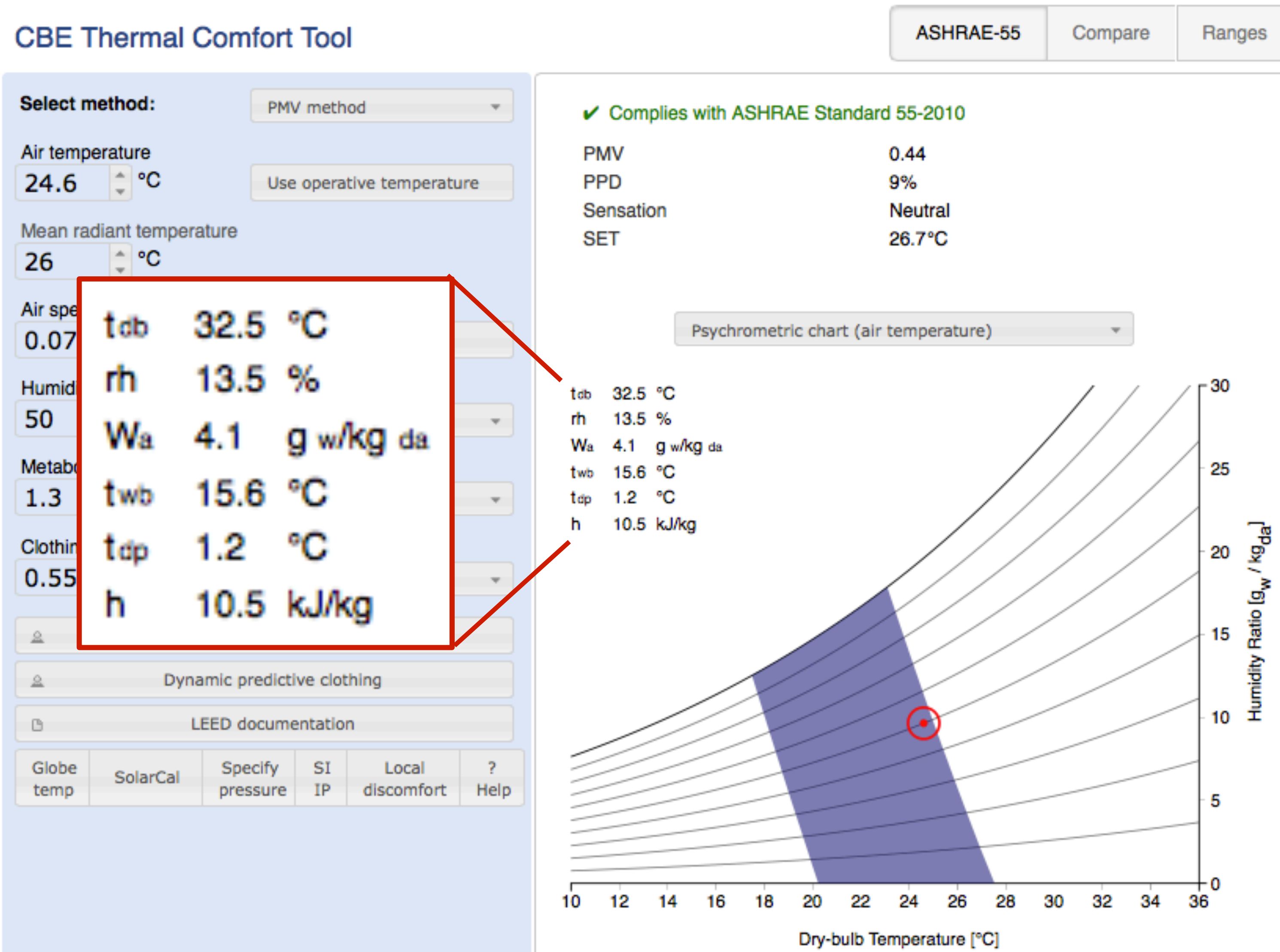
3 equations for operative temperatures:

$$t_o = \frac{(h_r t_{mr} + h_c t_a)}{h_r + h_c}$$

$$t_o = \frac{(t_{mr} + (t_a \times \sqrt{10v}))}{1 + \sqrt{10v}}$$

$$t_o = \frac{(t_a + t_{mr})}{2}$$

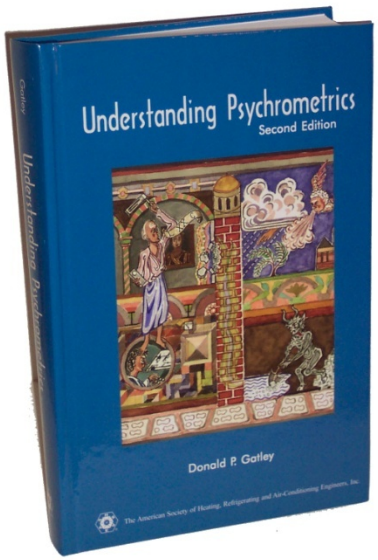
ASHRAE comfort zone: CBE Thermal Comfort Tool



http://smap.cbe.berkeley.edu/comforttool

PSYCHROMETRICS

Psychrometrics



<u>Psychrometrics</u> is the science and engineering of air/vapor mixtures

- For architectural engineers and building scientists, the vapor is usually **water vapor**
- We use psychrometrics to relate the thermodynamic and physical properties of moist air

Applying psychrometrics

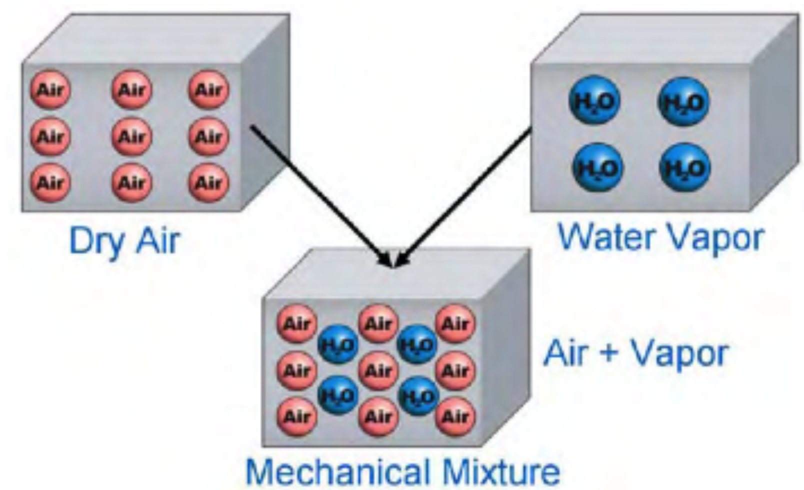
- We need to understand air temperature and moisture content to understand **human thermal comfort**
  - In hot, humid weather we design HVAC systems to remove moisture by dehumidification/cooling
  - In dry, cold weather, we add moisture by humidifiers

- We are also concerned about moisture for energy use, structural, aesthetic, and indoor air quality reasons

- Psychrometrics also involves learning how to use and combine a variety of moist air parameters

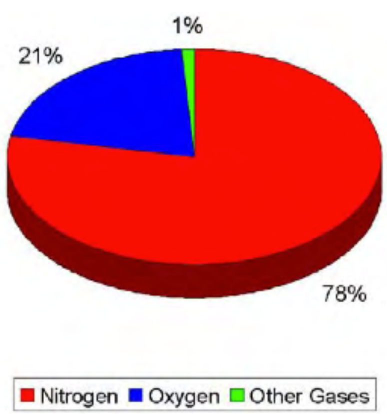
Some definitions for psychrometrics

- **Atmospheric air** contains:
  - Many gaseous components
  - Water vapor
  - Contaminants (particulate matter and gaseous pollutants)
- **Dry air** is atmospheric air with all of the water vapor removed
- **Moist air** is a two-component mixture of dry air and water vapor



Standard composition of dry air

Gas	Molecular weight (g/mol)	Volume %
Nitrogen (N_2)	32.000	78.084
Oxygen (O_2)	28.016	20.946
Argon (Ar)	39.444	0.9340
Carbon Dioxide (CO_2)	44.010	0.03697
Neon (Ne)	20.179	0.00182
Helium (He)	4.002	0.00052
Methane (CH_4)	16.042	0.00014
Krypton	83.800	0.00010



Where does water fit in?

Standard composition of **moist** air

Gas	Molecular weight (g/mol)	Volume %
Nitrogen (N_2)	32.000	78.084%
Oxygen (O_2)	28.016	20.946%
Water (H_2O)	**18.015**	**0 to 4%**
Argon (Ar)	39.444	0.9340%
Carbon Dioxide (CO_2)	44.010	0.03697%
Neon (Ne)	20.179	0.00182%
Helium (He)	4.002	0.00052%
Methane (CH_4)	16.042	0.00014%
Krypton	83.800	0.00010%

Key terms for describing moist air

- To describe and deal with moist air, we need to be able to describe the relative portions of dry air and water vapor
- There are several different equivalent measures…
- Which one you use depends on what data you have to start with and what quantity you are trying to find
- If you know two properties, you can usually get all the others

Key terms for describing moist air

Key terms to learn today:

1. Dry bulb temperature
2. Vapor pressure
3. Saturation
4. Relative humidity
5. Absolute humidity (or humidity ratio)
6. Dew point temperature
7. Wet bulb temperature
8. Enthalpy
9. Density
10. Specific volume

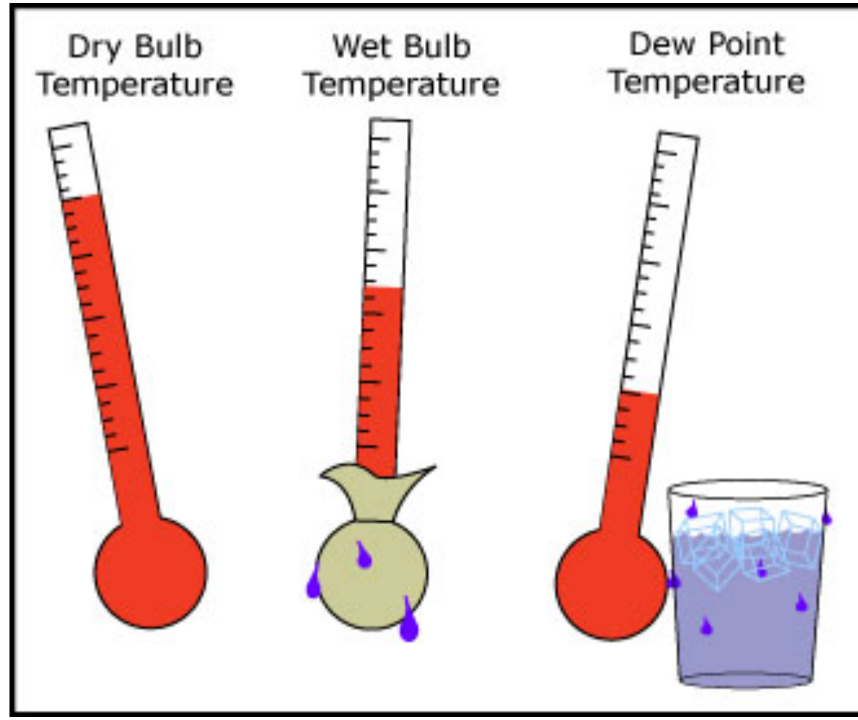
Three different temperatures: T, T_{dew}, and T_{wb}

The standard temperature, T, we are all familiar with is called the **dry-bulb** temperature, or T_d

- It is a measure of internal energy

We can also define:

- **Dew-point** temperature, T_{dew}
  - Temperature at which water vapor changes into liquid (condensation)
  - Air is maximally saturated with water vapor
- **Wet-bulb** temperature, T_{wb}
  - The temperature that a parcel of air would have if it were cooled to saturation (100% relative humidity) by the evaporation of water into it



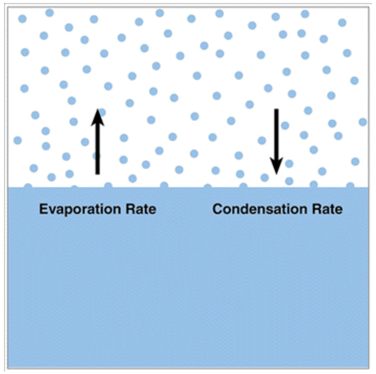
*Units of Celsius, Fahrenheit, or Kelvin

✓ The energy needed to evaporate liquid water (heat of vaporization) is taken from the air in the form of sensible heat and converted to latent heat, which lowers the temperature at constant enthalpy

Key concepts: Vapor pressure and Saturation

- Air can hold moisture (i.e., **water vapor**)
- **Vapor pressure** is the pressure exerted by a vapor in thermodynamic equilibrium with its condensed phases

p_w *Units of pressure, Pa or kPa (aka "partial pressure")



- The amount of moisture air can hold in vapor form before condensation occurs is dependent on temperature
  - We call the limit ***saturation***

p_{ws} *Units of pressure, Pa or kPa (aka "saturation vapor pressure")

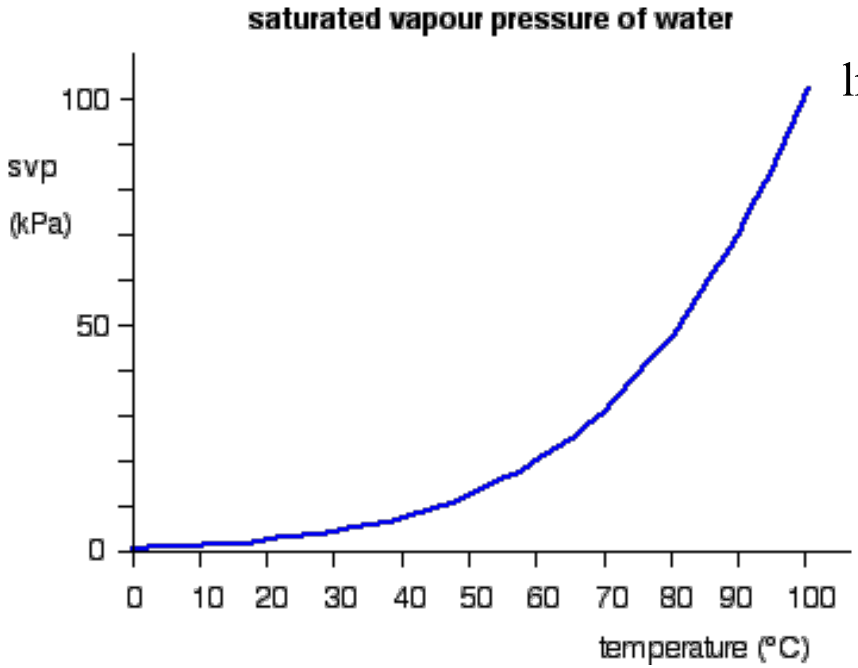
Key concept: Relative humidity, ϕ

- **Relative humidity** (RH, or ϕ) is the <u>ratio</u> of the vapor pressure of water vapor in a sample of air to the **saturation** vapor pressure at the dry bulb temperature of the sample
- Relative humidity ≠ absolute humidity!

$$\phi = \frac{p_w}{p_{ws}}$$

Key concept: Saturation vapor pressure, p_{ws}

- The **saturation vapor pressure** is the partial pressure of water vapor at saturation (p_{ws})   *Units of pressure, Pa or kPa
  - Cannot absorb any more moisture at that temperature
- We can look up p_{ws} in tables (as a function of T)
  - Table 3 in Ch.1 of 2013 ASHRAE Fundamentals
- We can also use empirical equations:



Equation for p_{ws}:

$$\ln p_{ws} = \frac{C_8}{T} + C_9 + C_{10}T + C_{11}T^2 + C_{12}T^3 + C_{13}\ln T$$

where

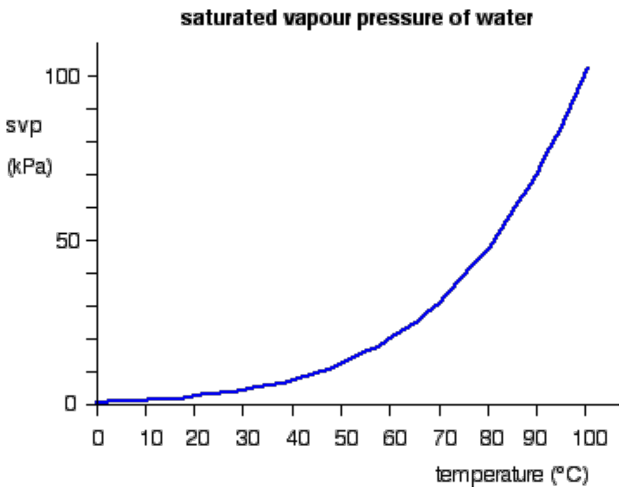
$C_8 = -5.800\,220\,6 \text{ E+03}$
$C_9 = 1.391\,499\,3 \text{ E+00}$
$C_{10} = -4.864\,023\,9 \text{ E-02}$
$C_{11} = 4.176\,476\,8 \text{ E-05}$
$C_{12} = -1.445\,209\,3 \text{ E-08}$
$C_{13} = 6.545\,967\,3 \text{ E+00}$

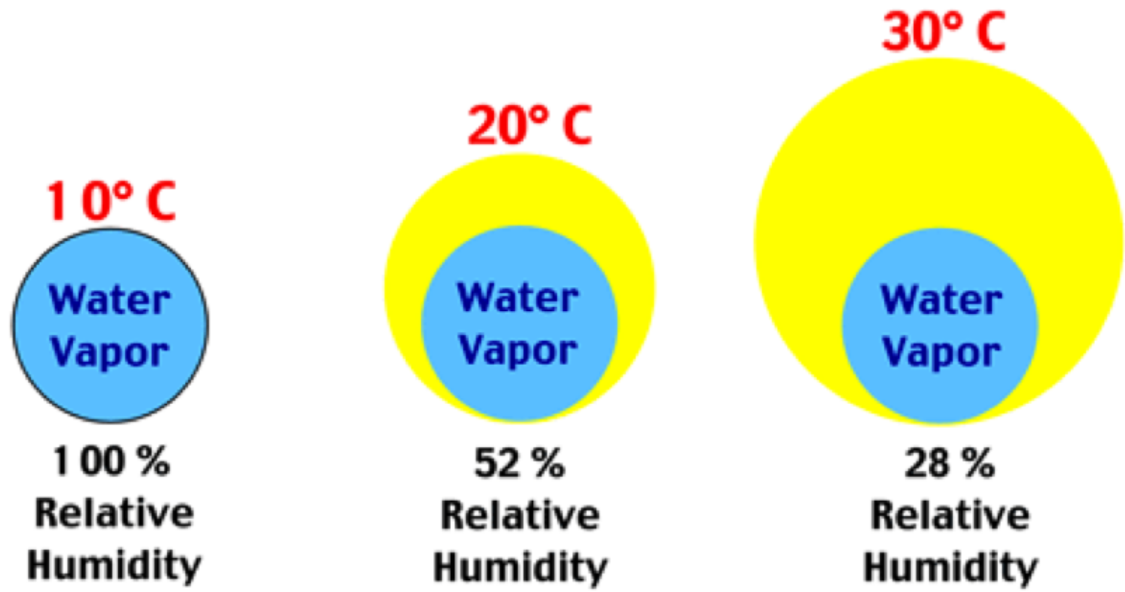
p_{ws} = saturation pressure, Pa
T = absolute temperature, K = °C + 273.15

