MEBS6006 Environmental Services I

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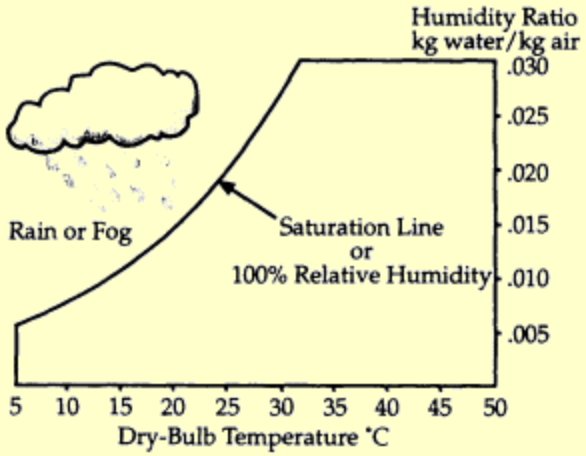

Advanced Psychrometry

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Contents

- Review of Basic Psychrometry
  - Introduction to Psychrometry
  - Psychrometric Processes
- Practical Applications of Psychrometry
  - Characteristics and use of psychrometric charts
  - Software for psychrometric analysis
- Techniques of Psychrometric Analysis
  - Psychrometrics and Bioclimatic Analysis

Introduction to Psychrometry

- Basics
  - Atmospheric air
    - Composes the gaseous components of dry air including nitrogen, oxygen, carbon dioxide, etc; as well as water vapour and other miscellaneous contaminants
    - The standard atmosphere is at sea level, temperature = 15°C, barometric pressure 101.325kPa
  - Dry Air
    - Atmosphere air with all water vapour and contaminants removed
    - Relative molecular mass of dry air = 28.966
    - Gas Constant R_{da} = 287.042 J/kg_{da}K

Introduction to Psychrometry

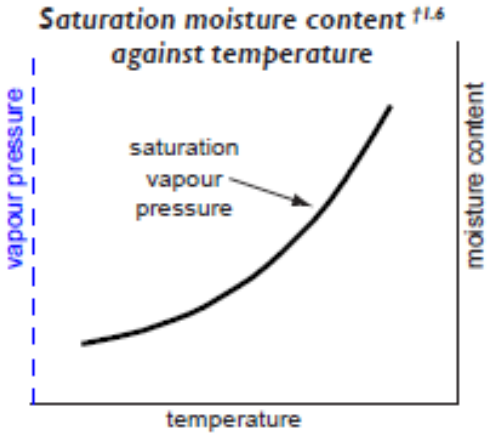
- Moist Air
  - A binary (only 2 component) mixture of dry air and water vapour
  - Water vapour exist in atmospheric air in certain amount from zero (dry air) to a maximum (saturated)
  - The amount of ‘saturated’ water vapour depends on temperature and pressure
  - ‘Saturation’ is a state of neutral equilibrium between moist air and the condensed water phase
  - Relative molecular mass = 18.015
  - Gas Constant for water vapour R_w = 461.524 J/kg_wK

Introduction to Psychrometry

- Saturated vapour pressure
  - Like other gaseous components, water vapour produces a pressure in its gaseous state (Dalton's Law of Partial Pressure)
  - Pressure produced by the water vapour in fully saturated condition = saturated vapour pressure
  - Saturated vapour pressure = constant at different temperature

Temp (°C)	10	20	30	40	50	60
Pressure (kPa)	1.23	2.34	4.25	7.38	12.35	19.95

  - Gradually at 100°C, the saturated vapour pressure = atmospheric pressure, water boils!
  - A plot of the vapour pressure against temperature is shown → the foundation of a Psychrometric Chart



Introduction to Psychrometry

- Psychrometry
  - The study of atmospheric air and its associated water vapour
  - Atmospheric air is moist air that can exist in the range from Dry Air to Saturated Moist Air
  - Psychrometry is thus related to the thermodynamic properties of this moist air at different temperatures
  - The pressure taken is usually at Standard Atmospheric Pressure = 101.325 kPa, but other pressure values (at elevated heights) may also be considered as necessary.

Introduction to Psychrometry

- Thermodynamic properties of moist air
  - Refer to Table 2 (from ASHRAE Handbook - Fundamentals)
  - Take note of the ‘reference’ zero at 0°C
    - Specific enthalpy h_{da} = 0 KJ/kg$_{da}$
    - Specific entropy s_{da} = 0 KJ/kg$_{da}$K
  - What are the meanings of the different columns?
    - Humidity ratio W_s ?
    - Specific volume?
    - Specific enthalpy?
    - Specific entropy?

Introduction to Psychrometry

- Thermodynamic properties of water at saturation
  - Refer to Table 3 (from ASHRAE Handbook - Fundamentals)
  - Take note of the ‘reference’ zero at 0.01°C (triple point of water)
  - This table is useful when determining the specific enthalpy of liquid water and steam in the air conditioning processes, e.g.
    - liquid water condensed at 10°C = 42.02 kg/kg_w
    - Steam at 110°C injected into the air = 2691.07 kg/kg_w

Introduction to Psychrometry

- Other definitions of humidity
  - humidity ratio W
    - Ratio of the mass of water vapour to the mass of dry air in the sample
    - $W = M_w/M_{da}$ (unit = g_w/kg_{da})
  - Specific humidity γ
    - Mass of water vapour to total mass of moist air sample
    - $\gamma = \frac{M_w}{M_w + M_{da}}$
    - $\gamma = \frac{W}{1+W}$
  - Absolute humidity d_v
    - Ratio of mass of water vapour to total volume of the sample
    - $d_v = M_w/V$

Introduction to Psychrometry

- Saturation humidity ratio $W_s(t, p)$
  - Humidity ratio of moist air saturated
- Degree of saturation μ
  - Ratio of air humidity ratio W to humidity ratio W_s of saturated air at the same temperature and pressure
  - $\mu = W/W_s$
- Relative Humidity ϕ
  - Ratio of the mole fraction of water vapour x_w in a given moist air sample to the mole fraction x_{ws} in an air sample saturated at the same temperature and pressure
  - $\phi = x_w/x_{ws}$
  - $\mu = \frac{\phi}{1+(1-\phi)W_s/0.621945}$ (the actual values differ slightly)