Relative humidity and temperature

- **Relative humidity** (RH, or ϕ) is a <u>function of temperature</u>

$$\phi = \frac{p_w}{p_{ws}}$$





Key concept: Humidity ratio, W

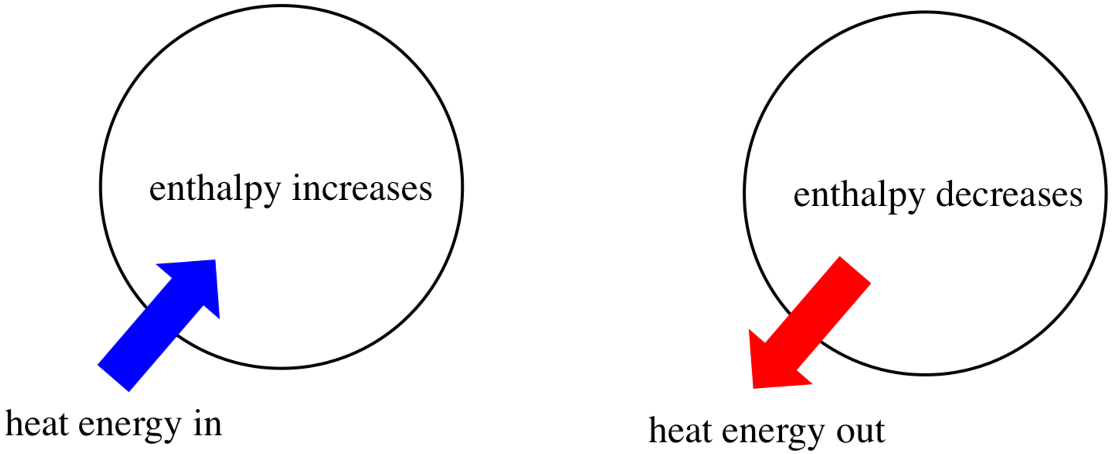
- The **humidity ratio** is a measure of the mass of water vapor present in a parcel of air (a measure of *absolute humidity*)

- The humidity ratio is simply the mass of water vapor that exists in a parcel of mass of *dry air*
  - Units of mass of water vapor per mass of dry air
    - kg/kg (kg_w/kg_{da})
    - g/kg (g_w/g_{da})

$$W = \frac{\text{mass of water vapor}}{\text{mass of dry air}} \quad [\frac{kg_w}{kg_{da}}]$$

Key concept: Enthalpy

- **Enthalpy** is a measure of the amount of energy in a system
  - Units of Joules or BTU (or J/kg or BTU/lb)
- The enthalpy of moist air is the total enthalpy of the dry air plus the water vapor mixture per mass of moist air
- Includes:
  - Enthalpy of dry air, or sensible heat
  - Enthalpy of evaporated water, or latent heat



Key concept: Density and specific volume

Air density

- Density is a measure of the mass of moist air per unit volume of air
- Includes mass of dry air + water vapor

$$\rho = \frac{\text{mass of moist air}}{\text{volume of moist air}} \quad [\frac{\text{kg}}{\text{m}^3}]$$

Specific volume

- Specific volume is the volume of unit mass of dry air at a given temperature, expressed as m^3/kg (inverse of dry air density)

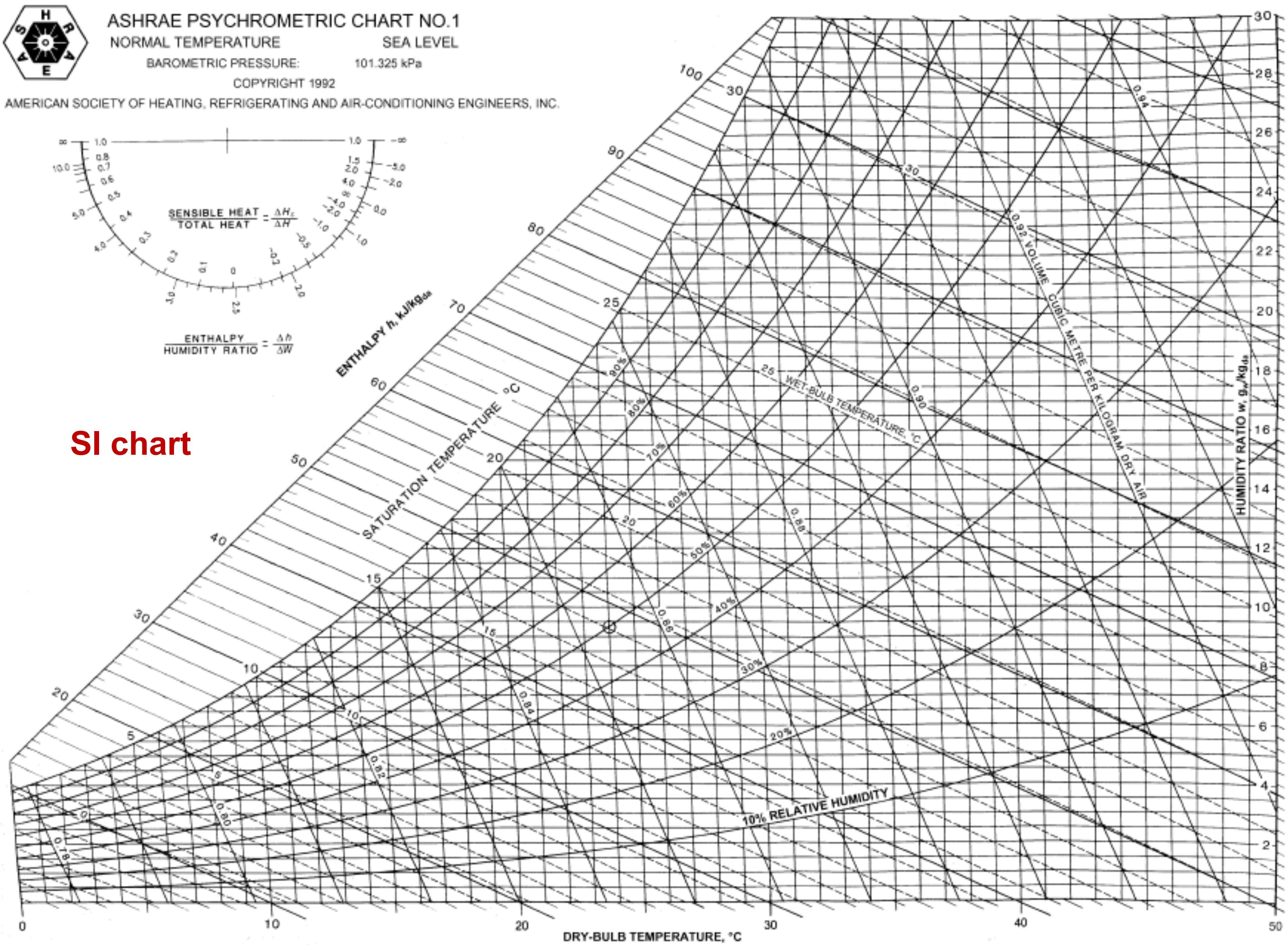
$$\upsilon = \frac{\text{volume of dry air}}{\text{mass of dry air}} \quad [\frac{\text{m}^3}{\text{kg}_{\text{da}}}]$$

The Psychrometric Chart

- There are both simple and complex ways to estimate these properties
  - Equations and tables (more complex, save for next lecture)
  - Graphically using …

- **The Psychrometric Chart**
  - Plots dry bulb temperature (T) on the x-axis and humidity ratio (W) on the y-axis
    - Shows relationships between T and W and relative humidity, wet-bulb temperature, vapor pressure, specific volume, and enthalpy
  - Charts are unique at each value of atmospheric pressure (p)

- Both SI and IP versions are on BB in the materials folder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SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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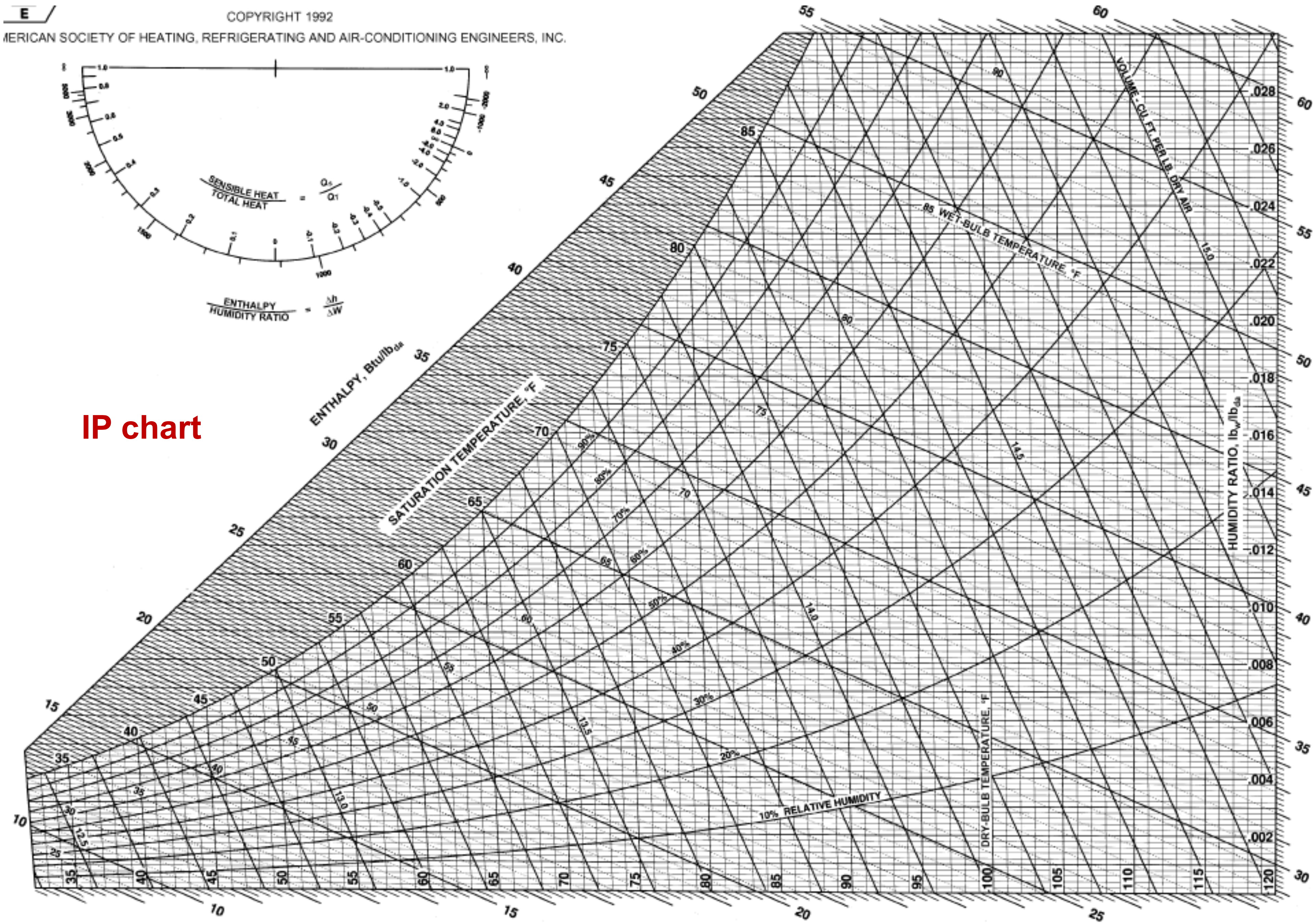
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C

SI chart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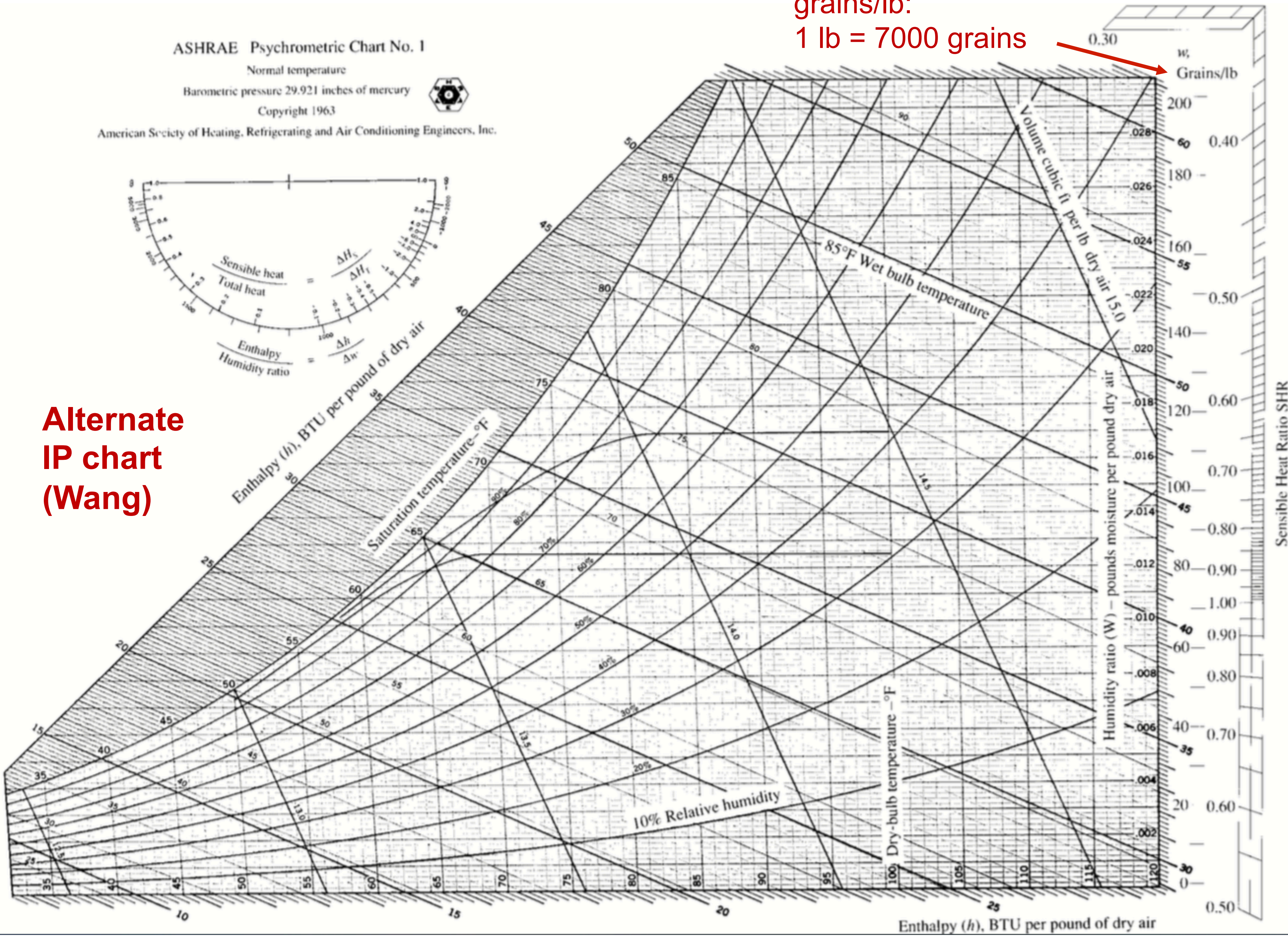
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY, Btu/lb_da
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE, °F
VOLUME, CU. FT. PER LB. DRY AIR
HUMIDITY RATIO, lb_w/lb_da
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °F

IP chart

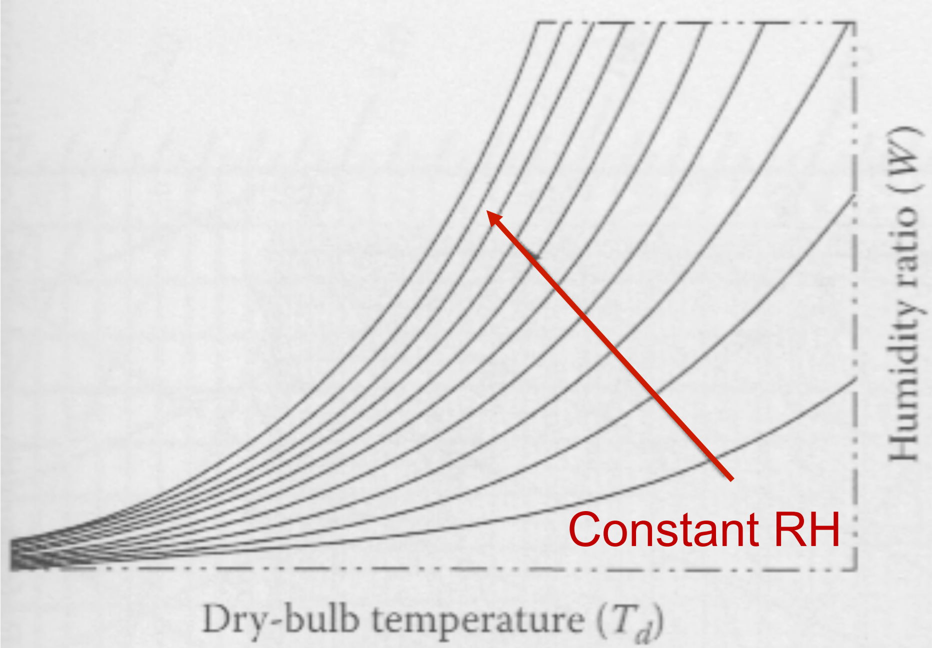
grains/lb:
1 lb = 7000 grains

Alternate IP chart (Wang)

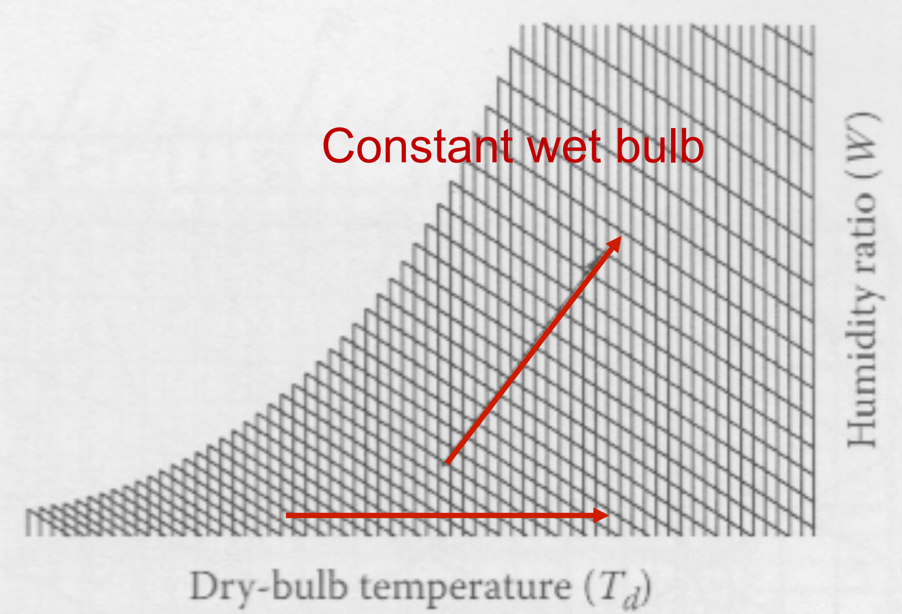


Deciphering the psychrometric chart

Lines of constant RH



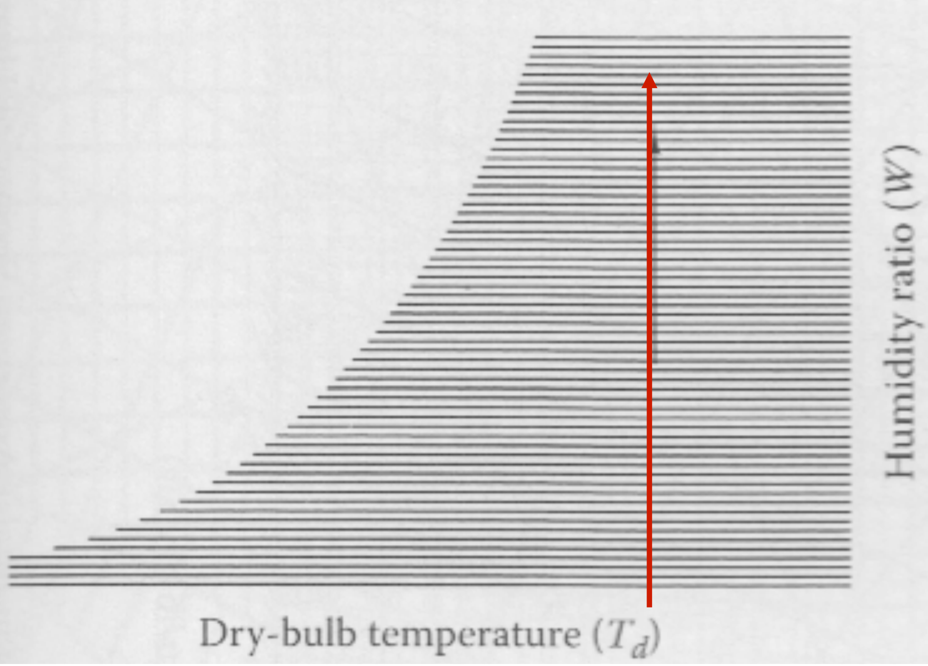
Lines of constant wet-bulb and dry-bulb



Constant dry bulb temperature

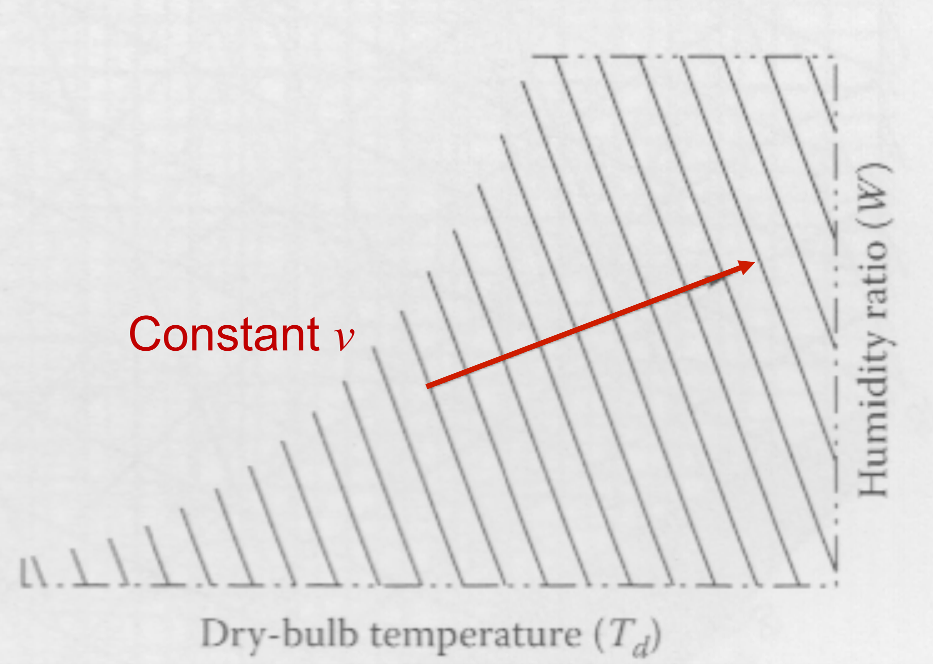
Deciphering the psychrometric chart

Lines of constant humidity ratio



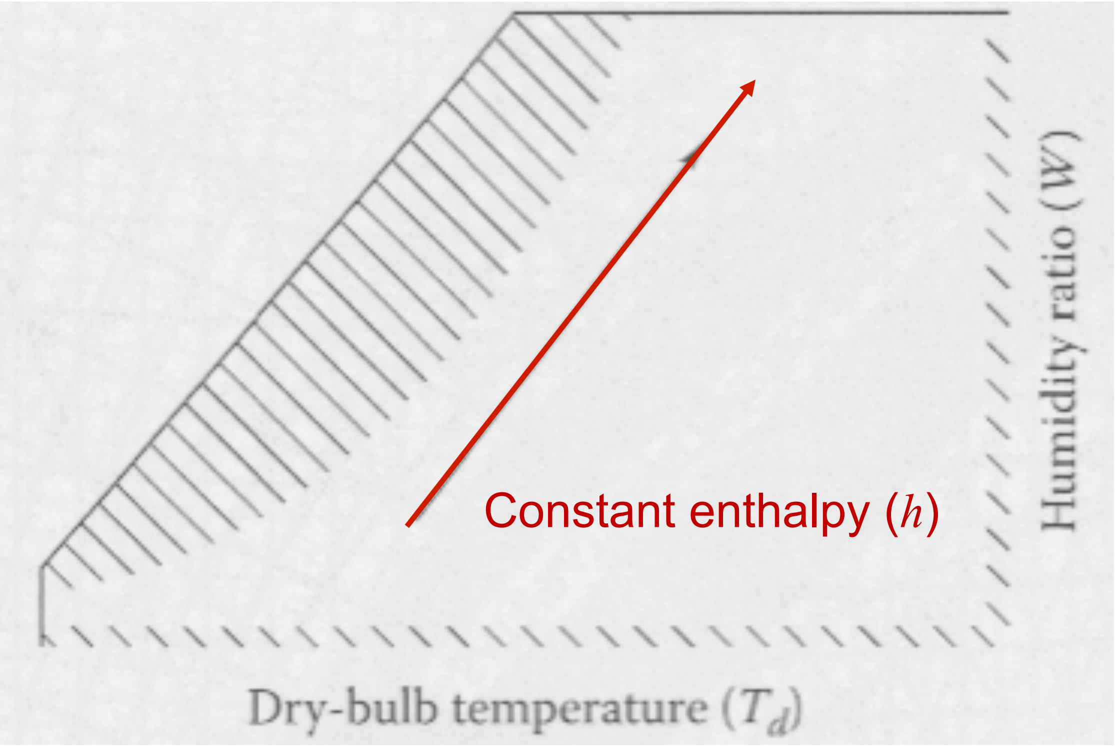
Constant W

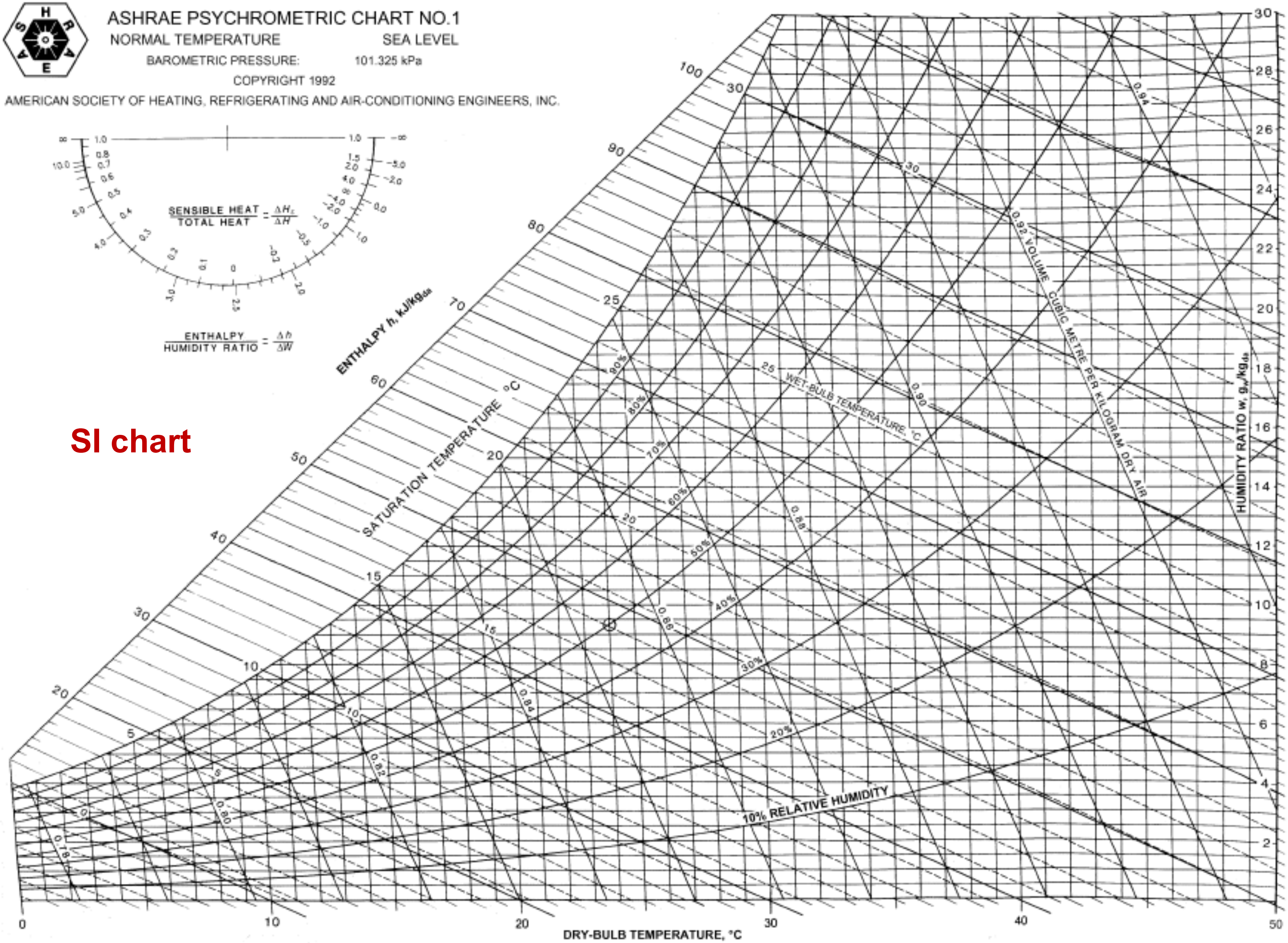
Lines of constant specific volume



Deciphering the psychrometric chart

Lines of constant enthalpy

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NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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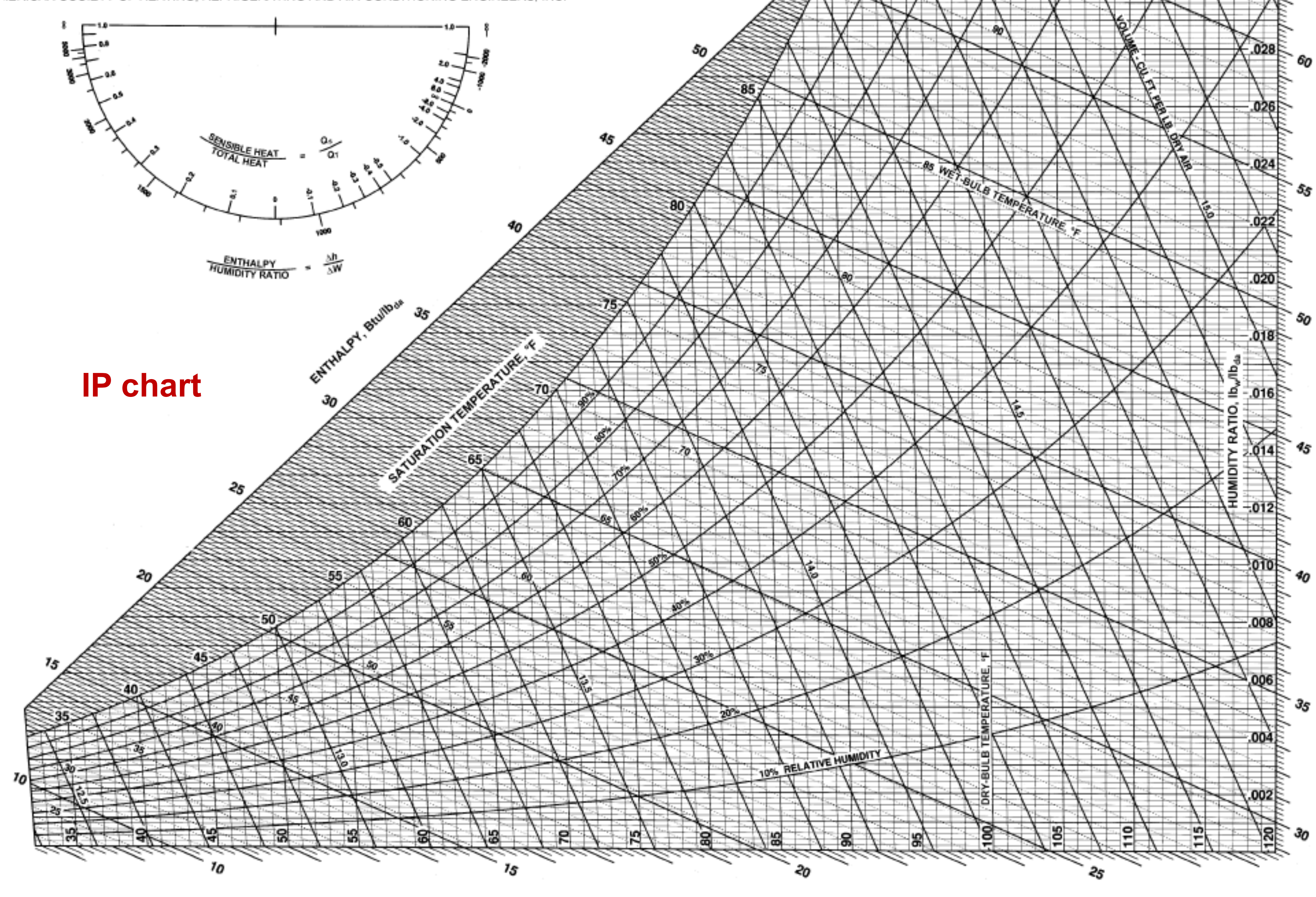
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO w, gw/kg da
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
0
10
20
30
40
50

SI chart

IP chart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ENTHALPY, Btu/lbda
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE, °F
VOLUME - CU. FT. PER LB. DRY AIR
HUMIDITY RATIO, lbw/lbda
DRY-BULB TEMPERATURE, °F
10% RELATIVE HUMIDITY
20%
30%
40%
50%
60%
70%
80%
90%

Some psychrometric examples

Moist air exists at 22°C dry-bulb temperature with 50% RH

Find the following:

(a) the humidity ratio, W

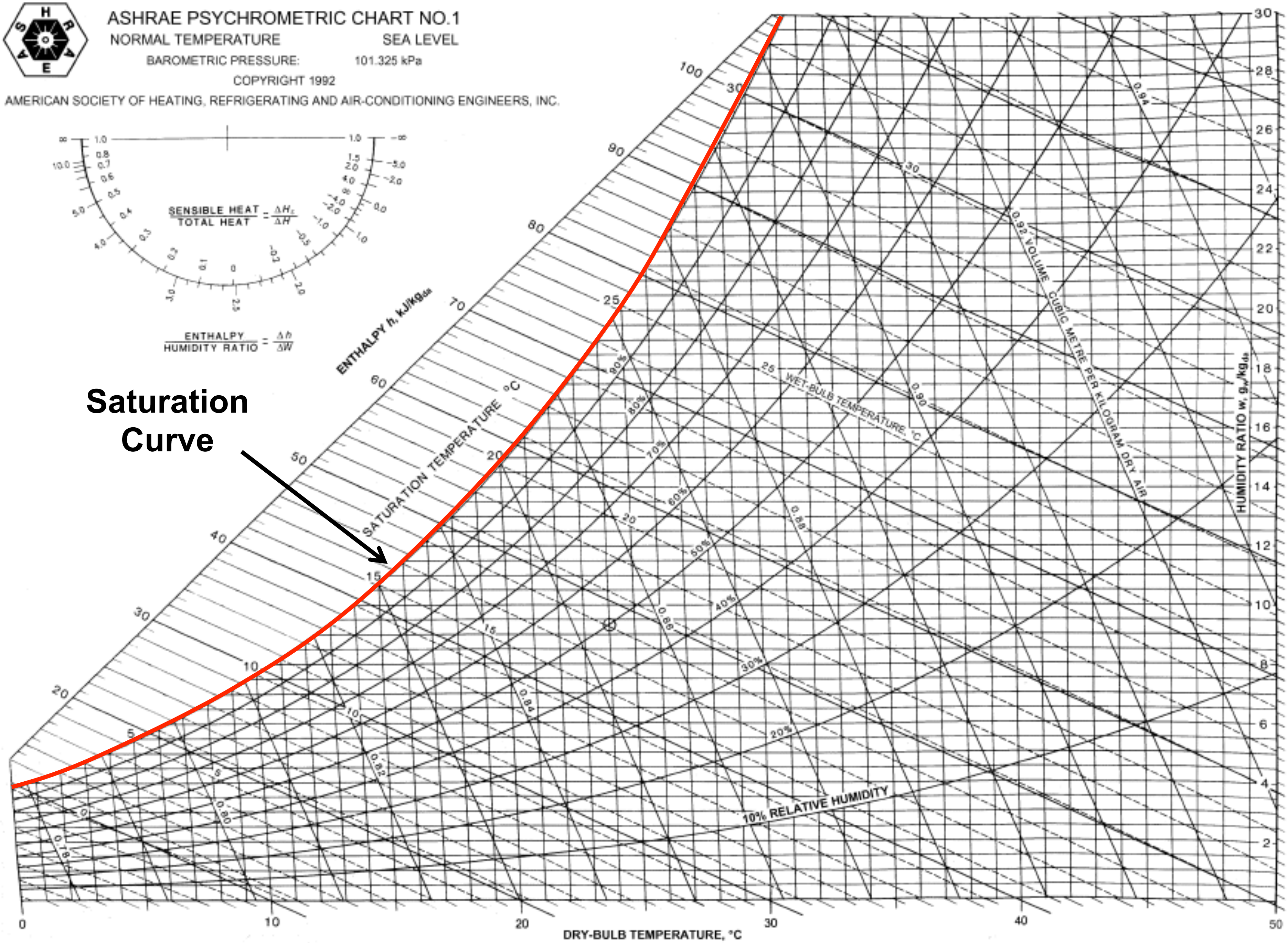
(b) dew point temperature, T_{dew}

(c) wet-bulb temperature, T_{wb}

(d) enthalpy, h

(e) specific volume, v

(f) dry air density, ρ



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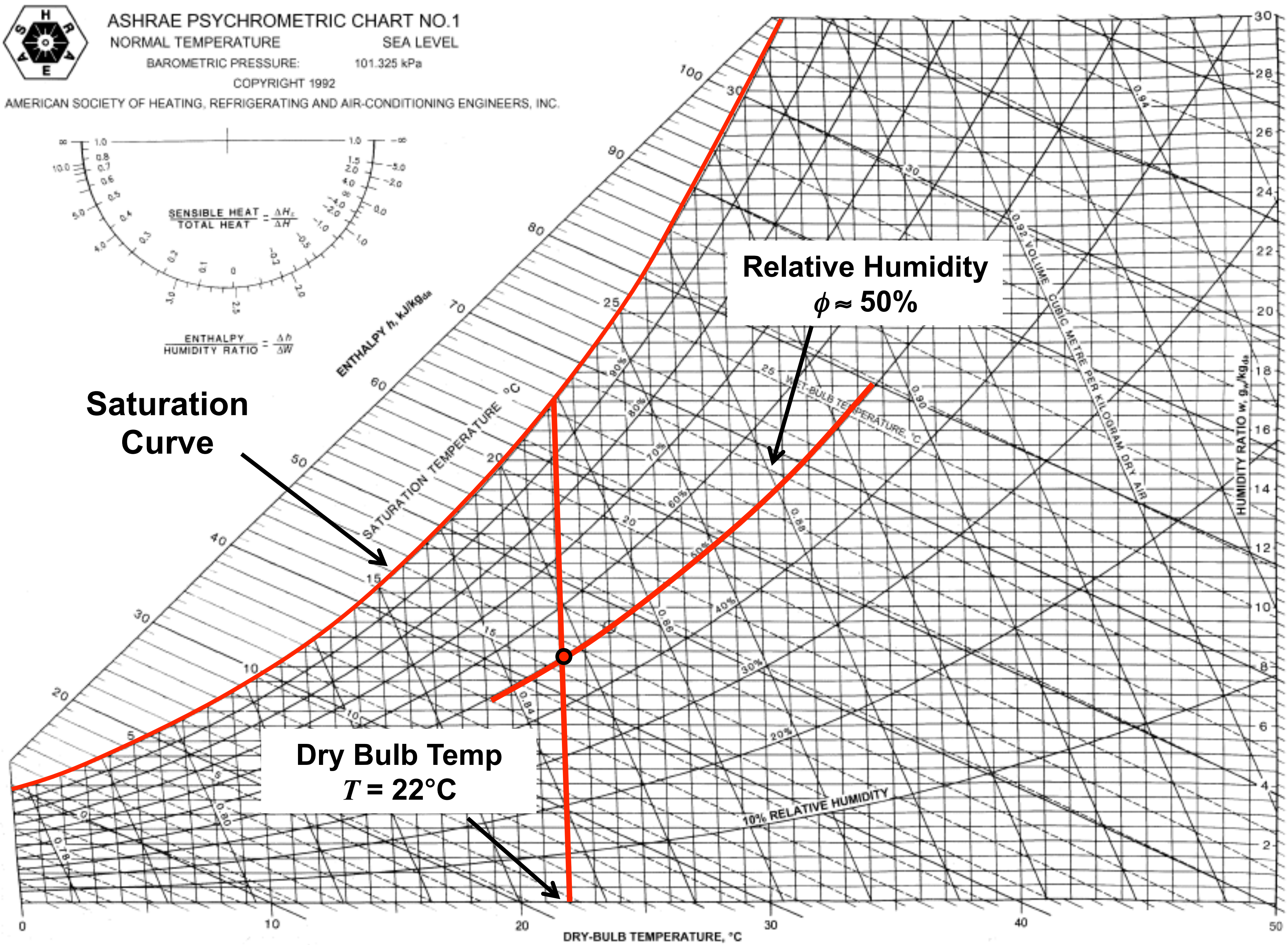
HUMIDITY RATIO w, gw/kgda
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
Saturation Curve



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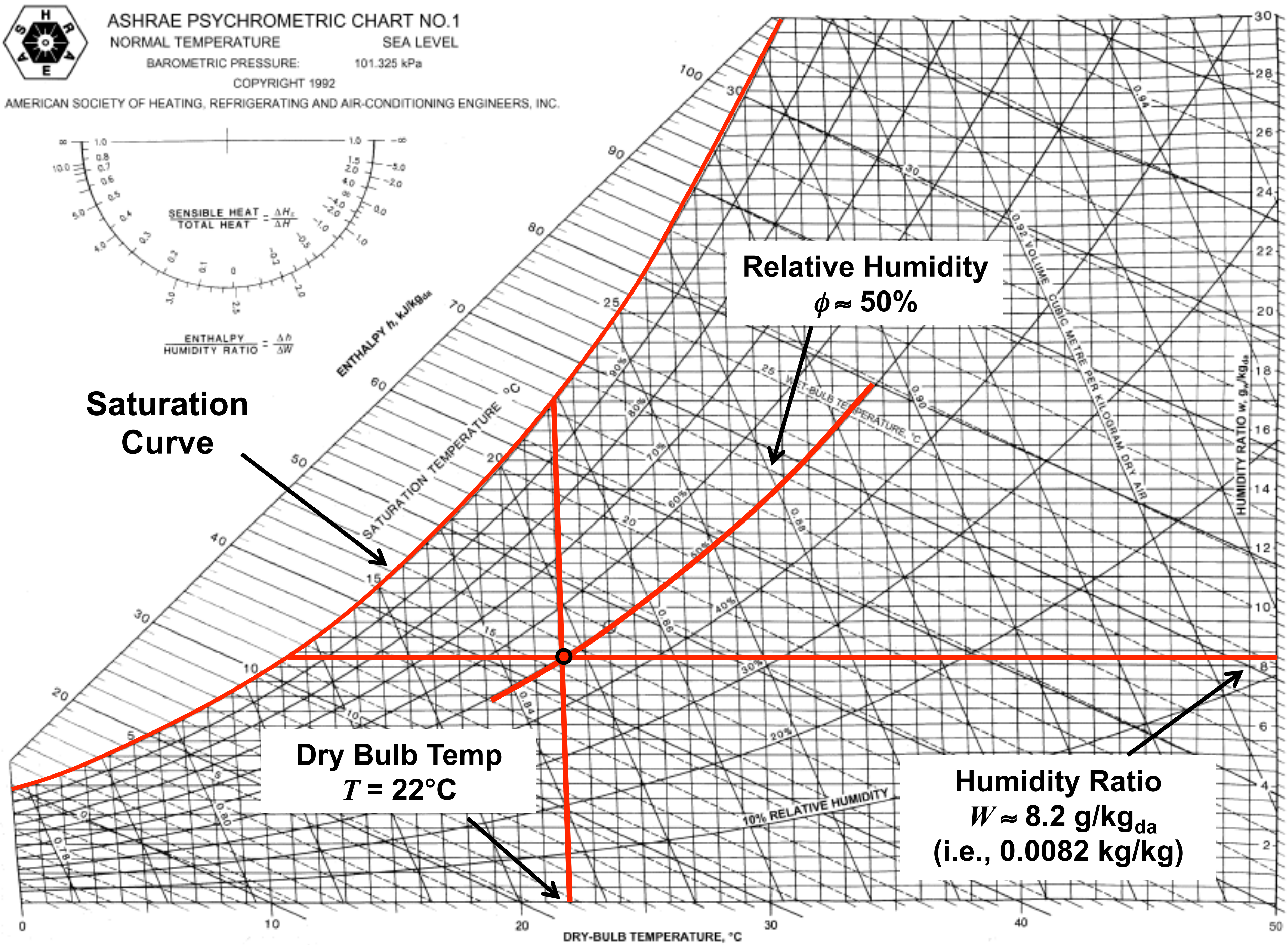
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
0.92 VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO w, gw/kgda
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
Saturation Curve
Relative Humidity
φ ≈ 50%
Dry Bulb Temp
T = 22°C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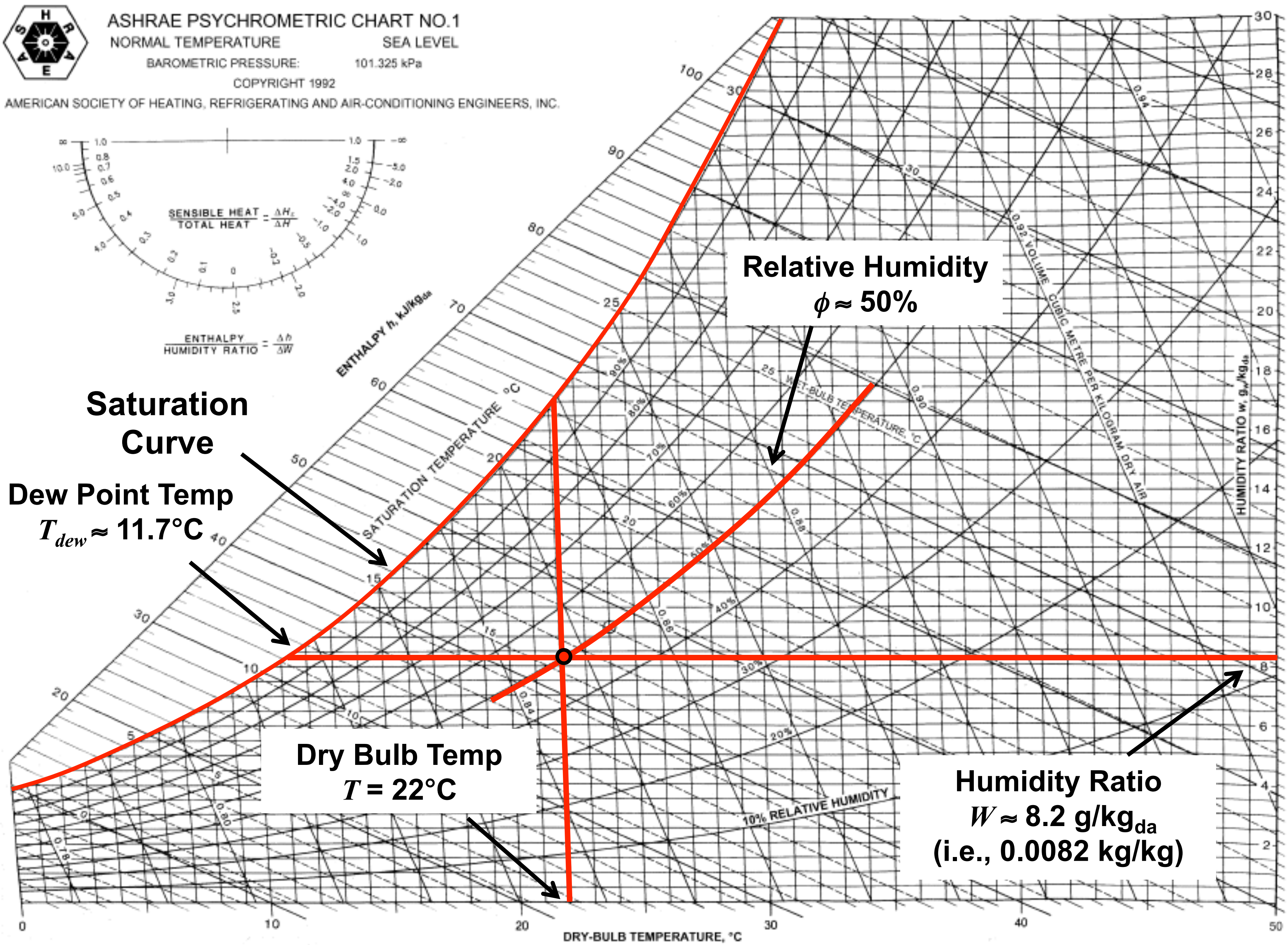
HUMIDITY RATIO w, g w/kg da
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
Saturation Curve
Relative Humidity
ϕ ≈ 50%
Dry Bulb Temp
T = 22°C
Humidity Ratio
W ≈ 8.2 g/kg da
(i.e., 0.0082 kg/kg)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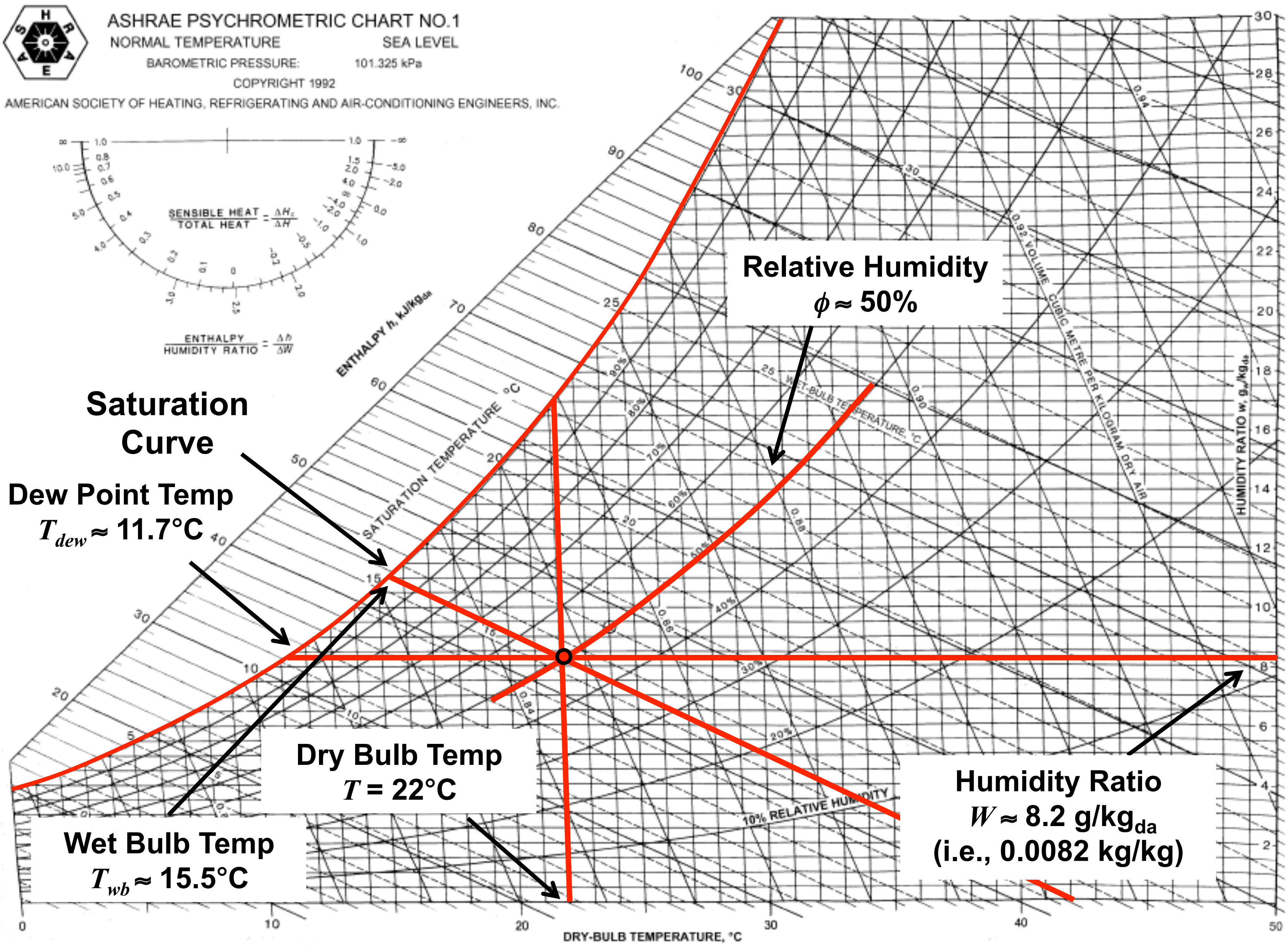
HUMIDITY RATIO w, gw/kg da
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
Saturation Curve
Dew Point Temp
$T_{dew} \approx 11.7$°C
Relative Humidity
$\phi \approx 50\%$
Dry Bulb Temp
$T = 22$°C
Humidity Ratio
$W \approx 8.2$ g/kg$_{da}$
(i.e., 0.0082 kg/kg)


ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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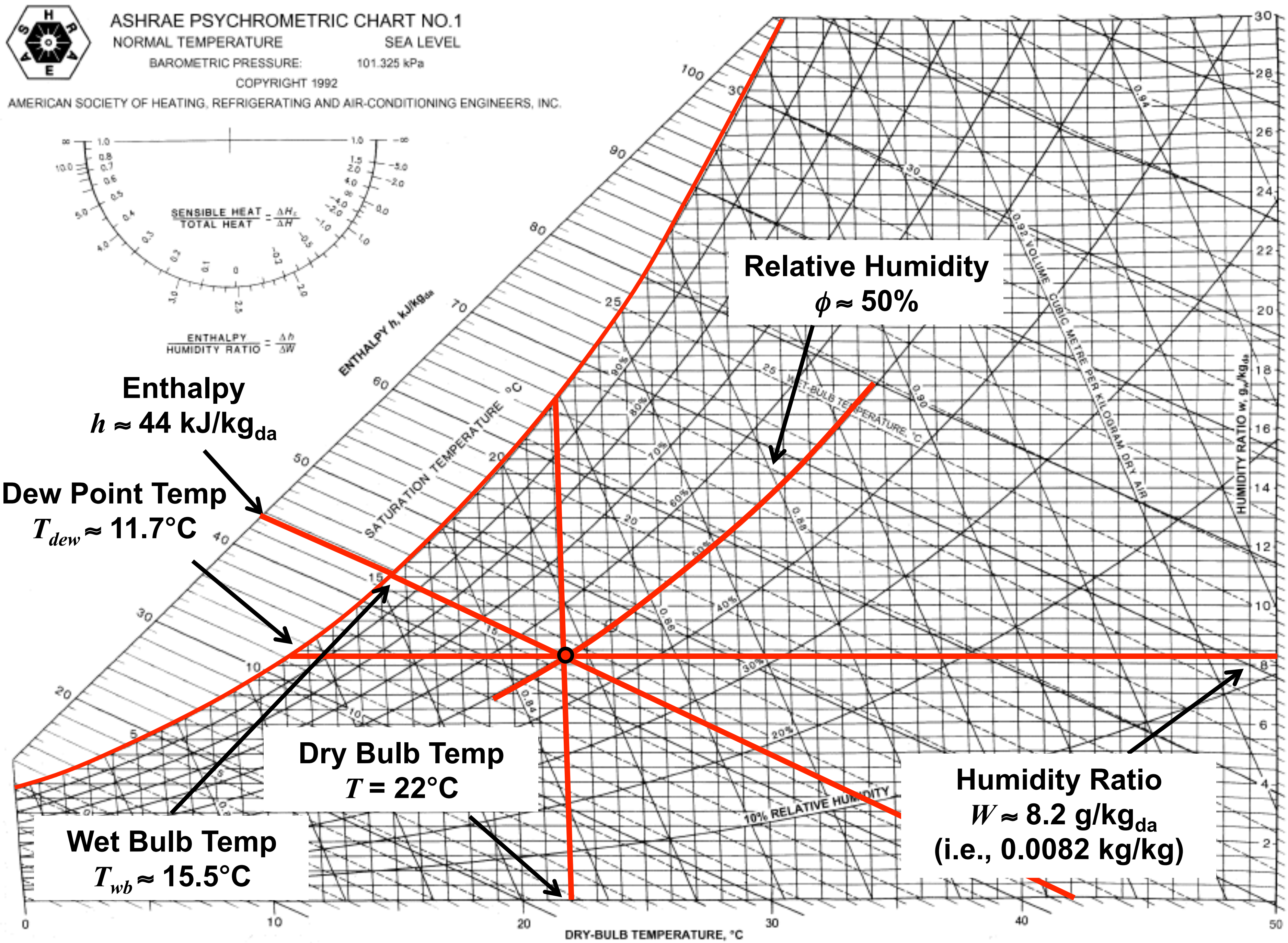
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, g/kg da
DRY-BULB TEMPERATURE, °C
Saturation Curve
Dew Point Temp
$T_{dew} \approx 11.7°C$
Relative Humidity
$\phi \approx 50\%$
Dry Bulb Temp
$T = 22°C$
Wet Bulb Temp
$T_{wb} \approx 15.5°C$
Humidity Ratio
$W \approx 8.2\ g/kg_{da}$
(i.e., 0.0082 kg/kg)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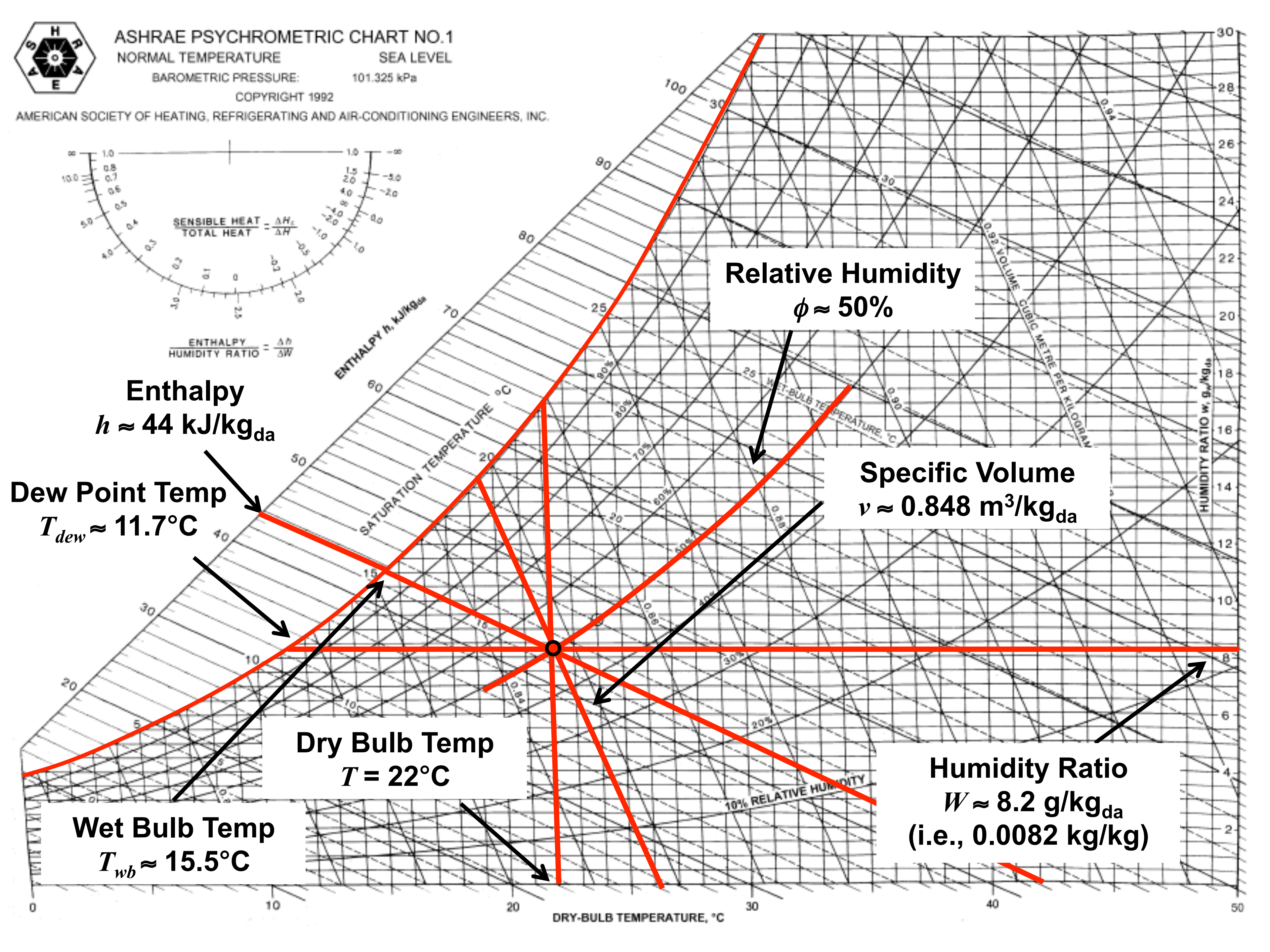
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO w, gw/kgda
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
Relative Humidity
$\phi \approx 50\%$
Enthalpy
$h \approx 44$ kJ/kg$_{da}$
Dew Point Temp
$T_{dew} \approx 11.7$°C
Dry Bulb Temp
$T = 22$°C
Wet Bulb Temp
$T_{wb} \approx 15.5$°C
Humidity Ratio
$W \approx 8.2$ g/kg$_{da}$
(i.e., 0.0082 kg/kg)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BAROMETRIC PRESSURE: 101.325 kPa
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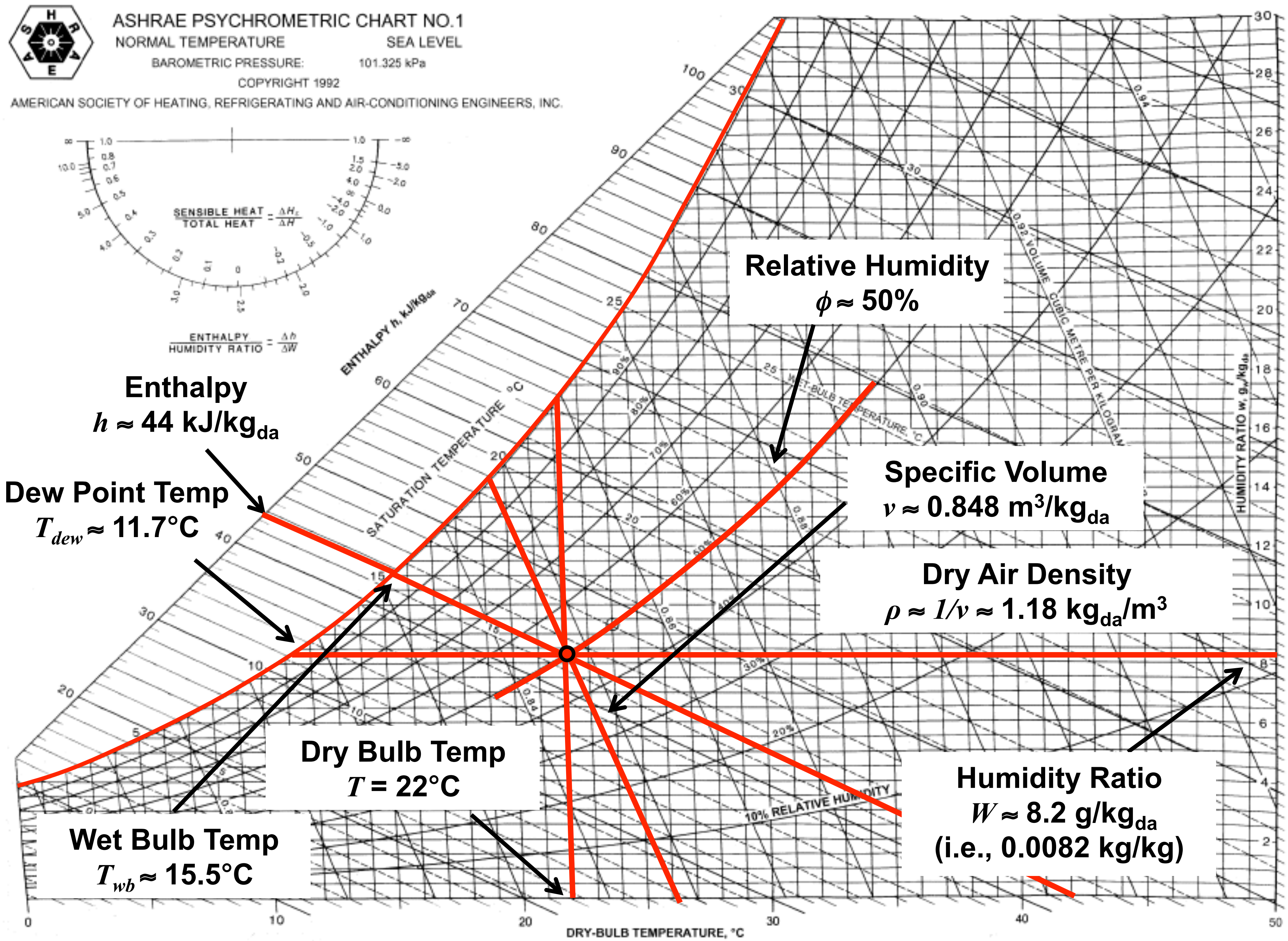
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, g/kg da
DRY-BULB TEMPERATURE, °C
Relative Humidity
$\phi \approx 50\%$
Enthalpy
$h \approx 44$ kJ/kg$_{da}$
Dew Point Temp
$T_{dew} \approx 11.7$°C
Specific Volume
$v \approx 0.848$ m^3/kg$_{da}$
Dry Bulb Temp
$T = 22$°C
Wet Bulb Temp
$T_{wb} \approx 15.5$°C
Humidity Ratio
$W \approx 8.2$ g/kg$_{da}$
(i.e., 0.0082 kg/kg)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NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Relative Humidity
ϕ ≈ 50%
Enthalpy
h ≈ 44 kJ/kgda
Specific Volume
v ≈ 0.848 m³/kgda
Dew Point Temp
Tdew ≈ 11.7°C
Dry Air Density
ρ ≈ 1/v ≈ 1.18 kgda/m³
Dry Bulb Temp
T = 22°C
Humidity Ratio
W ≈ 8.2 g/kgda
(i.e., 0.0082 kg/kg)
Wet Bulb Temp
Twb ≈ 15.5°C
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C

Some psychrometric examples

Moist air exists at 30°C dry-bulb temperature with a 15°C dew point temperature

Find the following:

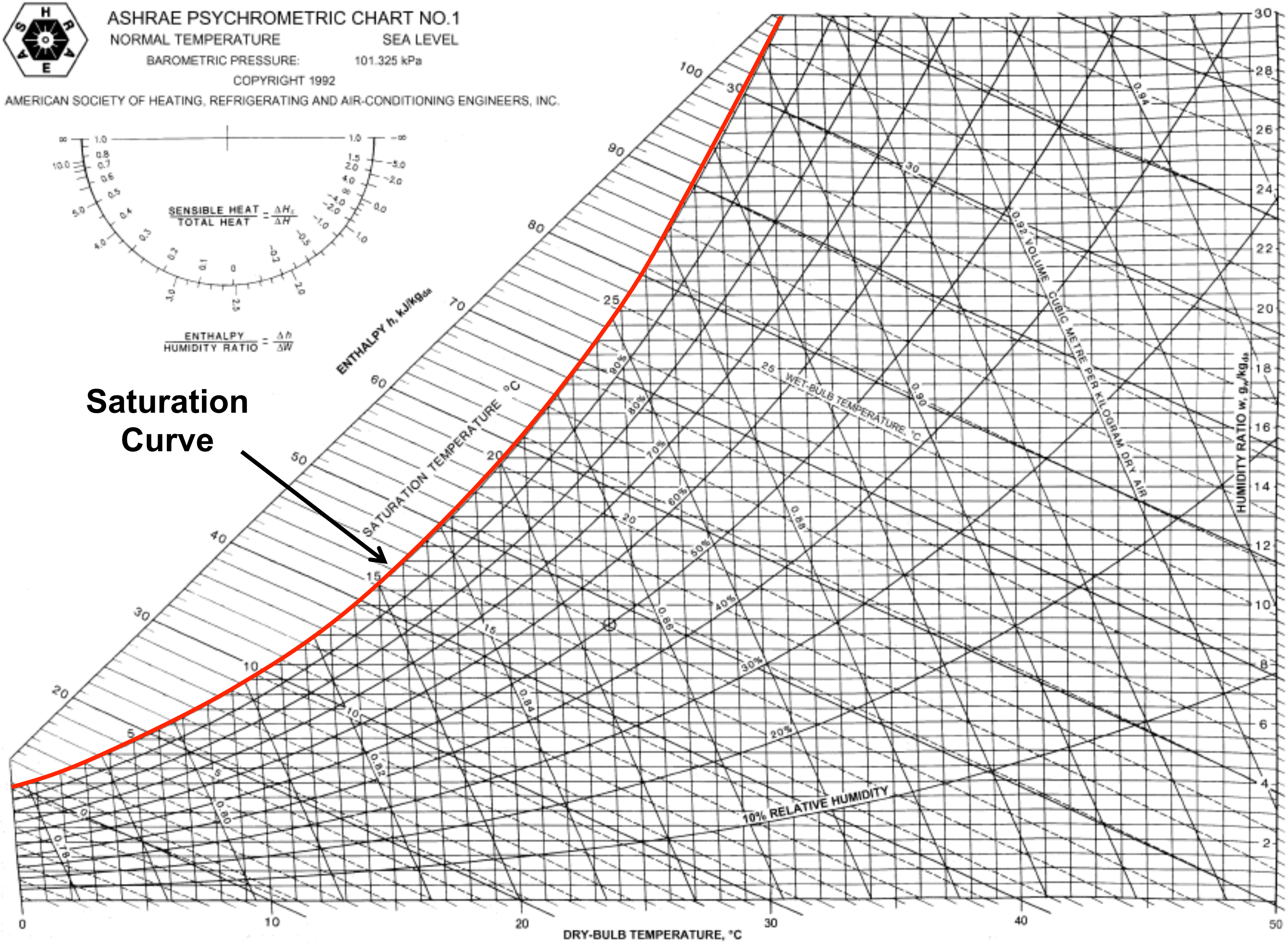
(a) the humidity ratio, W

(b) wet-bulb temperature, T_{wb}

(c) enthalpy, h

(d) specific volume, v

(e) relative humidity, ϕ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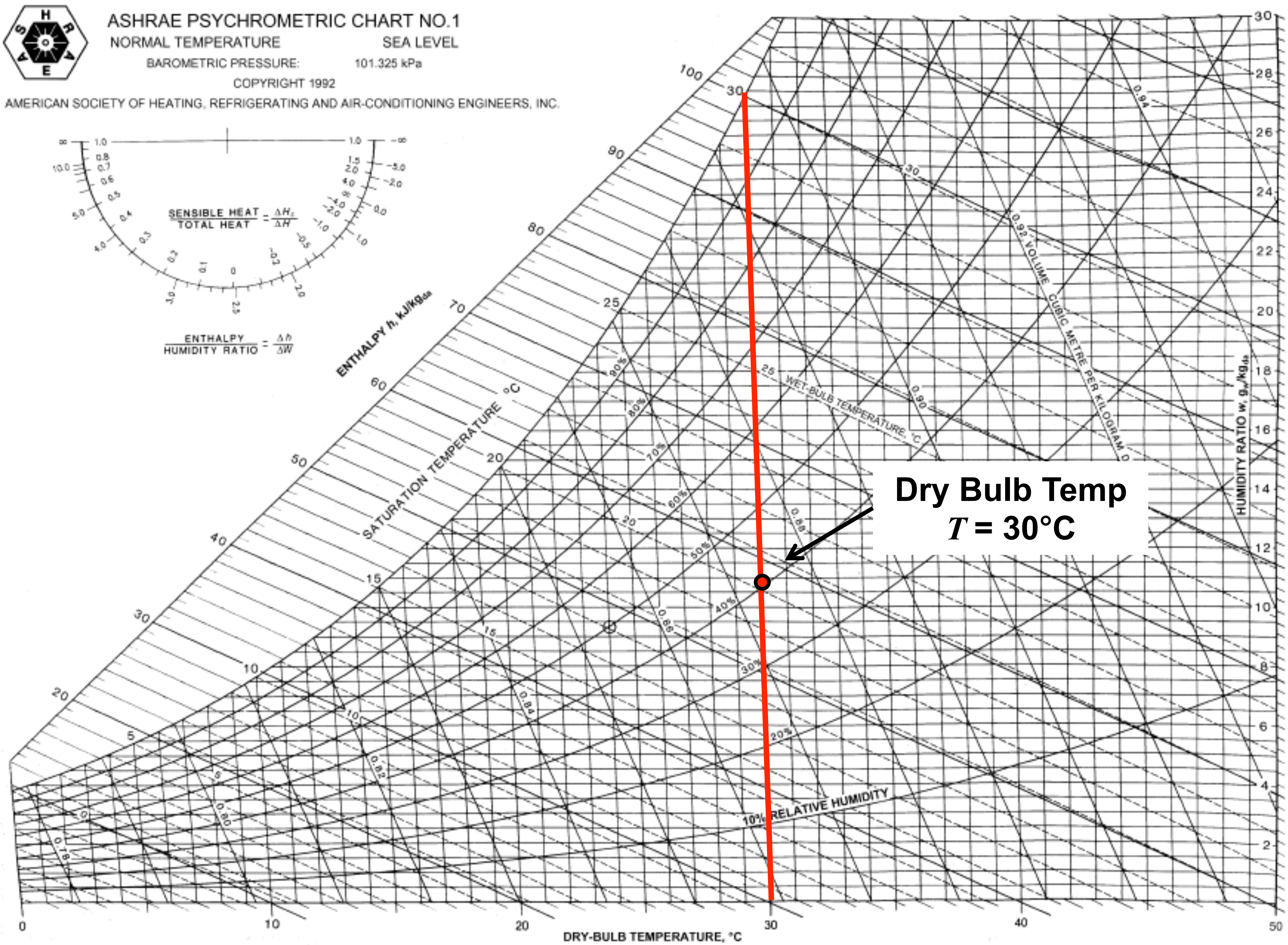
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C
Saturation Curve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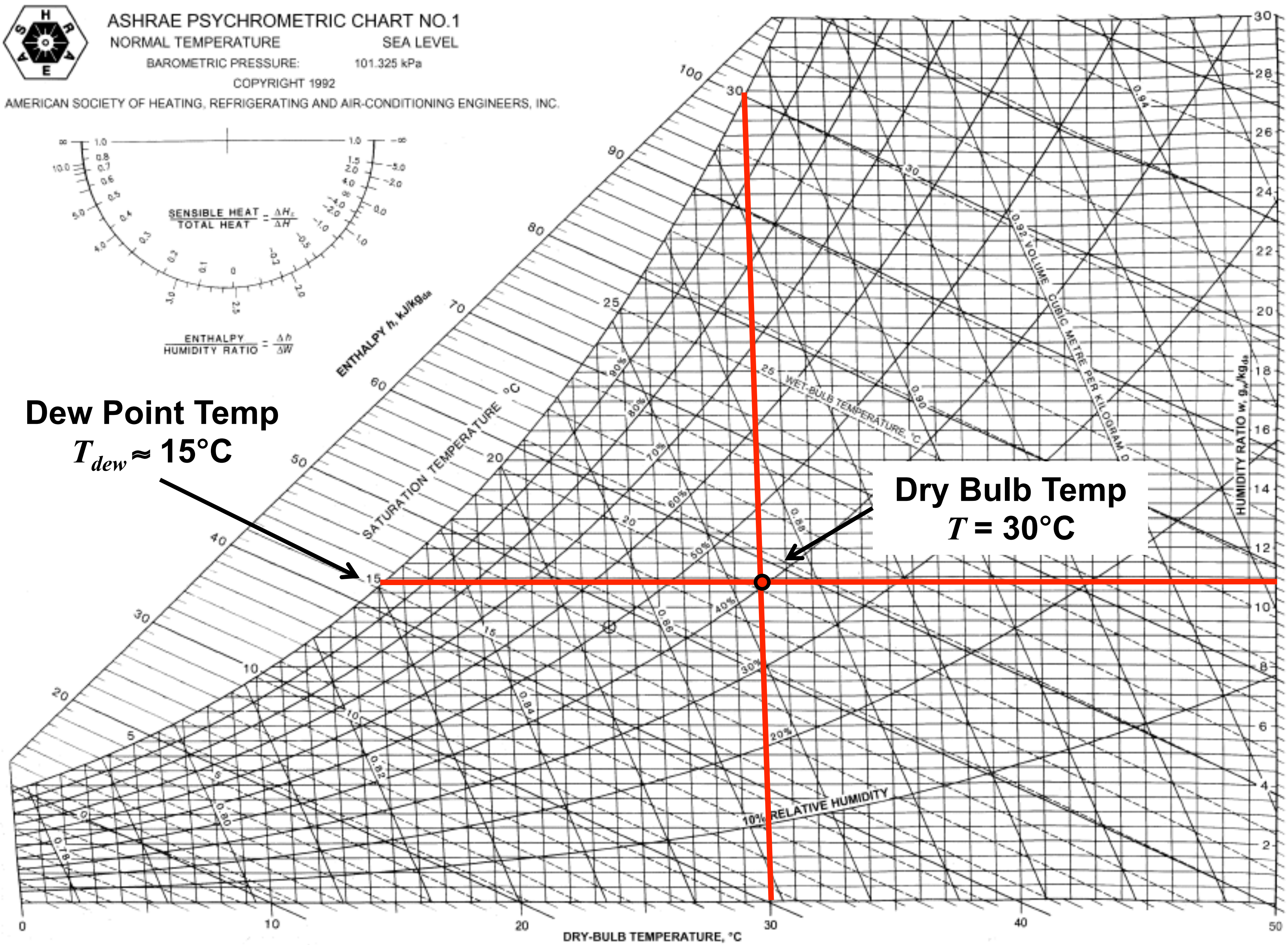
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C
Dry Bulb Temp
T = 30°C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SEA LEVEL
BAROMETRIC PRESSURE:
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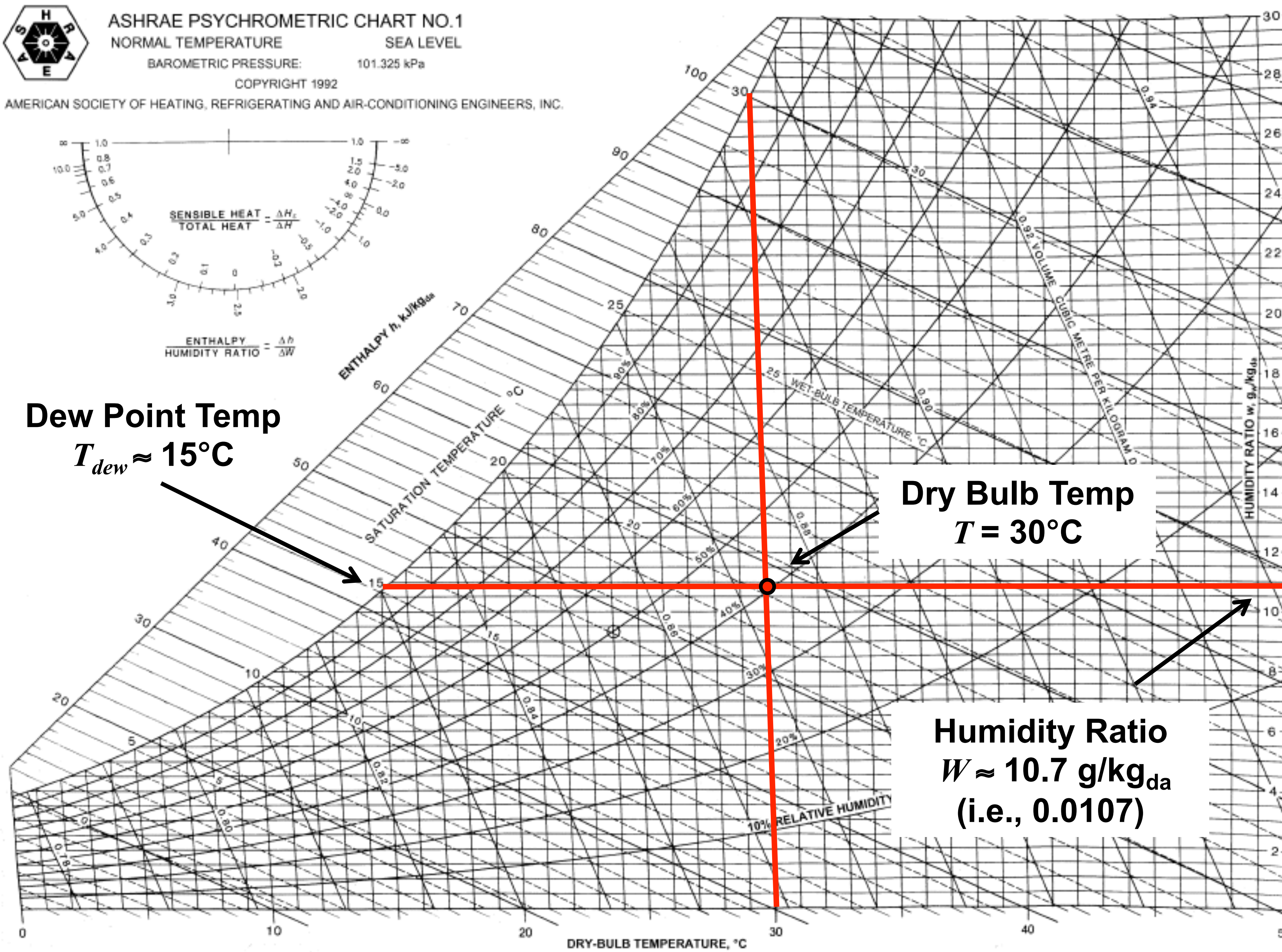
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM
HUMIDITY RATIO w, gw/kgda
10% RELATIVE HUMIDITY
DRY-BULB TEMPERATURE, °C
Dew Point Temp
$T_{dew} \approx 15°C$
Dry Bulb Temp
$T = 30°C$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NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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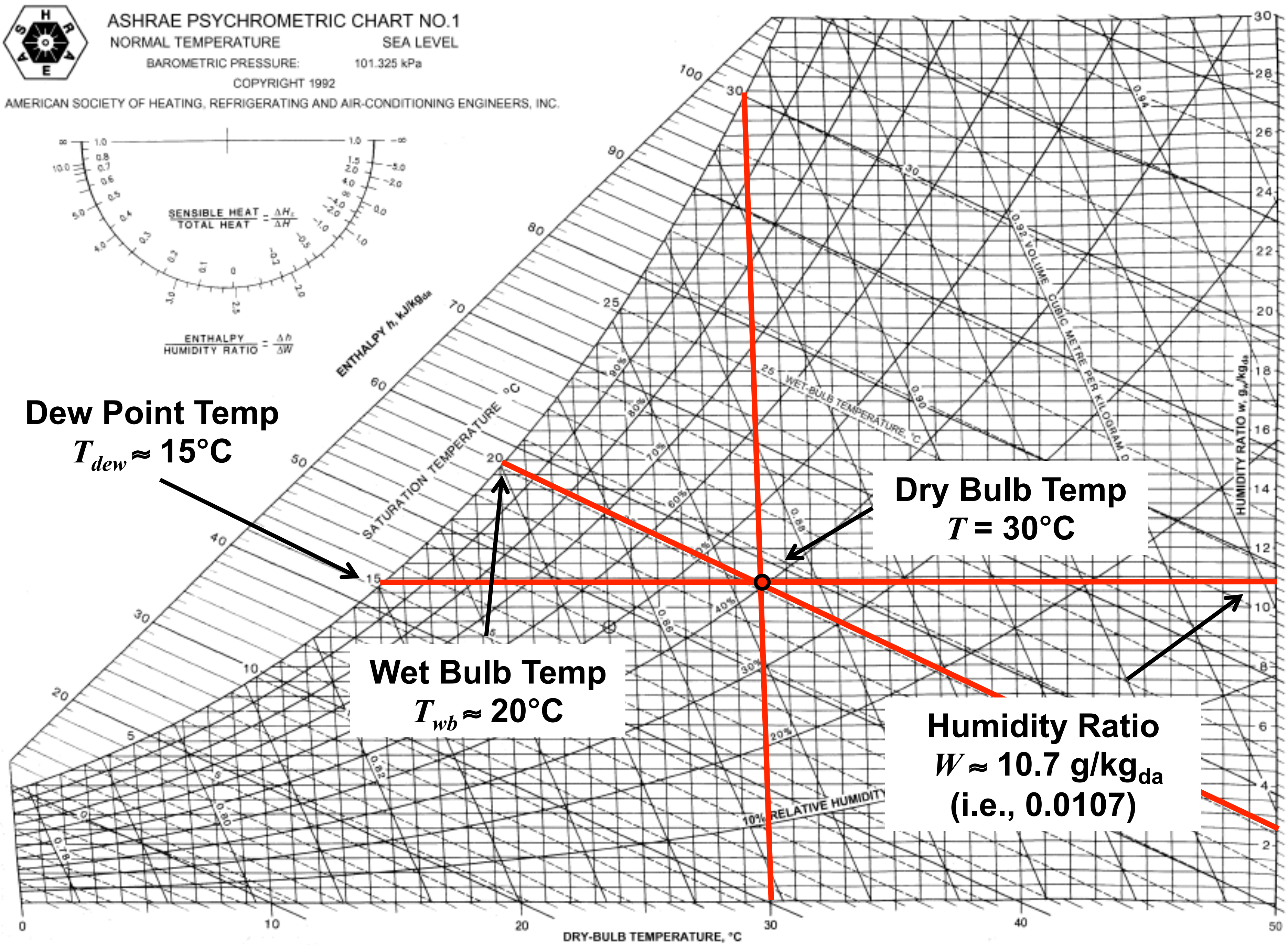
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE, °C
0.92 VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C
Dew Point Temp
T dew ≈ 15°C
Dry Bulb Temp
T = 30°C
Humidity Ratio
W ≈ 10.7 g/kg da
(i.e., 0.0107)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NORMAL TEMPERATURE
SEA LEVEL
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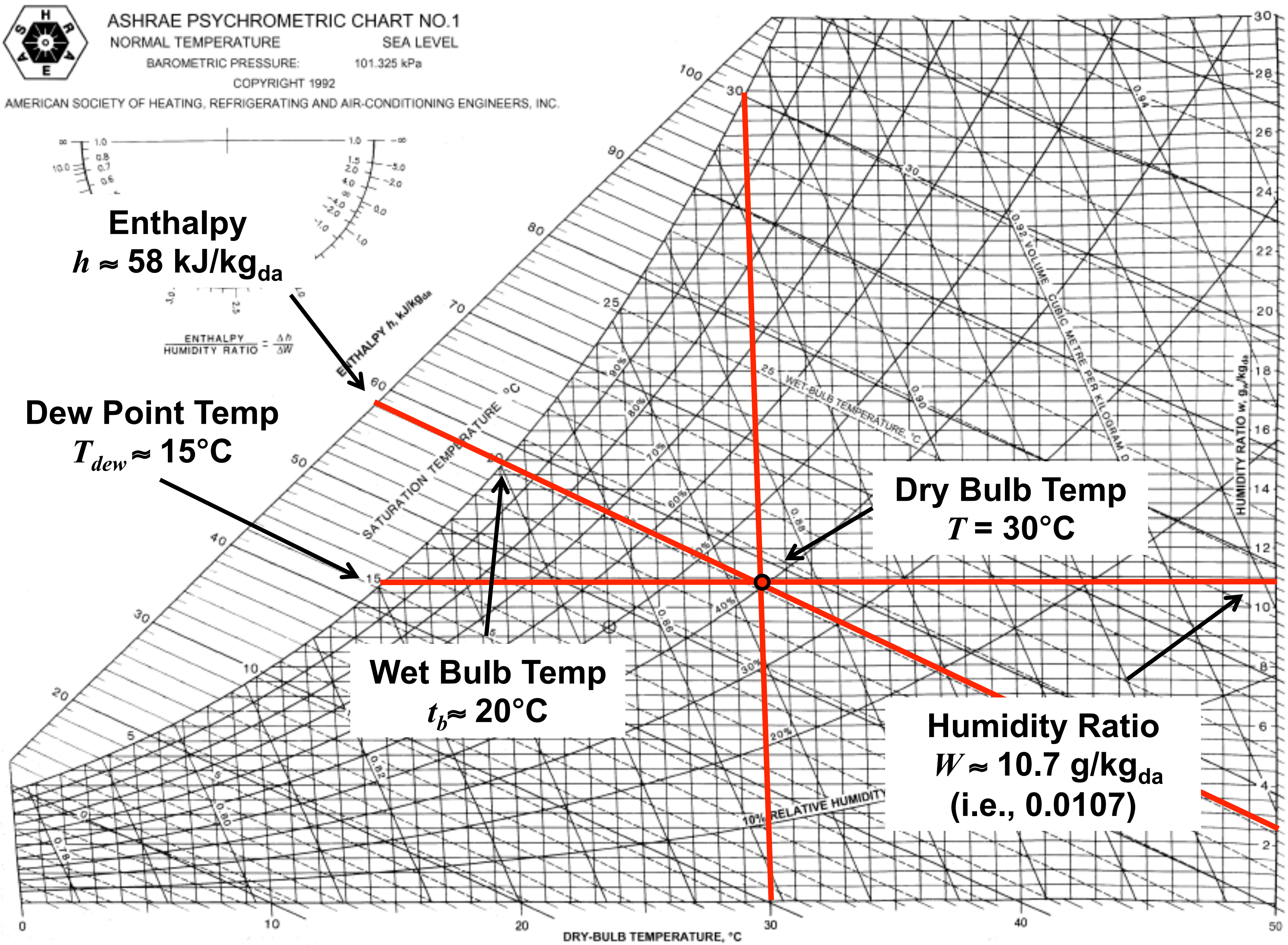
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C
Dew Point Temp
$T_{dew} \approx 15°C$
Wet Bulb Temp
$T_{wb} \approx 20°C$
Dry Bulb Temp
$T = 30°C$
Humidity Ratio
$W \approx 10.7\ g/kg_{da}$
(i.e., 0.0107)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NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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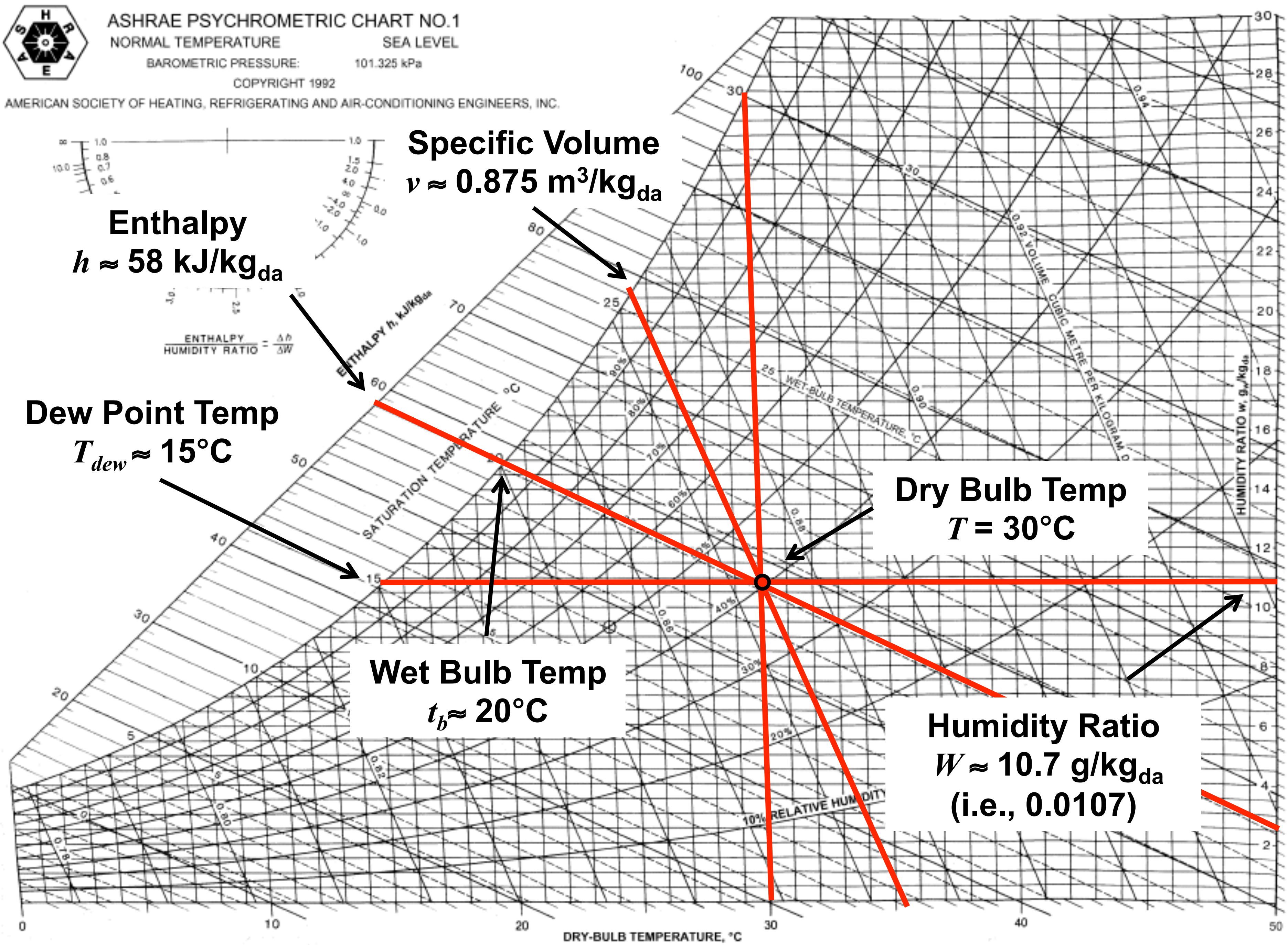
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Enthalpy
h ≈ 58 kJ/kgda
Dew Point Temp
Tdew ≈ 15°C
Wet Bulb Temp
tb ≈ 20°C
Dry Bulb Temp
T = 30°C
Humidity Ratio
W ≈ 10.7 g/kgda
(i.e., 0.0107)
ENTHALPY h, kJ/kgda
SATURATION TEMPERATURE °C
WET BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, gw/kgda
DRY-BULB TEMPERATURE, °C