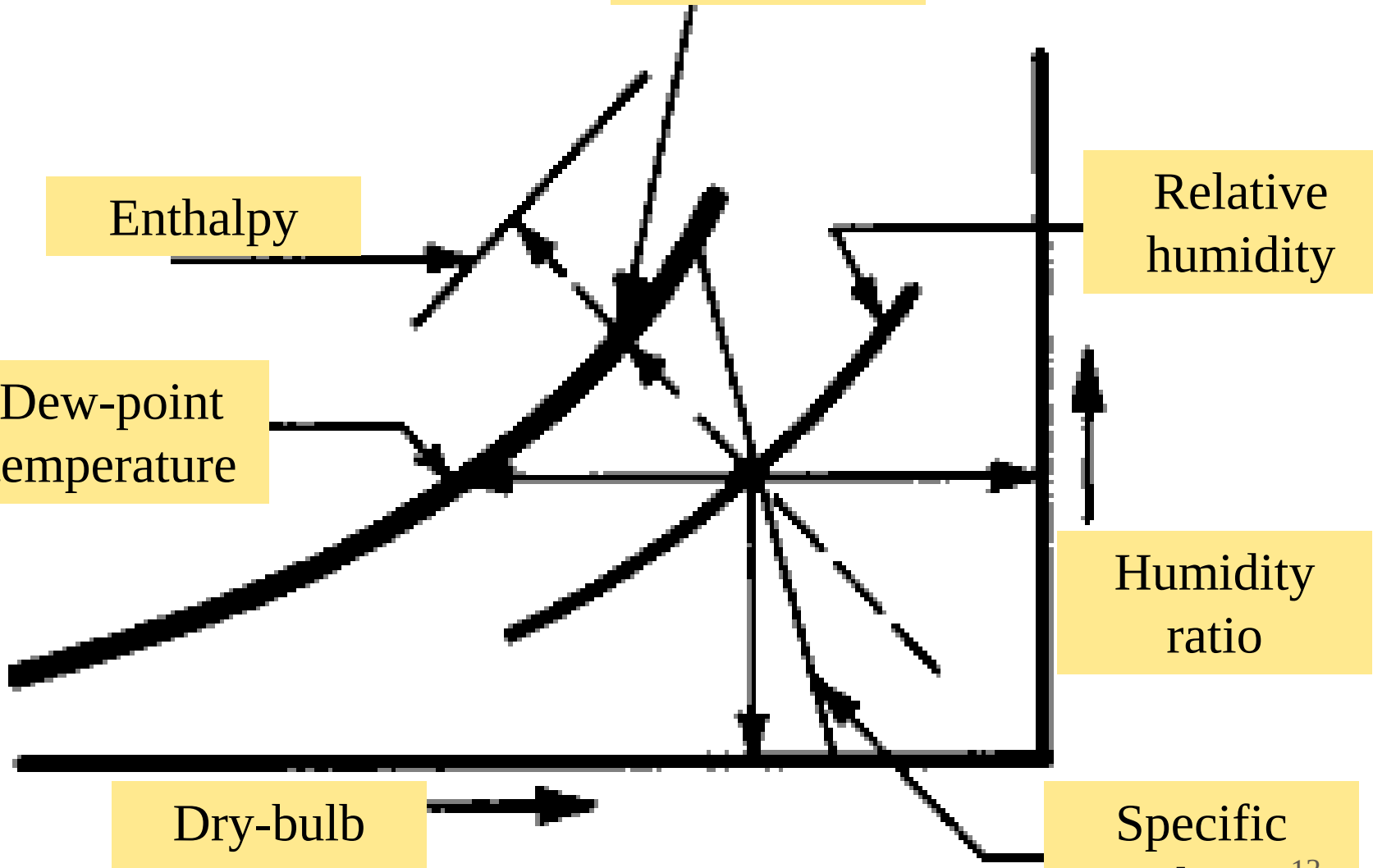
Introduction to Psychrometry

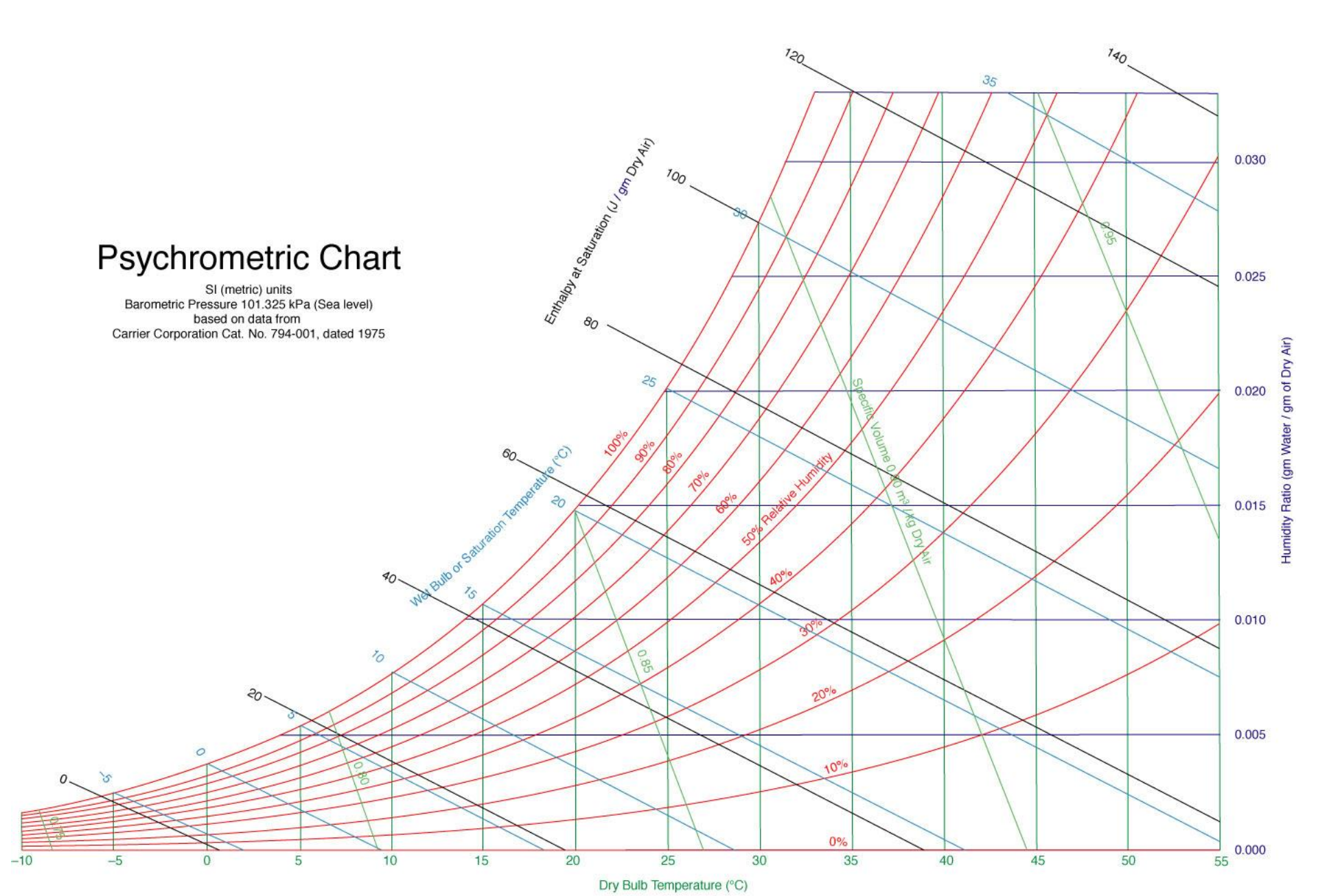
- Dew-point temperature t_d
  - Temperature of moist air saturated at pressure p with the same humidity ratio W as that of the given same of moist air
- Thermodynamic wet-bulb temperature t^*
  - Temperature at which water, by evaporating into moist air at dry bulb temperature t and humidity ratio W, can bring air to saturation adiabatically at the same temperature t^* when total pressure p is constant
  - The wet-bulb temperature measured out using a psychrometer is not exactly the thermodynamic wet-bulb temperature but with slight differences
  - The wet-bulb temperature on the psychrometric chart is thermo-dynamic wet-bulb temperature

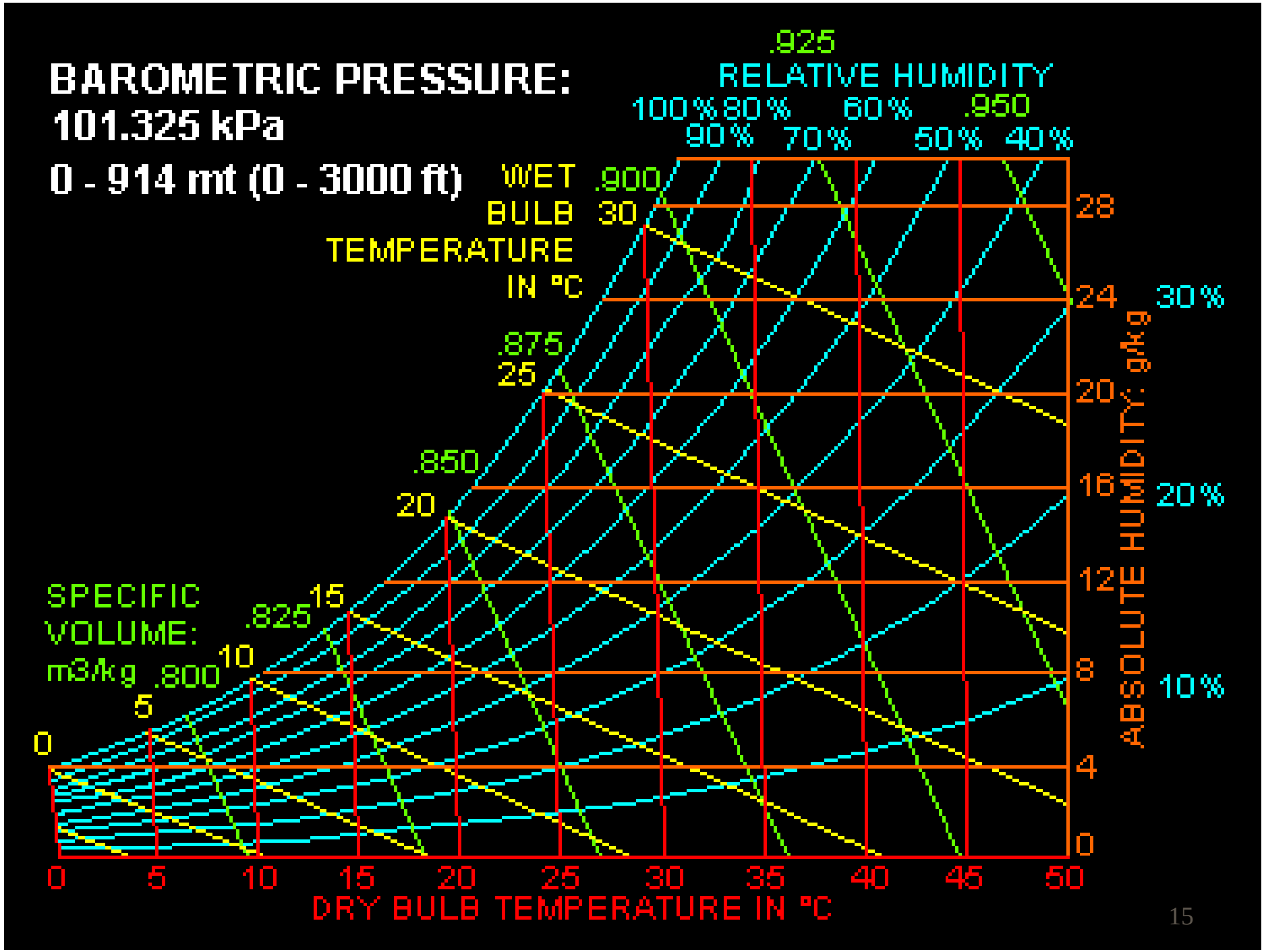
Introduction to Psychrometry

- Psychrometric Chart
  - A graphical representation of the thermodynamic properties of moist air
  - Coordinates for a psychrometric chart
    - Arbitrary but most charts have the ‘oblique’ coordinates of enthalpy and humidity ratio
      - **Humidity ratio** lines are horizontal
      - **Enthalpy** lines are oblique lines precisely parallel
      - **Dry bulb temperature** lines are straight, not precisely parallel
      - **Thermodynamic wet bulb temperature** lines are oblique and straight, slightly different direction from enthalpy lines, but not precisely parallel
      - **Relative humidity** lines are curves
      - **Specific volume** lines are straight, not precisely parallel

Psychrometric Chart

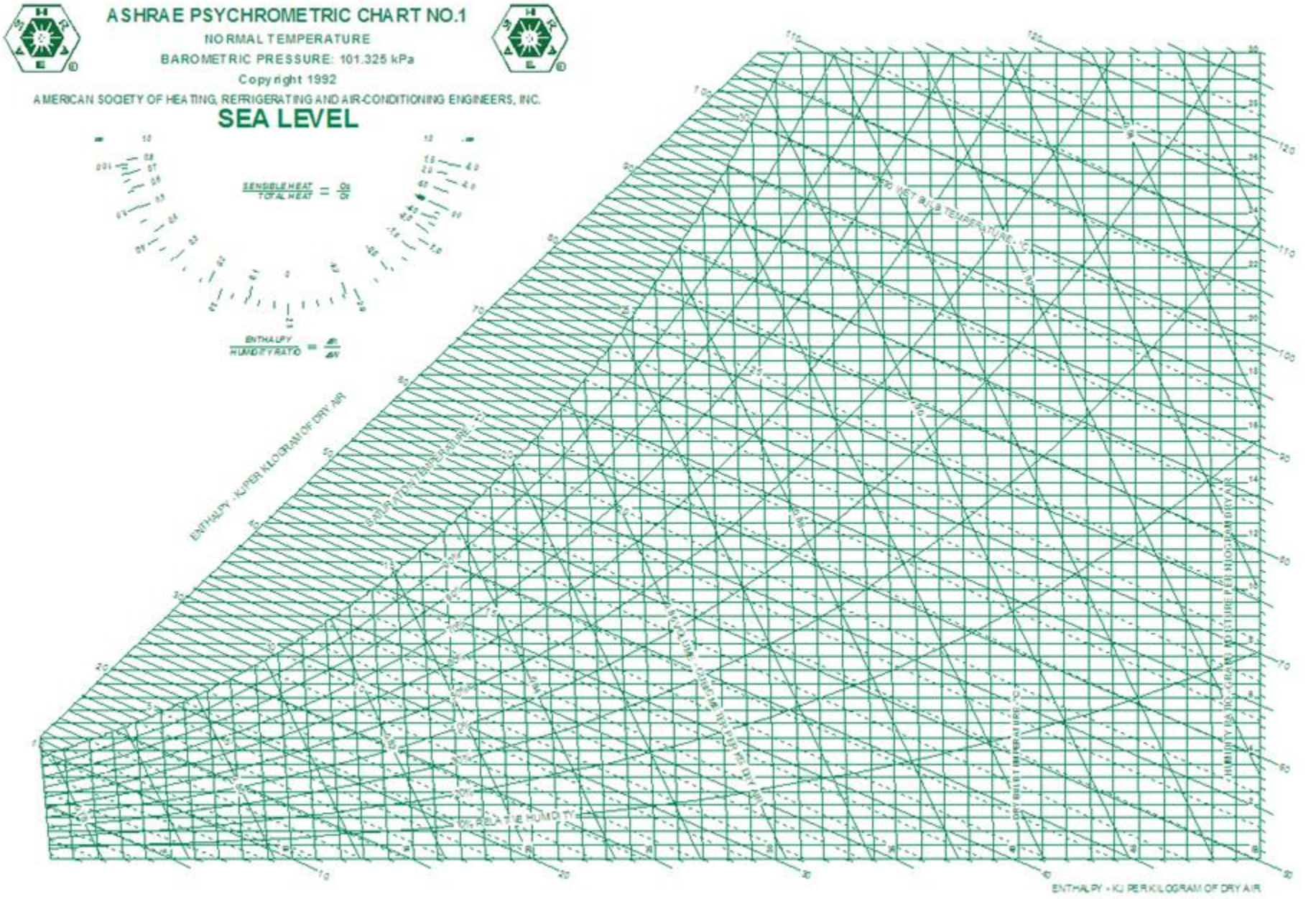


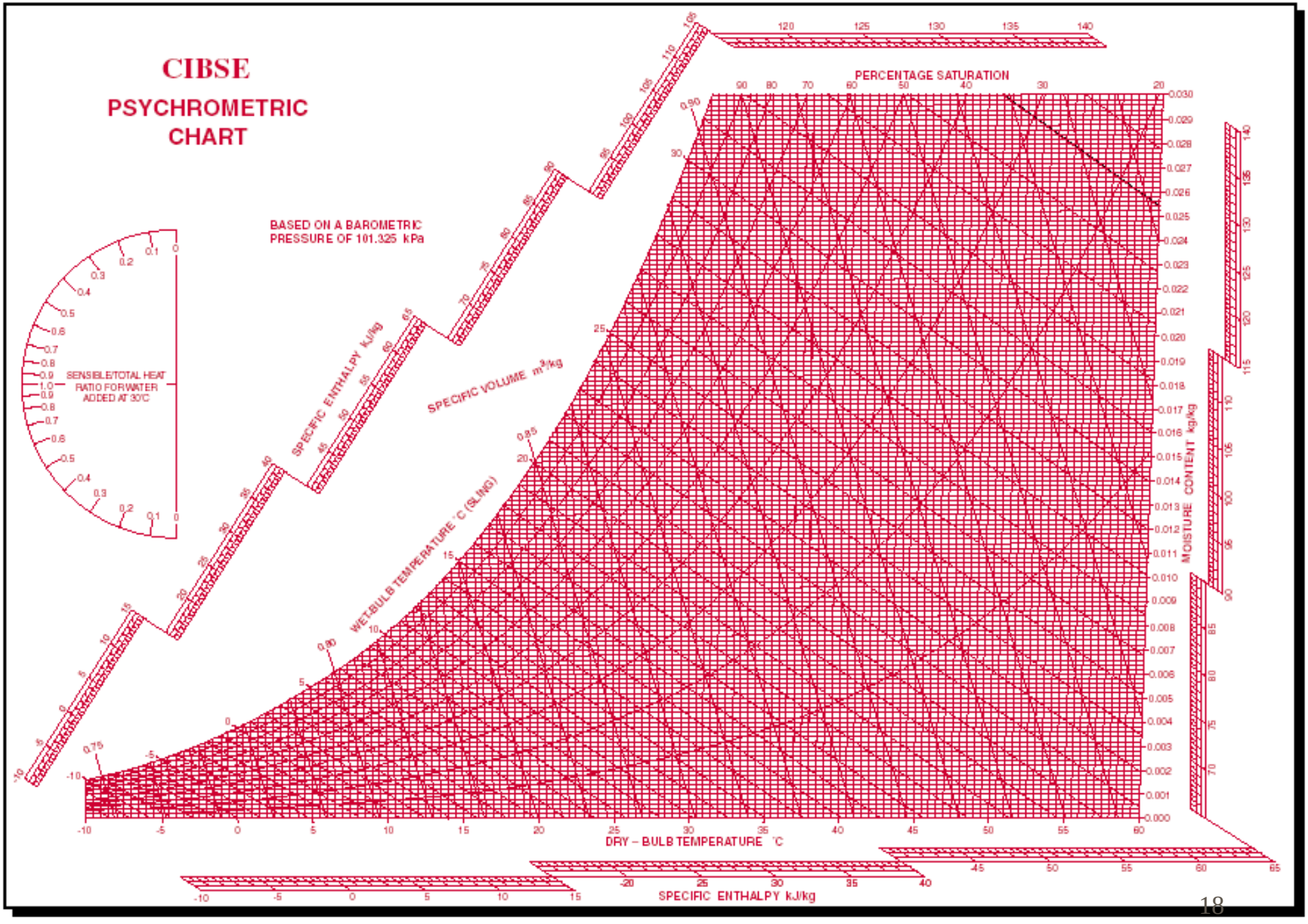

Psychrometric Chart
SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, dated 1975
Enthalpy at Saturation (J / gm Dry Air)
Wet Bulb or Saturation Temperature (°C)
Dry Bulb Temperature (°C)
Humidity Ratio (gm Water / gm of Dry Air)
Specific Volume 0.80 m³/kg Dry Air
0.85
0.90
0.95
100%
90%
80%
70%
60%
50% Relative Humidity
40%
30%
20%
10%
0%


BAROMETRIC PRESSURE:
101.325 kPa
0 - 914 mt (0 - 3000 ft)
.925
RELATIVE HUMIDITY
100% 80% 60% .950
90% 70% 50% 40%
WET
BULB
TEMPERATURE
IN °C
.900
30
.875
25
.850
20
.825
15
.800
10
5
0
SPECIFIC
VOLUME:
m3/kg
28
24
20
16
12
8
4
0
30%
20%
10%
ABSOLUTE HUMIDITY: g/kg
0 5 10 15 20 25 30 35 40 45 50
DRY BULB TEMPERATURE IN °C

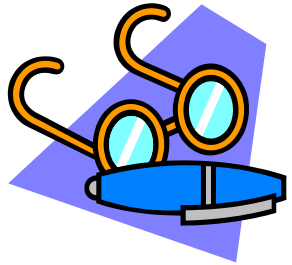
Introduction to Psychrometry

- Psychrometric Chart
  - ASHRAE develops a set of psychrometric charts for different uses
  - Charts 1 to 4 are at sea level
    - Chart 1 to 4 at different temperature ranges
    - Chart 1 : 0°C to 50°C (most commonly used)
  - Chart 5 at 750m altitude (0°C to 50°C)
  - Chart 6 at 1500m altitude (0°C to 50°C)
  - Chart 7 at 2250m altitude (0°C to 50°C)
  - Chart 8 to 16 for 200 to 320 °C


ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 101.325 kPa
Copyright 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SEA LEVEL
SENSIBLE HEAT / TOTAL HEAT = Qs/Qt
ENTHALPY / HUMIDITY RATIO = Δh/Δw
ENTHALPY - KJ PER KILOGRAM OF DRY AIR
DEGREES CELSIUS DRY-BULB TEMPERATURE
DEGREES CELSIUS WET-BULB TEMPERATURE
% RELATIVE HUMIDITY
HUMIDITY RATIO - GRAMS OF MOISTURE PER KILOGRAM OF DRY AIR
SPECIFIC VOLUME - CUBIC METRES PER KILOGRAM OF DRY AIR
ENTHALPY - KJ PER KILOGRAM OF DRY AIR

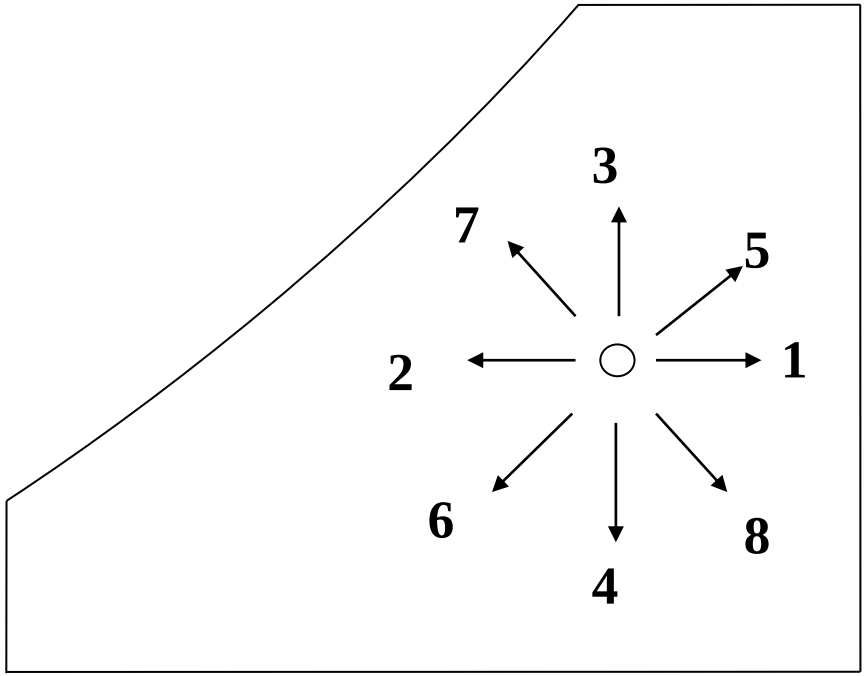

CIBSE
PSYCHROMETRIC CHART
BASED ON A BAROMETRIC PRESSURE OF 101.325 kPa
SENSIBLE/TOTAL HEAT RATIO FOR WATER ADDED AT 30°C
SPECIFIC ENTHALPY kJ/kg
SPECIFIC VOLUME m³/kg
WET-BULB TEMPERATURE °C (SLING)
PERCENTAGE SATURATION
MOISTURE CONTENT kg/kg
DRY – BULB TEMPERATURE °C
SPECIFIC ENTHALPY kJ/kg