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NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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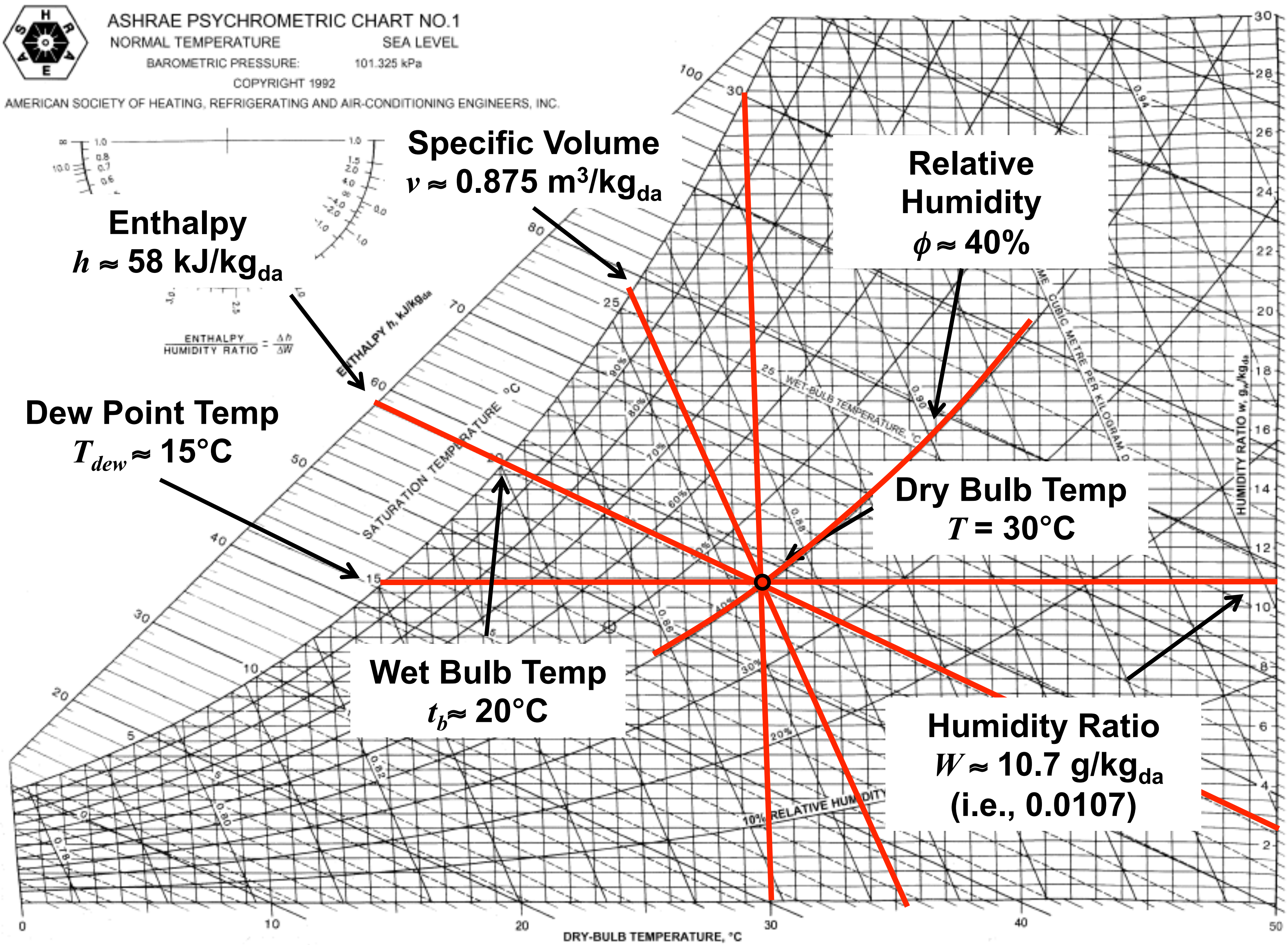
Specific Volume
$v \approx 0.875$ m^3/kg$_{da}$
Enthalpy
$h \approx 58$ kJ/kg$_{da}$
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg$_{da}$
SATURATION TEMPERATURE °C
Dew Point Temp
$T_{dew} \approx 15$°C
Wet Bulb Temp
$t_b \approx 20$°C
Dry Bulb Temp
$T = 30$°C
Humidity Ratio
$W \approx 10.7$ g/kg$_{da}$
(i.e., 0.0107)
WET BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
HUMIDITY RATIO w, g$_w$/kg$_{da}$
DRY-BULB TEMPERATURE, °C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NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
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Specific Volume
$v \approx 0.875\ m^3/kg_{da}$
Relative Humidity
$\phi \approx 40\%$
Enthalpy
$h \approx 58\ kJ/kg_{da}$
Dew Point Temp
$T_{dew} \approx 15°C$
Dry Bulb Temp
$T = 30°C$
Wet Bulb Temp
$t_b \approx 20°C$
Humidity Ratio
$W \approx 10.7\ g/kg_{da}$
(i.e., 0.0107)
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
WET-BULB TEMPERATURE °C
CUBIC METRE PER KILOGRAM
10% RELATIVE HUMIDITY
HUMIDITY RATIO W, gw/kgda
DRY-BULB TEMPERATURE, °C

Psychrometrics: IP units example

- Moist air exists at 100°F dry bulb, 65°F wet bulb and 14.696 psia

Find:

a) Humidity ratio
b) Enthalpy
c) Dew-point temperature
d) Relative humidity
e) Specific volume

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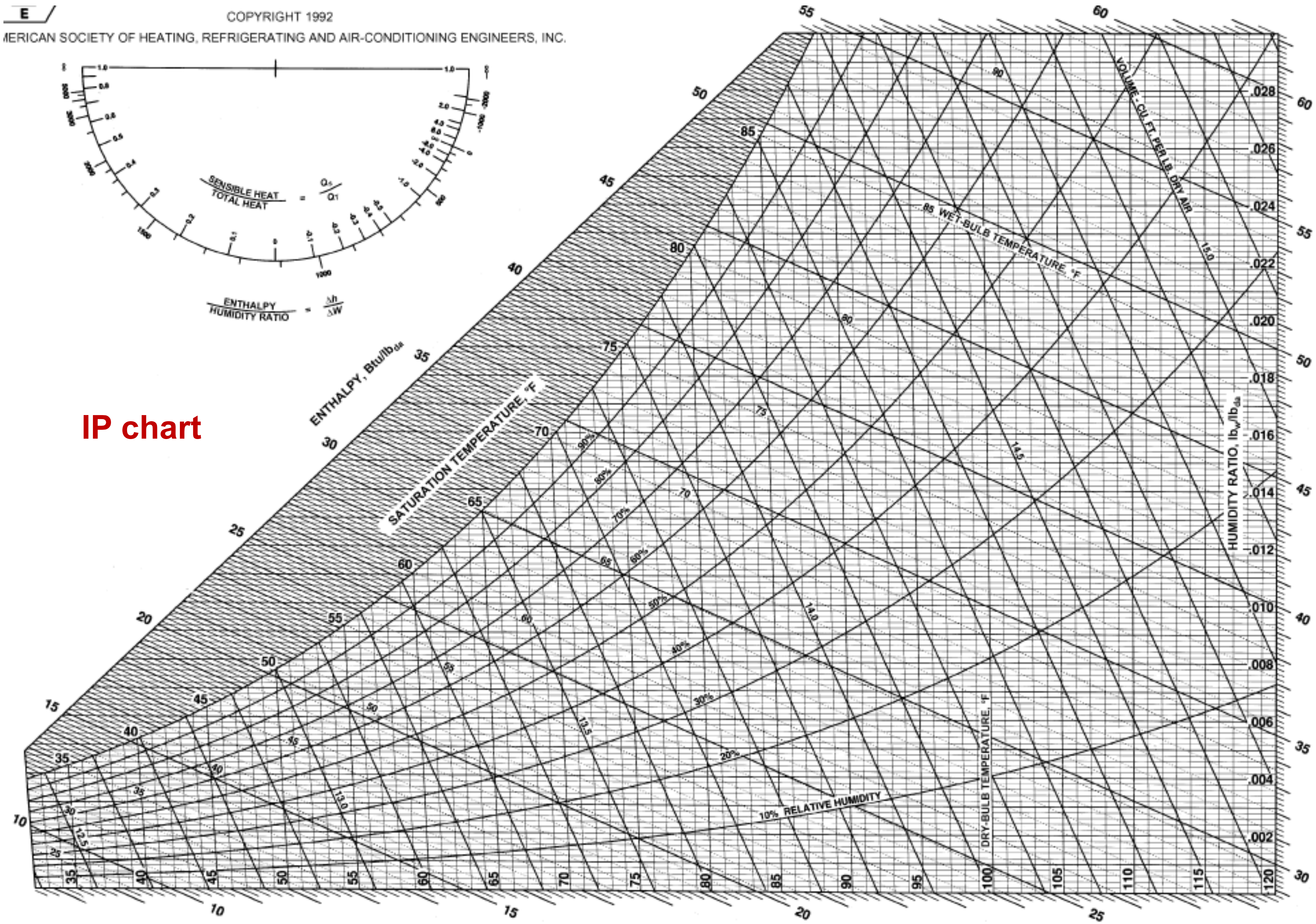
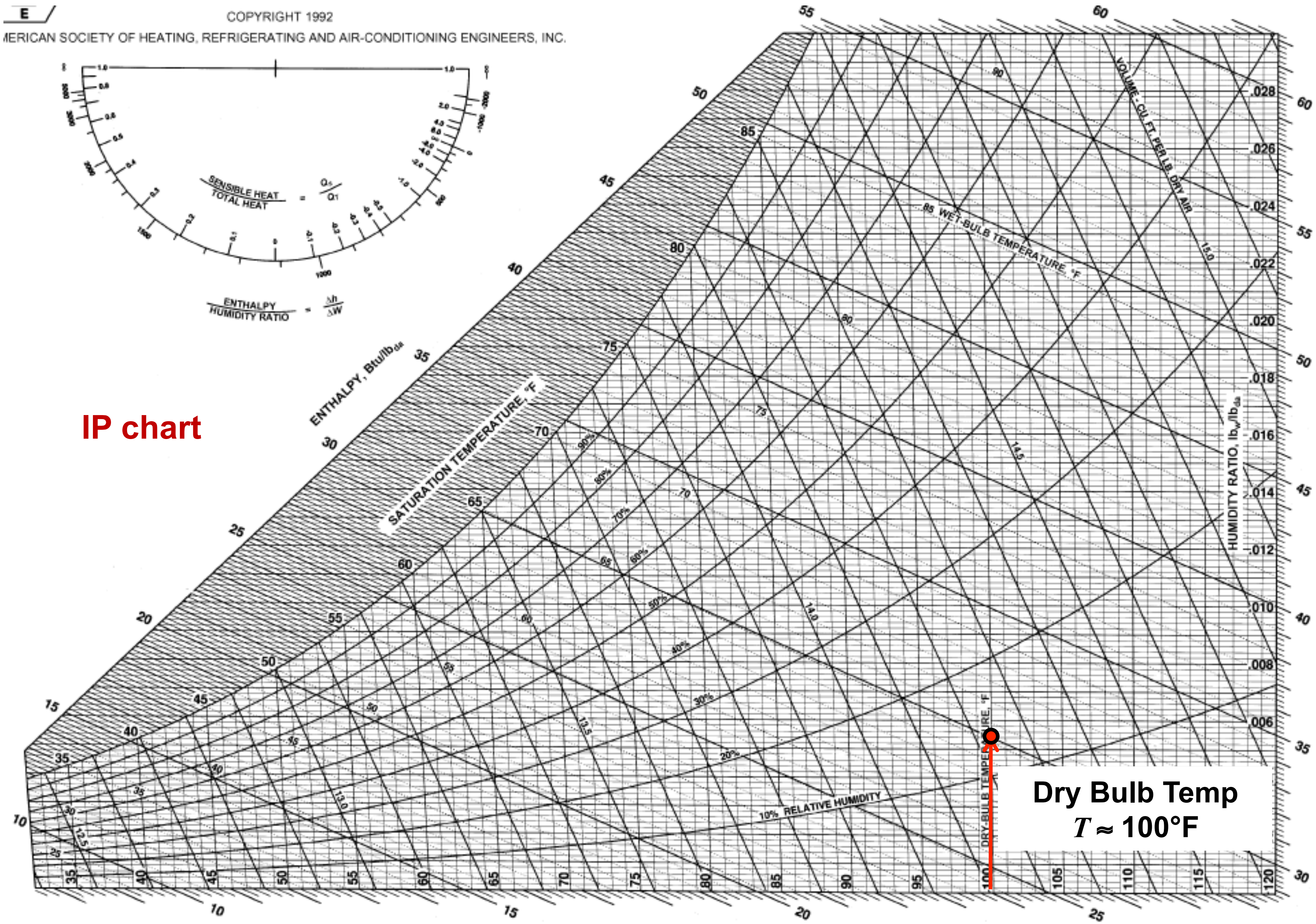