Psychrometric Processes



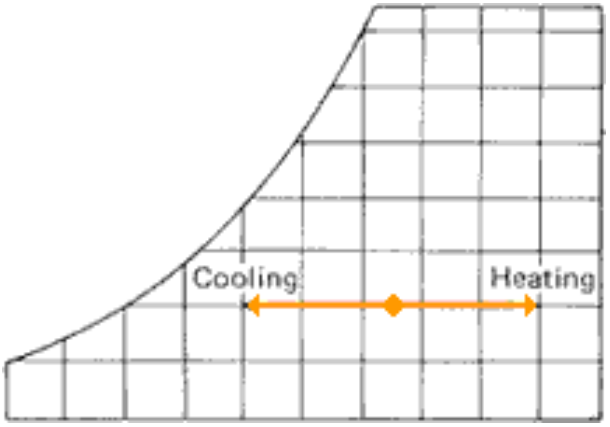
- Common processes:
  - Sensible cooling / sensible heating
  - Cooling and dehumidification / heating and humidification
  - Humidification / dehumidification
  - Evaporative cooling / chemical dehydration
- Typical devices:
  - Cooling/heating coils
  - Humidifiers / dehumidifiers

Basic psychrometric processes

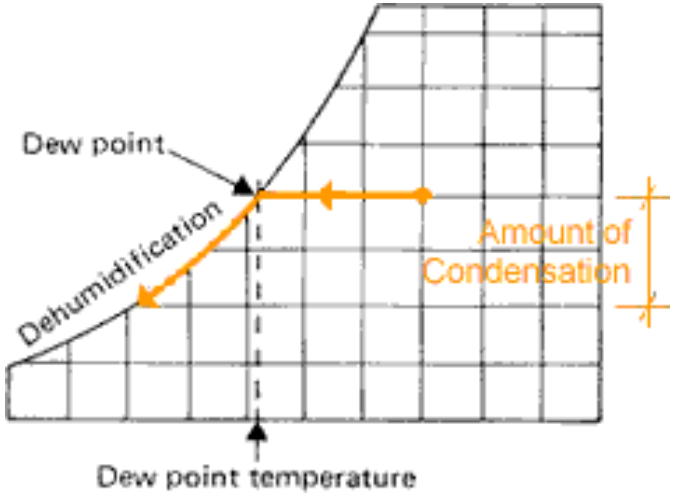


Process 0-1: Sensible heating
Process 0-2: Sensible cooling
Process 0-3: Humidifying
Process 0-4: Dehumidifying
Process 0-5: Heating and humidifying
Process 0-6: Cooling and dehumidifying
Process 0-7: Cooling and humidifying
Process 0-8: Heating and dehumidifying

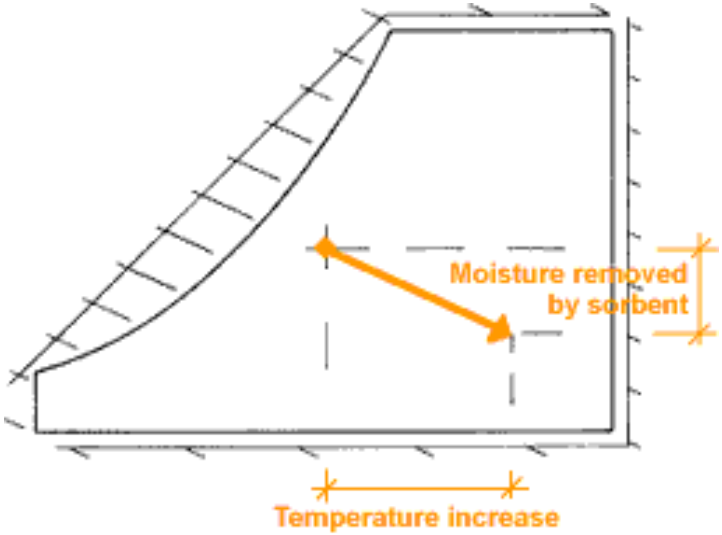
Psychrometric processes



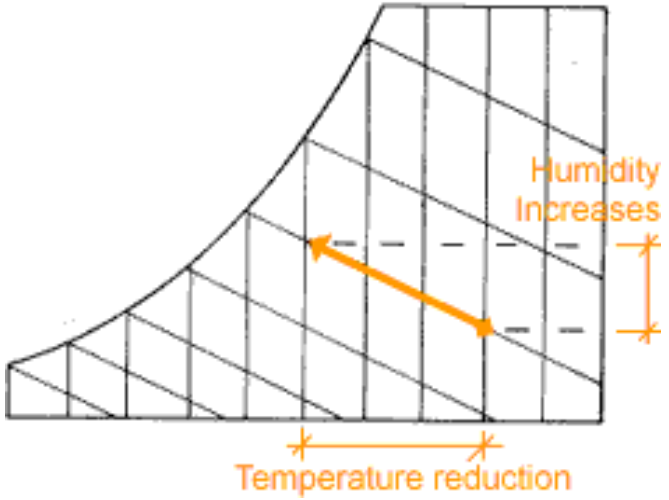
Sensible cooling/heating



Cooling and dehumidification

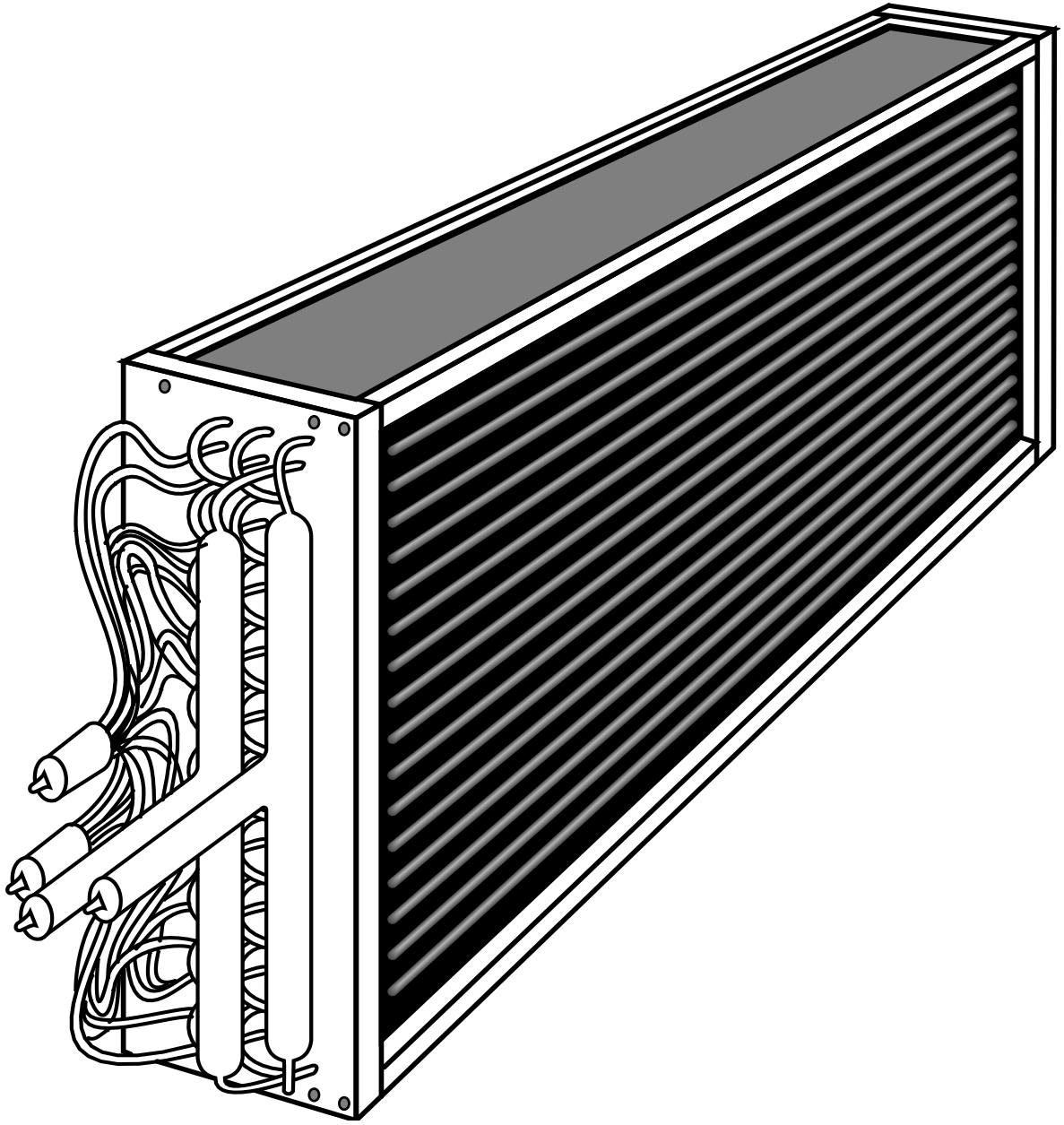


Adiabatic dehumidification

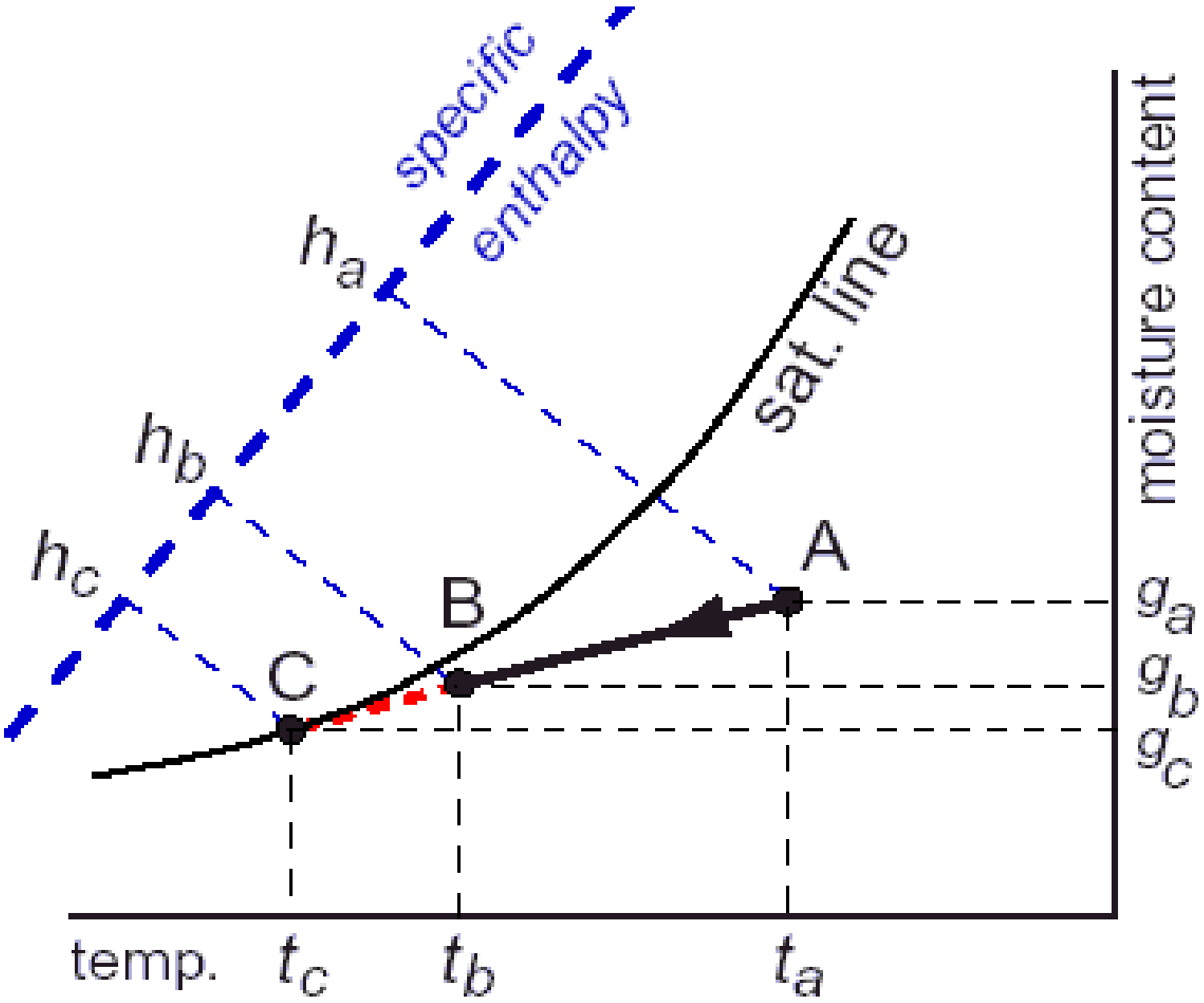


Evaporative cooling

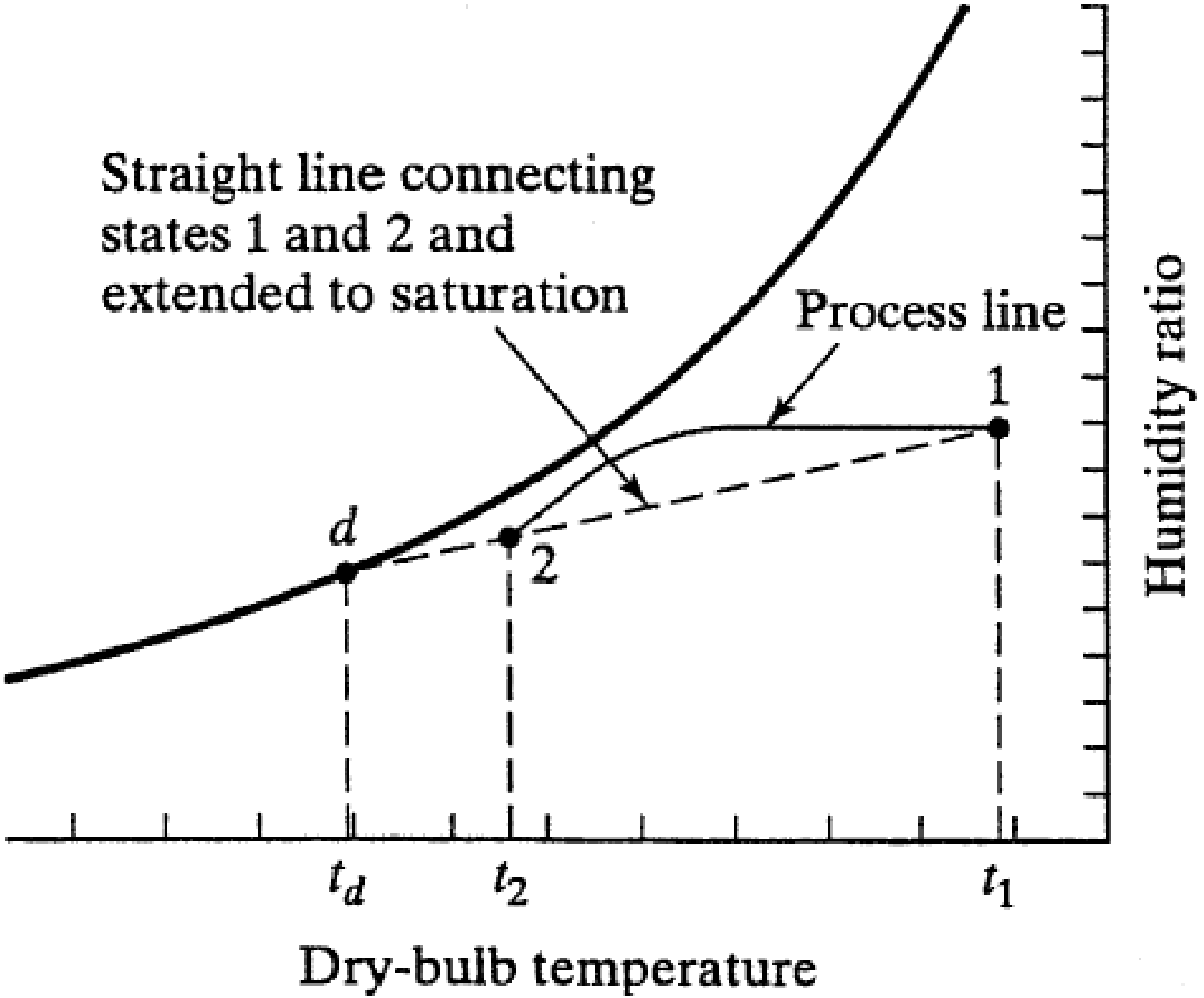
Cooling coil



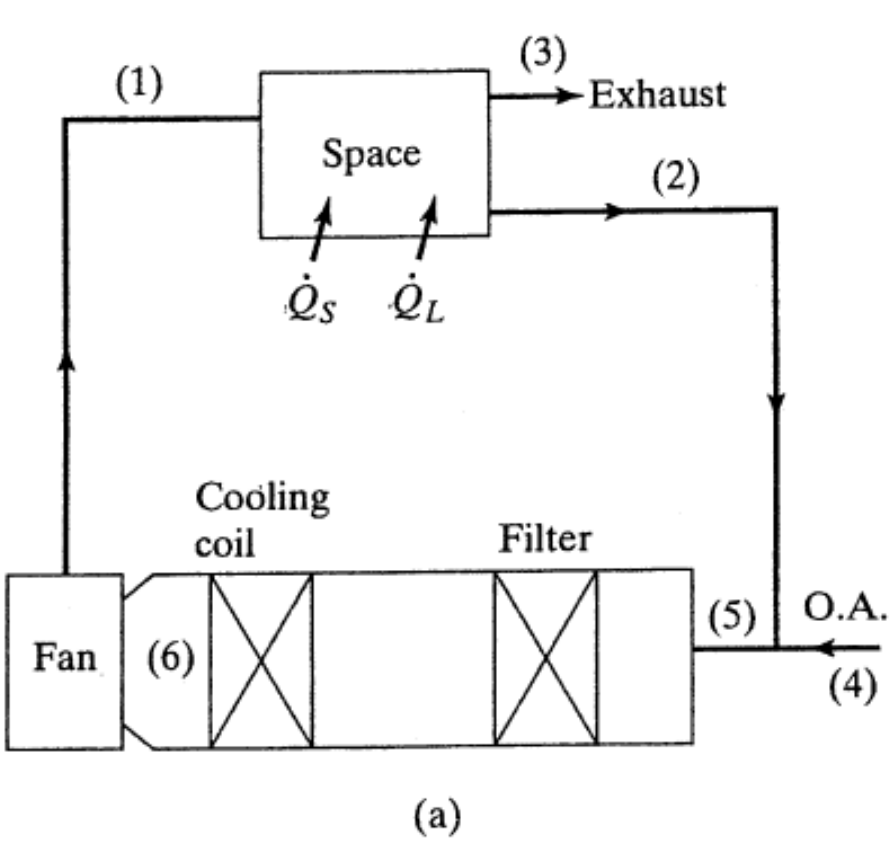
Cooling and dehumidification



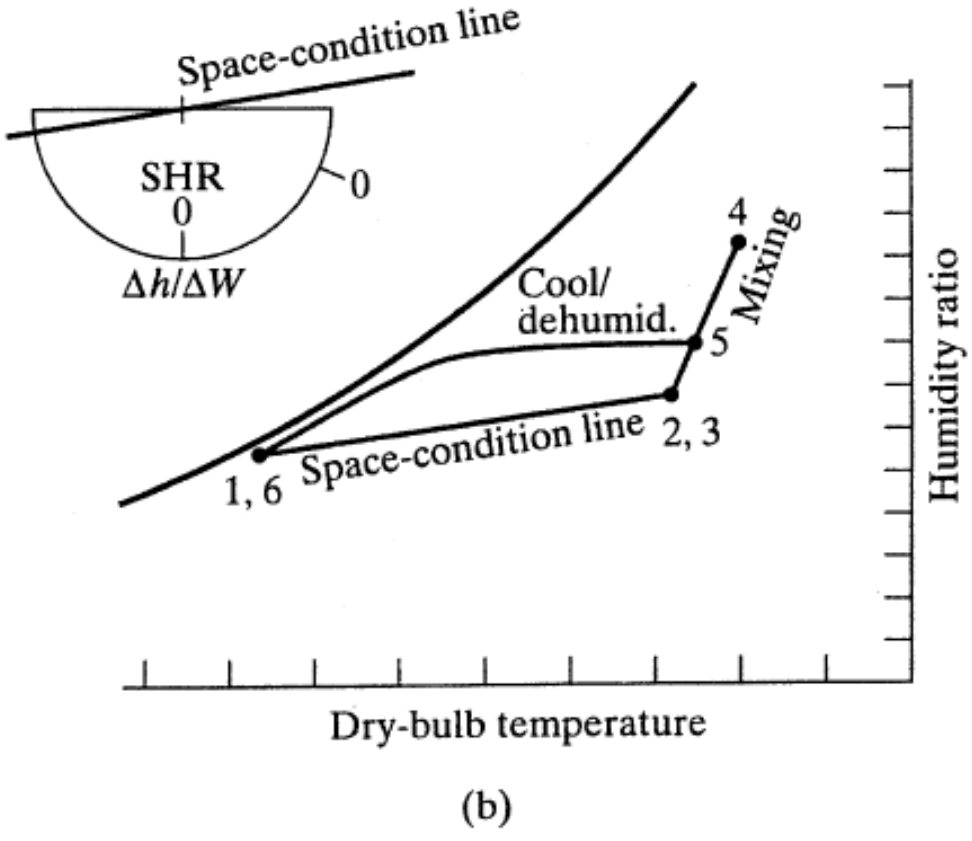
Cooling and dehumidification



Simple air conditioning cycle



(a)