IP chart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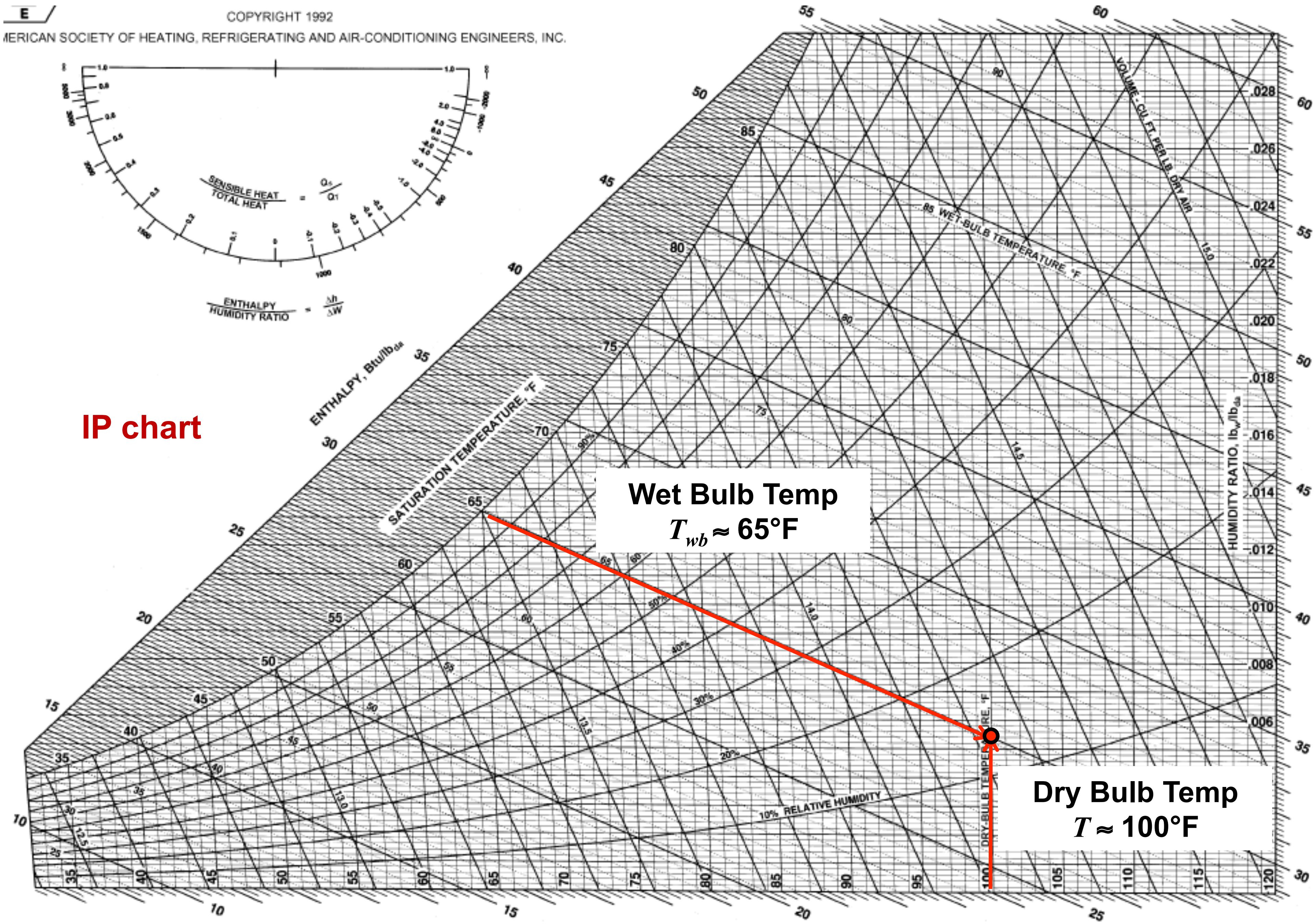
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
IP chart
ENTHALPY, Btu/lb da
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE, °F
VOLUME, CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb w/lb da
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE, °F
Dry Bulb Temp
T ≈ 100°F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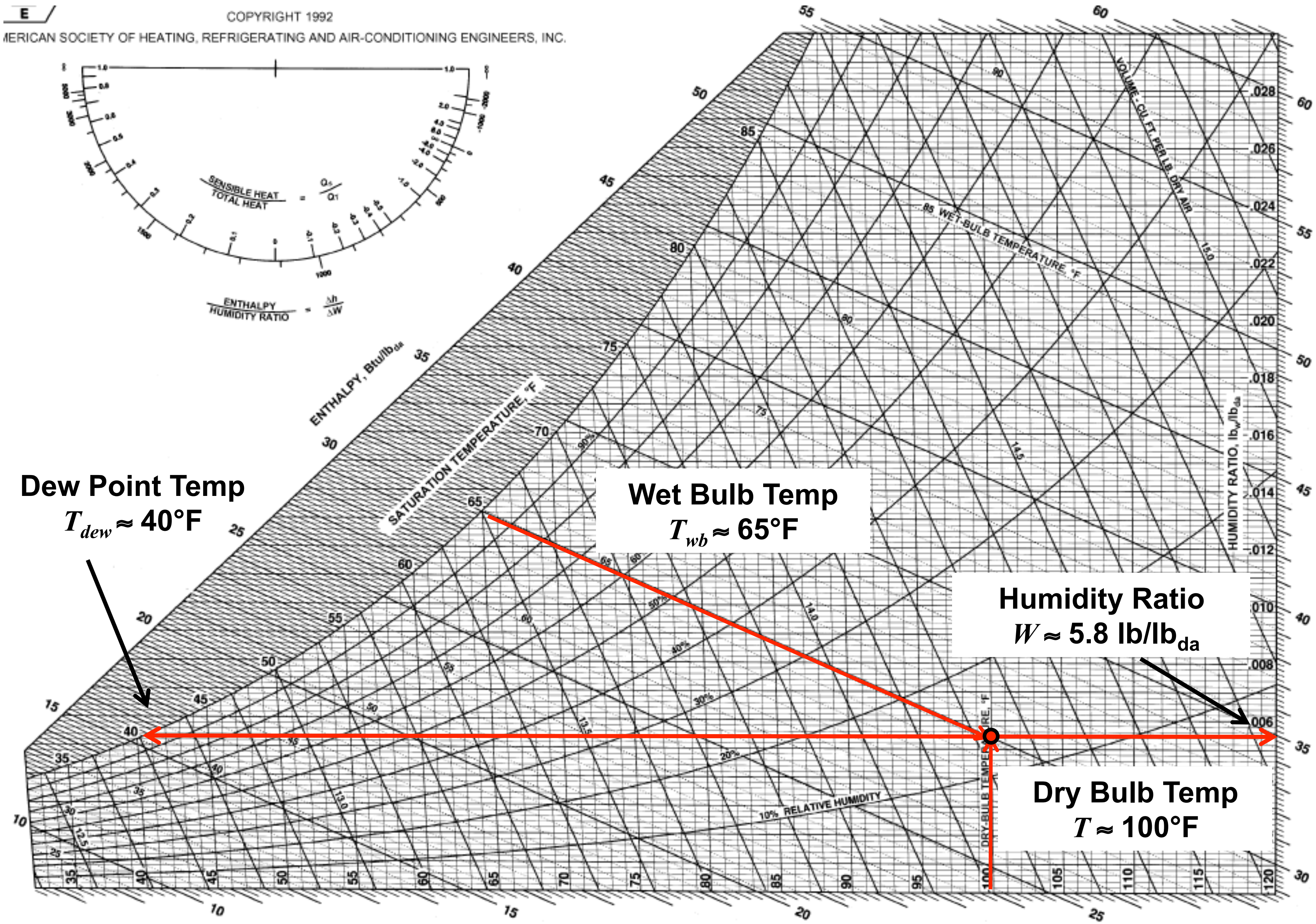
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
IP chart
ENTHALPY, Btu/lb_da
SATURATION TEMPERATURE, °F
85 WET-BULB TEMPERATURE, °F
VOLUME, CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb_w/lb_da
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE, °F
Wet Bulb Temp
$T_{wb} \approx$ 65°F
Dry Bulb Temp
$T \approx$ 100°F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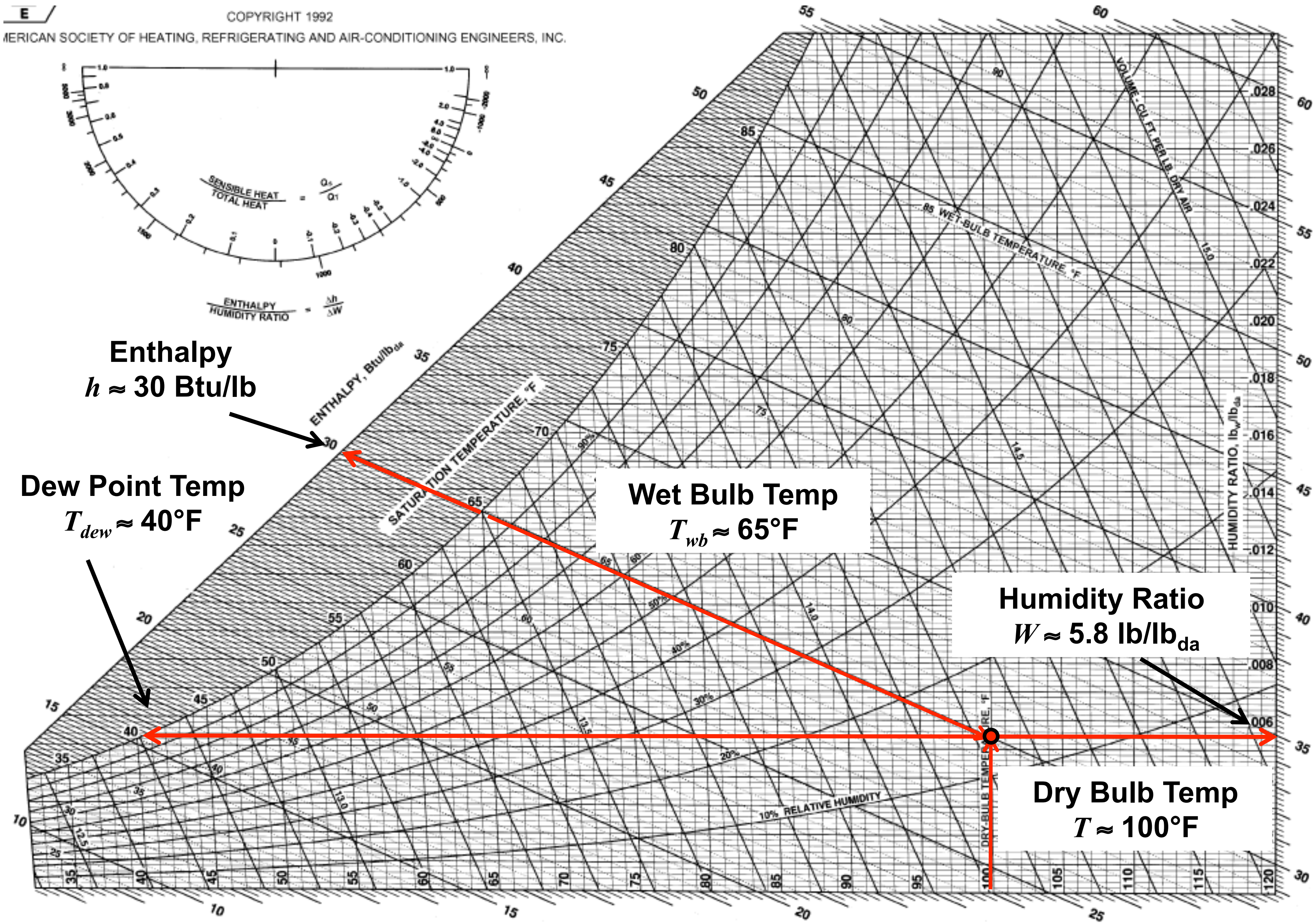
SENSIBLE HEAT / TOTAL HEAT = Q_s / Q_t
ENTHALPY / HUMIDITY RATIO = $\Delta h / \Delta W$
ENTHALPY, Btu/lb$_{da}$
SATURATION TEMPERATURE, °F
85 WET-BULB TEMPERATURE, °F
VOLUME - CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb$_w$/lb$_{da}$
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE, °F
Dew Point Temp
$T_{dew} \approx$ 40°F
Wet Bulb Temp
$T_{wb} \approx$ 65°F
Humidity Ratio
$W \approx$ 5.8 lb/lb$_{da}$
Dry Bulb Temp
$T \approx$ 100°F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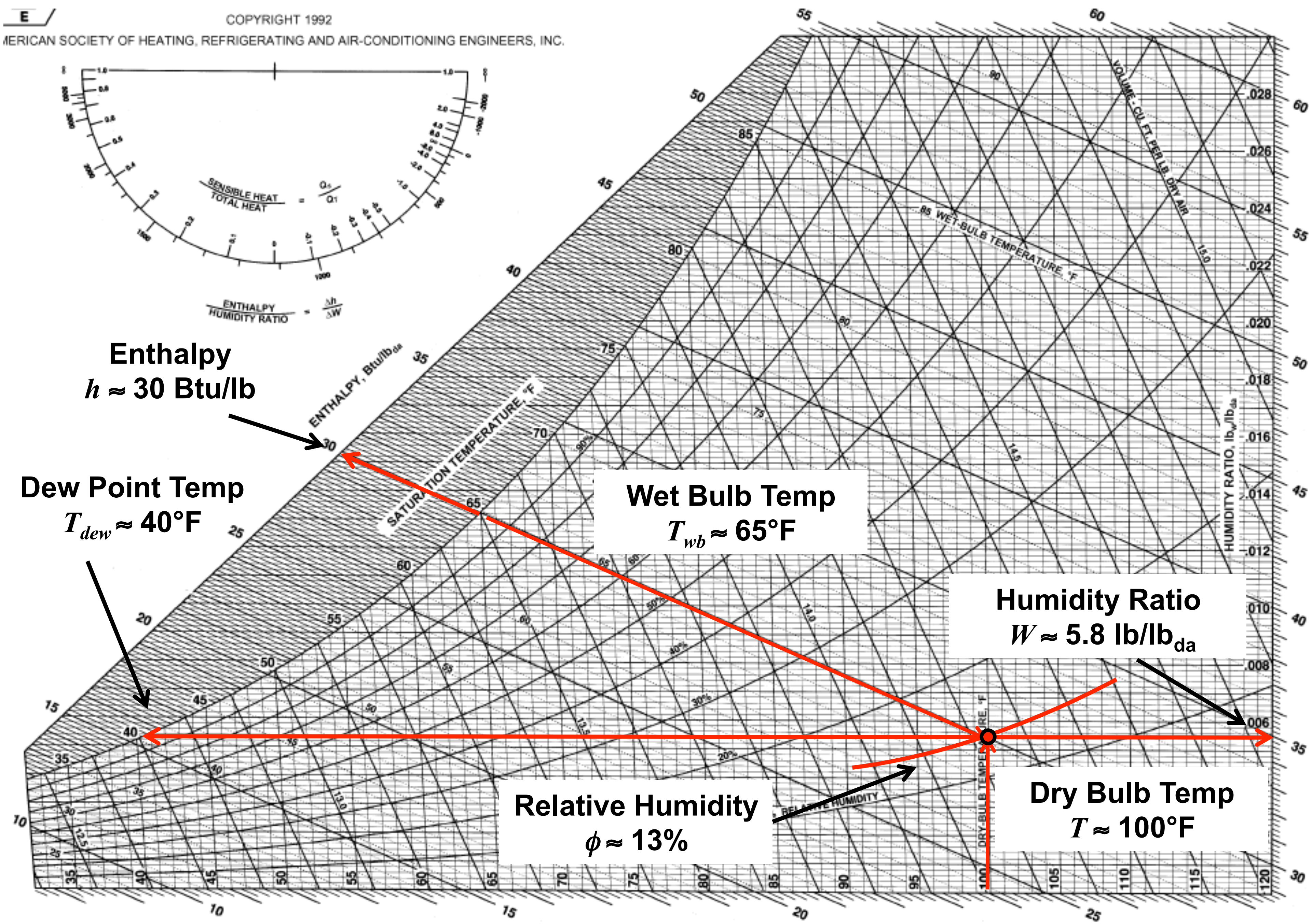
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Enthalpy
h ≈ 30 Btu/lb
Dew Point Temp
T_dew ≈ 40°F
Wet Bulb Temp
T_wb ≈ 65°F
Humidity Ratio
W ≈ 5.8 lb/lb_da
Dry Bulb Temp
T ≈ 100°F
ENTHALPY, Btu/lb_da
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE, °F
VOLUME, CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb_w/lb_da
10% RELATIVE HUMIDITY
DRY BULB TEMPERATURE, °F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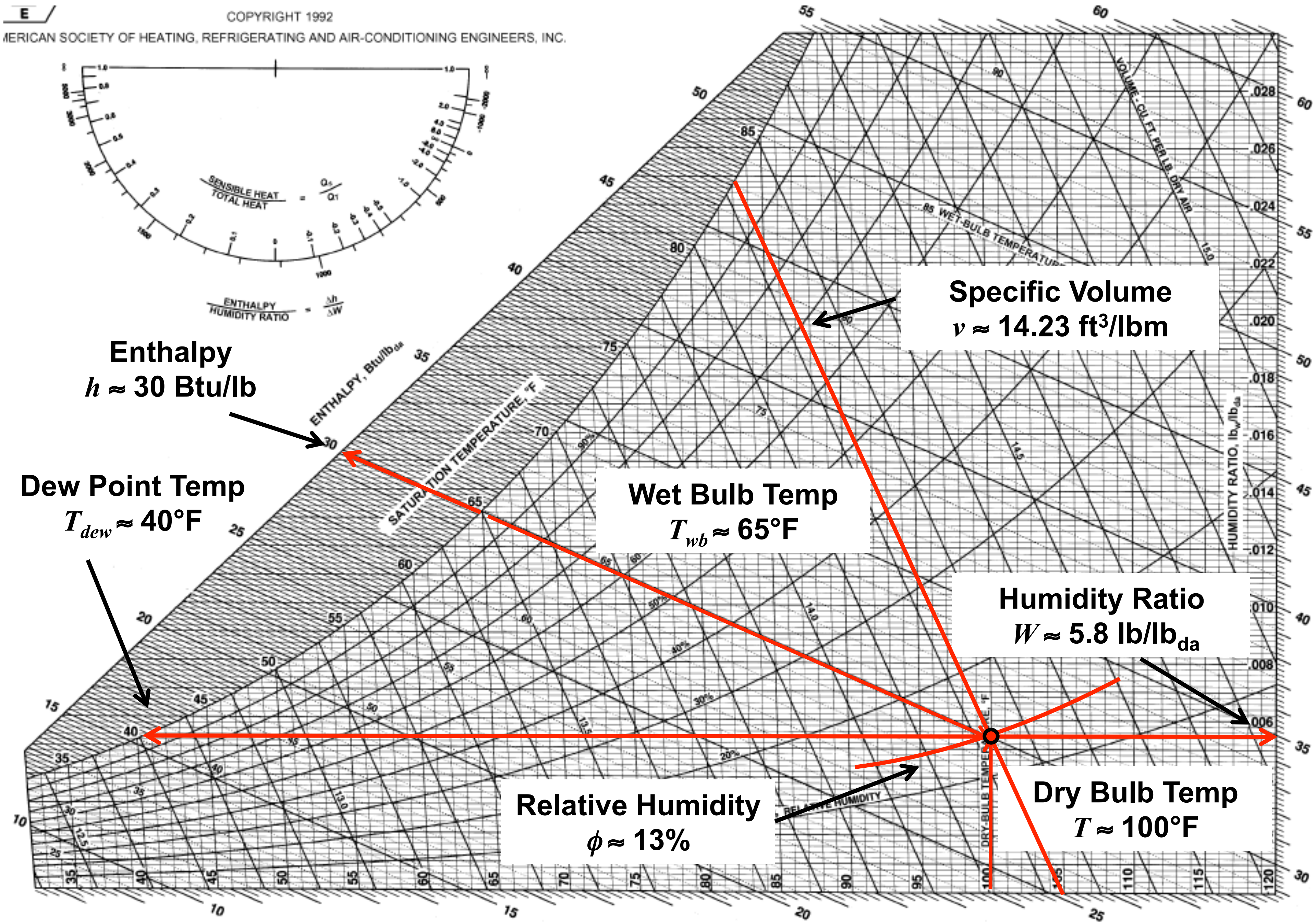
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Enthalpy
h ≈ 30 Btu/lb
Dew Point Temp
T_dew ≈ 40°F
Wet Bulb Temp
T_wb ≈ 65°F
Humidity Ratio
W ≈ 5.8 lb/lb_da
Relative Humidity
φ ≈ 13%
Dry Bulb Temp
T ≈ 100°F
ENTHALPY, Btu/lb_da
SATURATION TEMPERATURE, °F
85 WET-BULB TEMPERATURE, °F
VOLUME, CU.FT. PER LB. DRY AIR
HUMIDITY RATIO, lb_w/lb_da
RELATIVE HUMIDITY
DRY BULB TEMPERATURE, °F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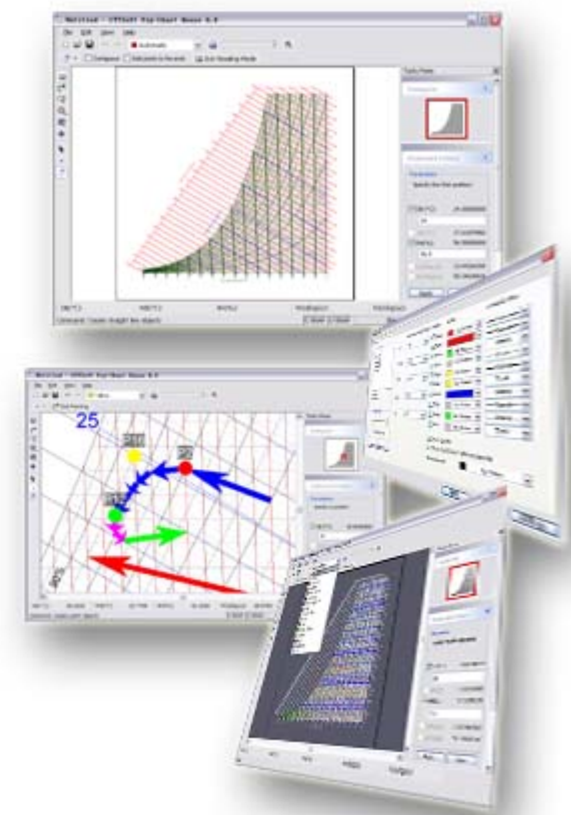
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
Enthalpy
h ≈ 30 Btu/lb
Dew Point Temp
T_dew ≈ 40°F
Wet Bulb Temp
T_wb ≈ 65°F
Specific Volume
v ≈ 14.23 ft³/lbm
Humidity Ratio
W ≈ 5.8 lb/lb_da
Relative Humidity
φ ≈ 13%
Dry Bulb Temp
T ≈ 100°F
ENTHALPY, Btu/lb_da
SATURATION TEMPERATURE, °F
WET-BULB TEMPERATURE
VOLUME - CU FT. PER LB. DRY AIR
HUMIDITY RATIO, lb_w/lb_da
RELATIVE HUMIDITY
DRY BULB TEMPERATURE, °F

Applying psychrometrics



- We can also use psychrometric charts or software
  - Psych and Psychpro
    - Very popular psych chart and analysis software
    - I think at least one of these is in the AM 218 lab
- There are a bunch of online calculators as well
  - http://www.psychrometric-calculator.com
  - http://www.sugartech.co.za/psychro/
  - http://www.wolframalpha.com/examples/Psychrometrics.html
- And smart phone apps too
- You can also make your own (i.e., in Excel)
  - You will have a HW problem where you have to do this

Psychrometrics also involves learning how to use and combine those quantities to determine things like sensible and latent heating and cooling loads (i.e., ***processes***) (covered in a future lecture)