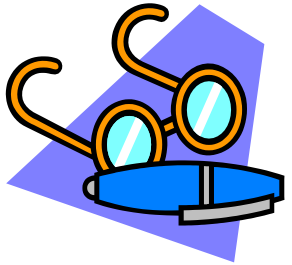


(b)

A sample cycle for Hong Kong summer conditions

- Outdoor: DBT = 33 ℃; WBT = 28 ℃; flow = 20% of supply air
- Indoor: DBT = 25 ℃; RH = 50%
- Air leaving cooling coil: DBT = 13 ℃; %RH = 95%

Psychrometric Processes



- Sensible heating coils
- Cooling coils
- Mixing air streams
- Humidifiers
  - Water spray types
  - Steam humidifier
- Room psychrometric process

Moist Air Sensible Heating

- Energy equation
  - $q = \dot{m}_{da}(h_2 - h_1)$
- E.g.
  - State 1: moist air saturated at 2°C, v = 10m^3/s
  - State 2: 40 °C
  - Find rate of heating q

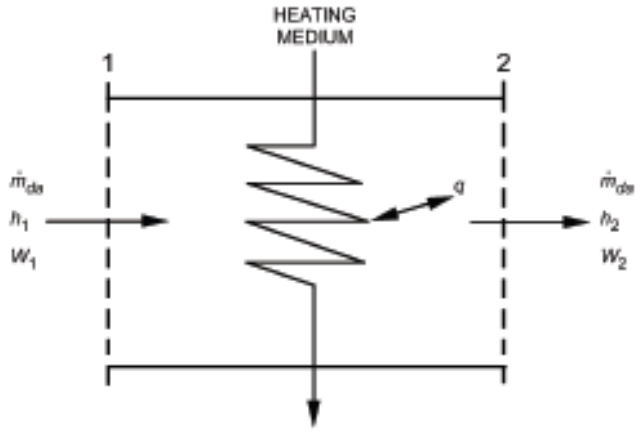
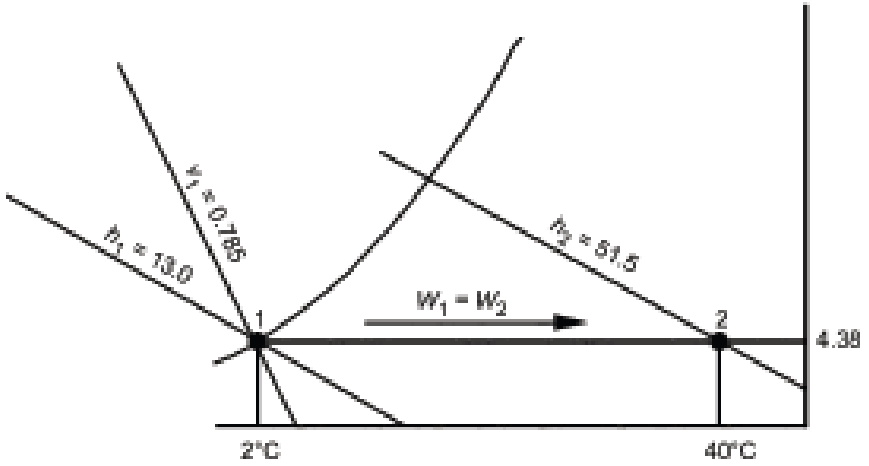


Fig. 2 Schematic of Device for Heating Moist Air



Moist Air Cooling and Dehumidification

- Energy and mass equations
  - $\dot{m}_{da} h_1 = \dot{m}_{da} h_2 + \mathrm{q} + \dot{m}_w h_w$
  - $\dot{m}_{da} W_1 = \dot{m}_{da} W_2 + \dot{m}_w$
- E.g.
  - State 1: moist air 30°C DB, 50% RH, v = 5m^3/s
  - State 2: saturated moist air at 10°C
  - Find refrigeration (kW)

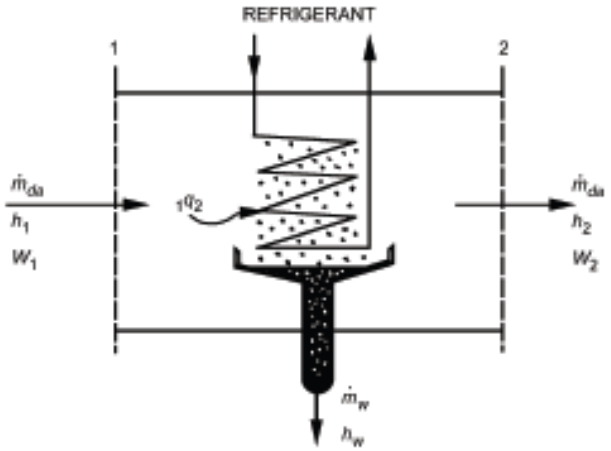
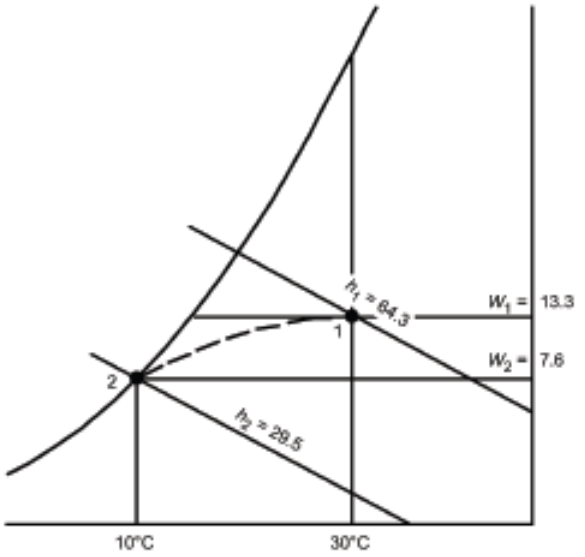


Fig. 3 Schematic of Device for Cooling Moist Air



Adiabatic Mixing

- Energy and Mass equations
  - $\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2 = \dot{m}_{da3}h_3$
  - $\dot{m}_{da1} + \dot{m}_{da2} = \dot{m}_{da3}$
  - $\dot{m}_{da1}W_1 + \dot{m}_{da2}W_2 = \dot{m}_{da3}W_3$
- E.g.
  - State 1: 2m^3/s, 4°C DBT, 2°C WBT
  - State 2: 6.25m^3/s, 25°C DBT, 50% RH
  - Find DBT and WBT of mixture

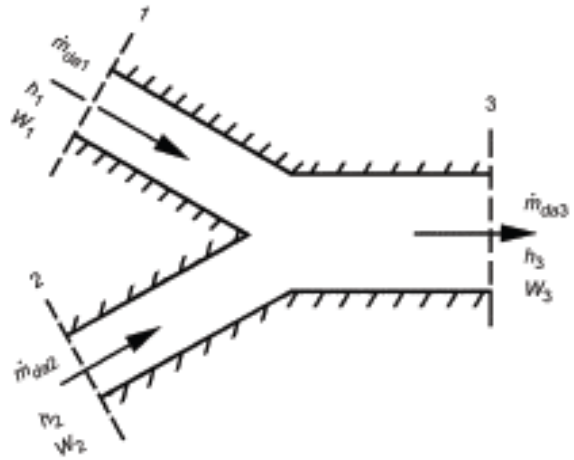
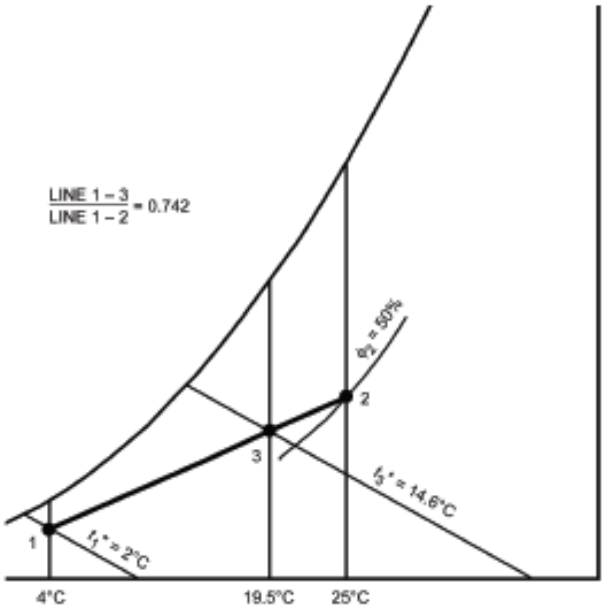


Fig. 6 Adiabatic Mixing of Two Moist Airstreams



Adiabatic Mixing of Water injected into Moist Air (water spray / steam)

- Energy and Mass equations
  - $\dot{m}_{da1}h_1 + \dot{m}_w h_w = \dot{m}_{da2}h_2$
  - $\dot{m}_{da1}W_1 + \dot{m}_w = \dot{m}_{da2}W_2$
- E.g.
  - State 1: 20°C DBT, 8°C WBT, m = 2 kg_{da}/s
  - State 2: air with dew point 13 °C
  - Injected steam = 110°C
  - Find DBT of air and steam flow

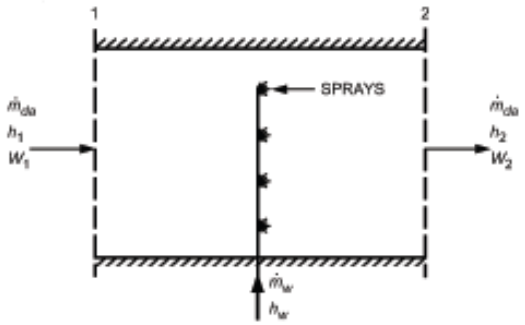
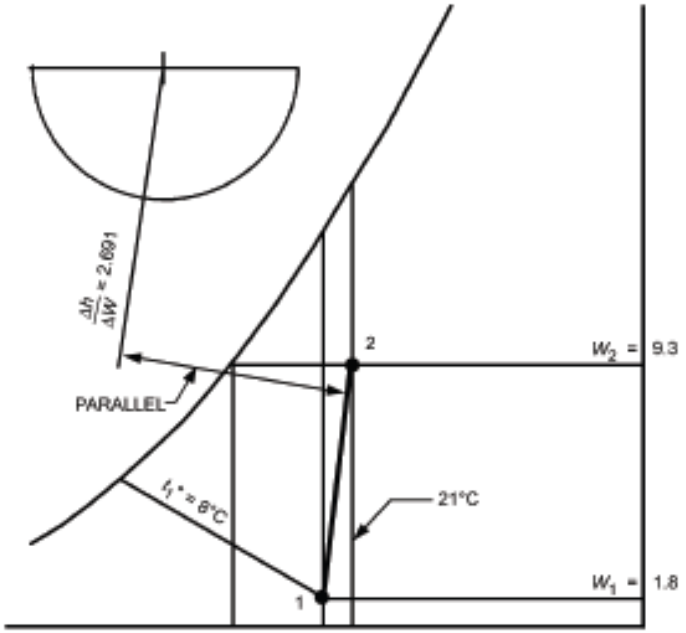


Fig. 8 Schematic Showing Injection of Water into Moist Air



Space heat absorption and moist air moisture gains

- Energy and Mass equations
  - $\dot{m}_{da1} h_1 + q_s + \sum \dot{m}_w h_w = \dot{m}_{da2} h_2$
  - $\dot{m}_{da1} W_1 + \sum \dot{m}_w = \dot{m}_{da2} W_2$
- E.g.
  - State 2: 25°C DBT, 19°C WBT
  - Sensible heat = 9kW
  - Moisture gain = 0.0015kg/s at 30 °C
  - State 1: 15°C DBT
  - Find WBT and volume flowrate

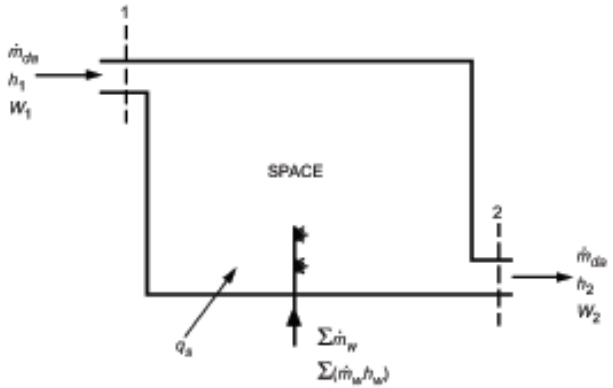
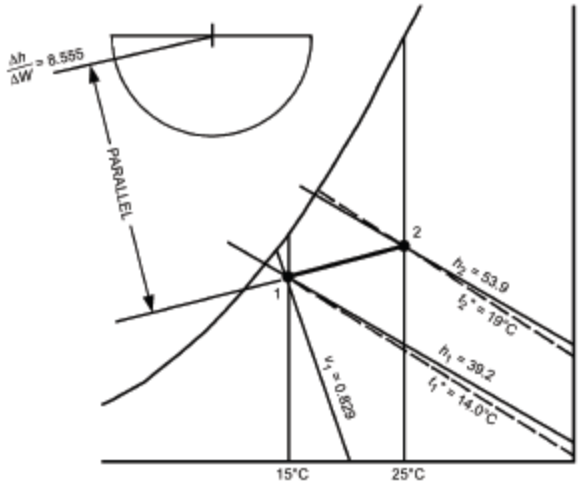
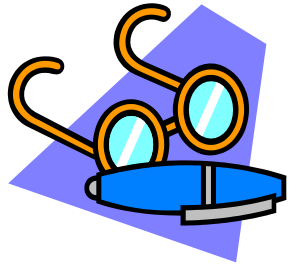


Fig. 10 Schematic of Air Conditioned Space

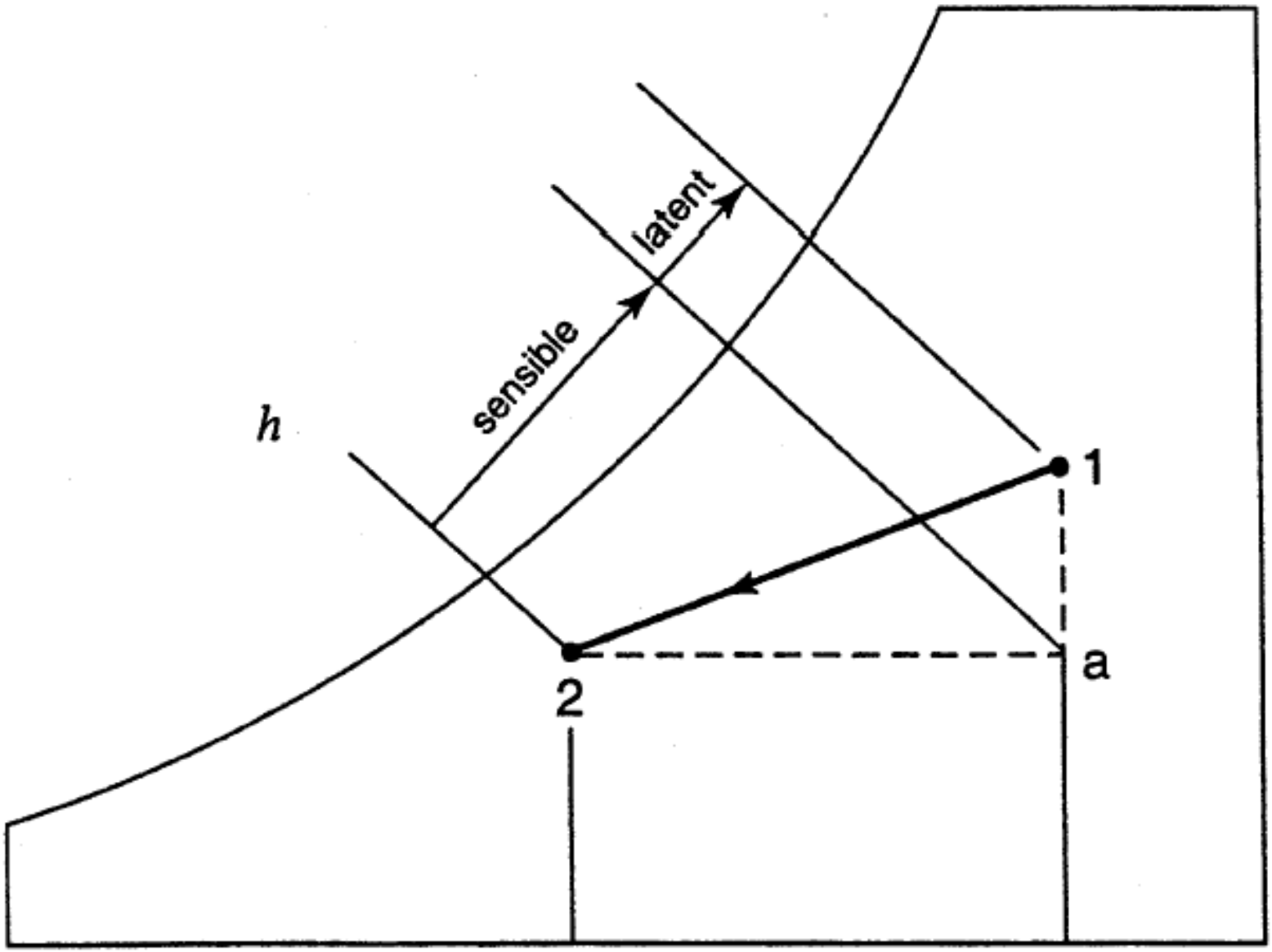


Psychrometric Processes



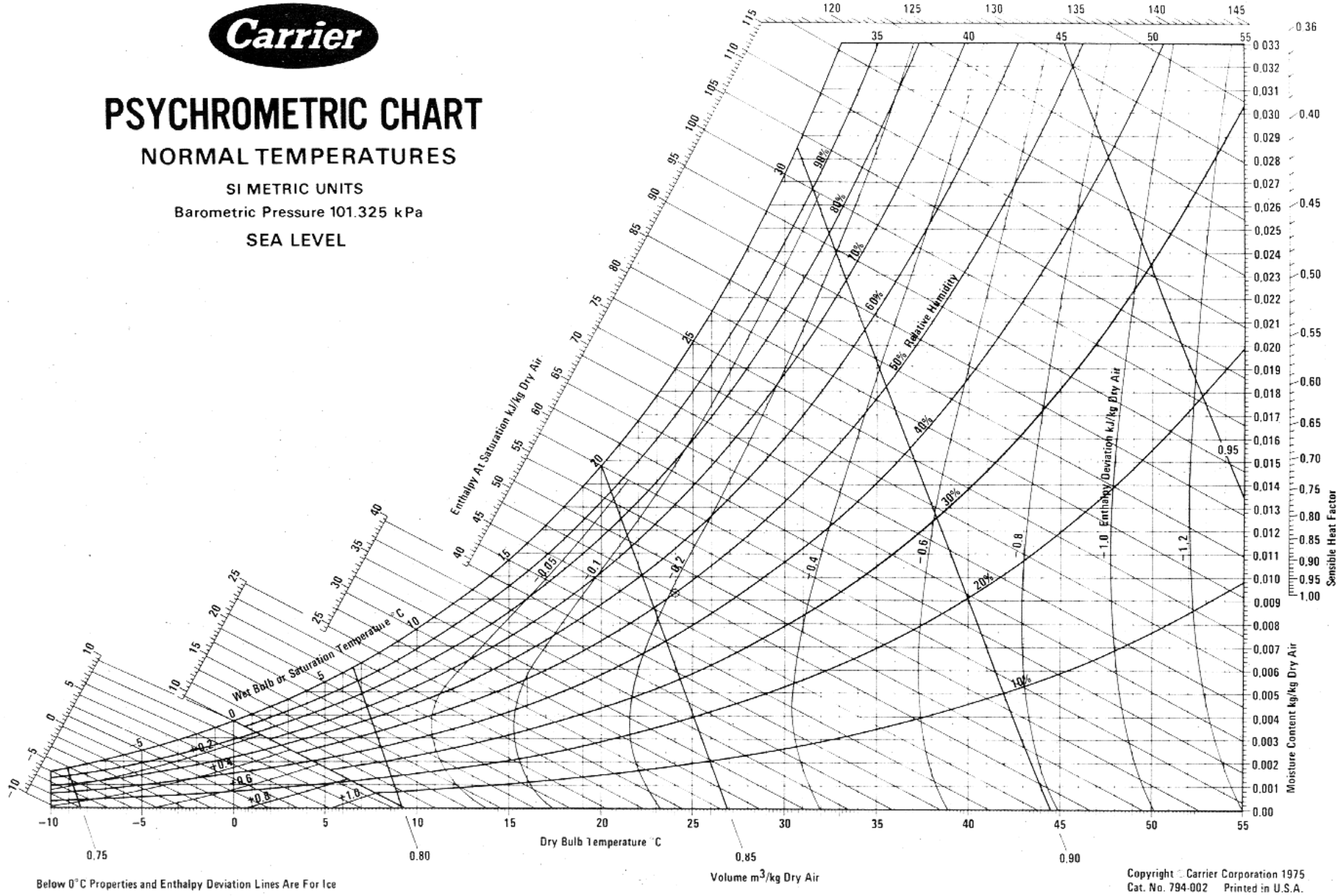
- Observations:
  - Sensible heat ratio (SHR) /
    Ratio of enthalpy and humidity ratio
  - Space cooling load
  - Cooling coil's load/capacity
  - Humidification capacity
  - Mixing processes
    - Principles of heat balance & conservation of mass

Sensible and latent cooling loads

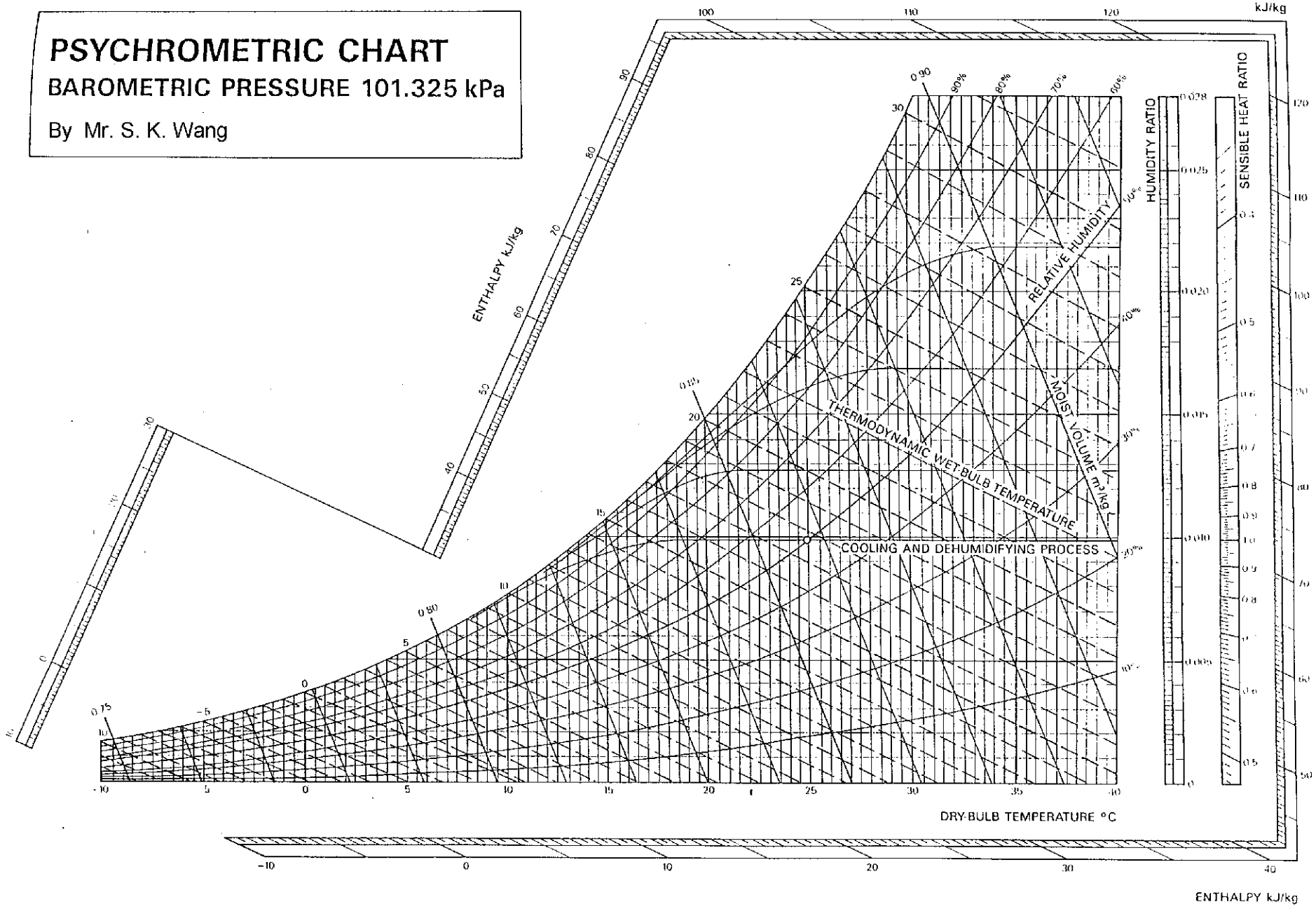


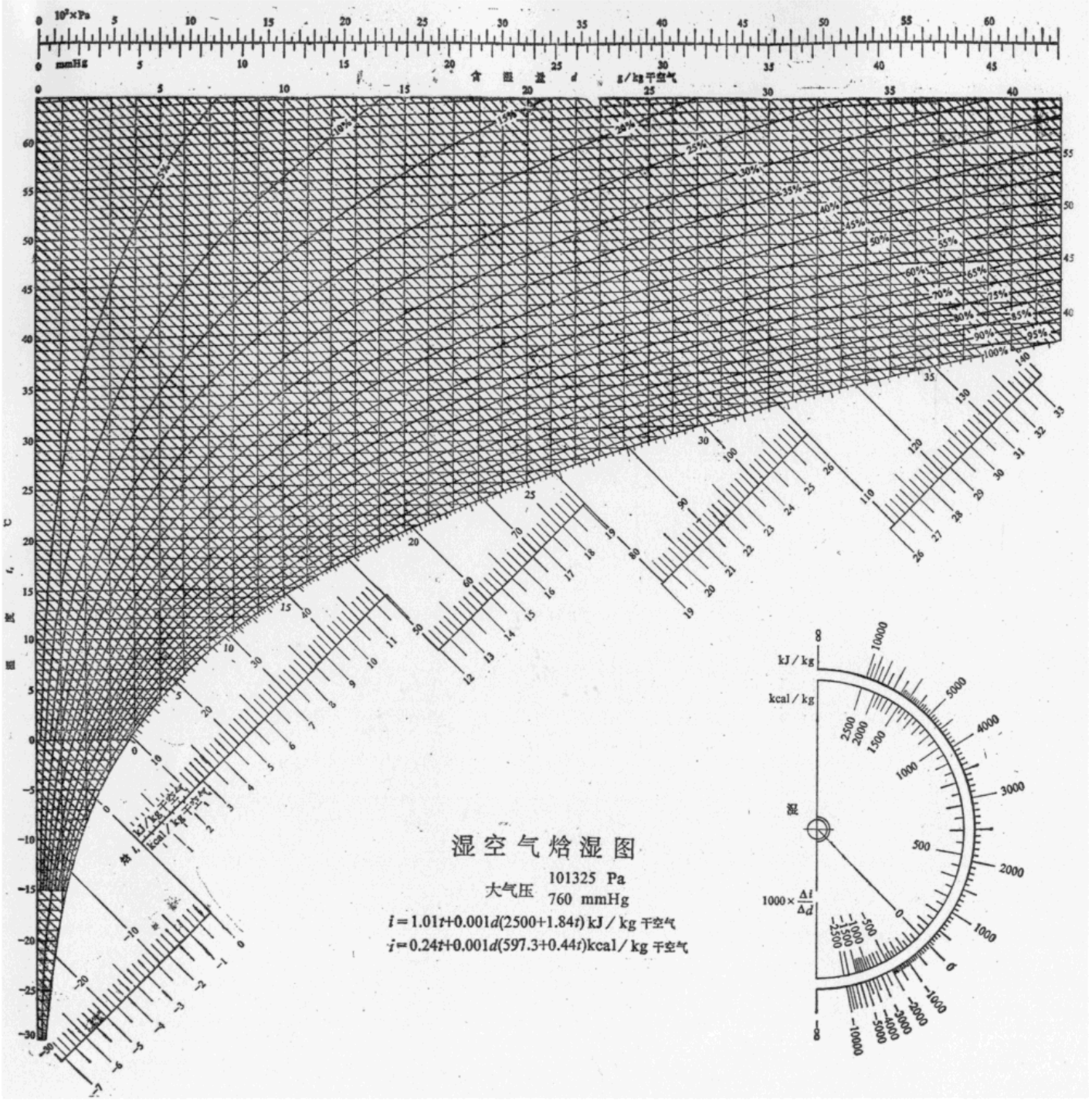
Practical Use of Psych. Chart

- Examples of psychrometric charts
  - ASHRAE
  - CIBSE
  - Carrier
  - Mr. S K Wang (similar to Trane)
  - Mollier Diagram (used in Mainland China, Russia…)



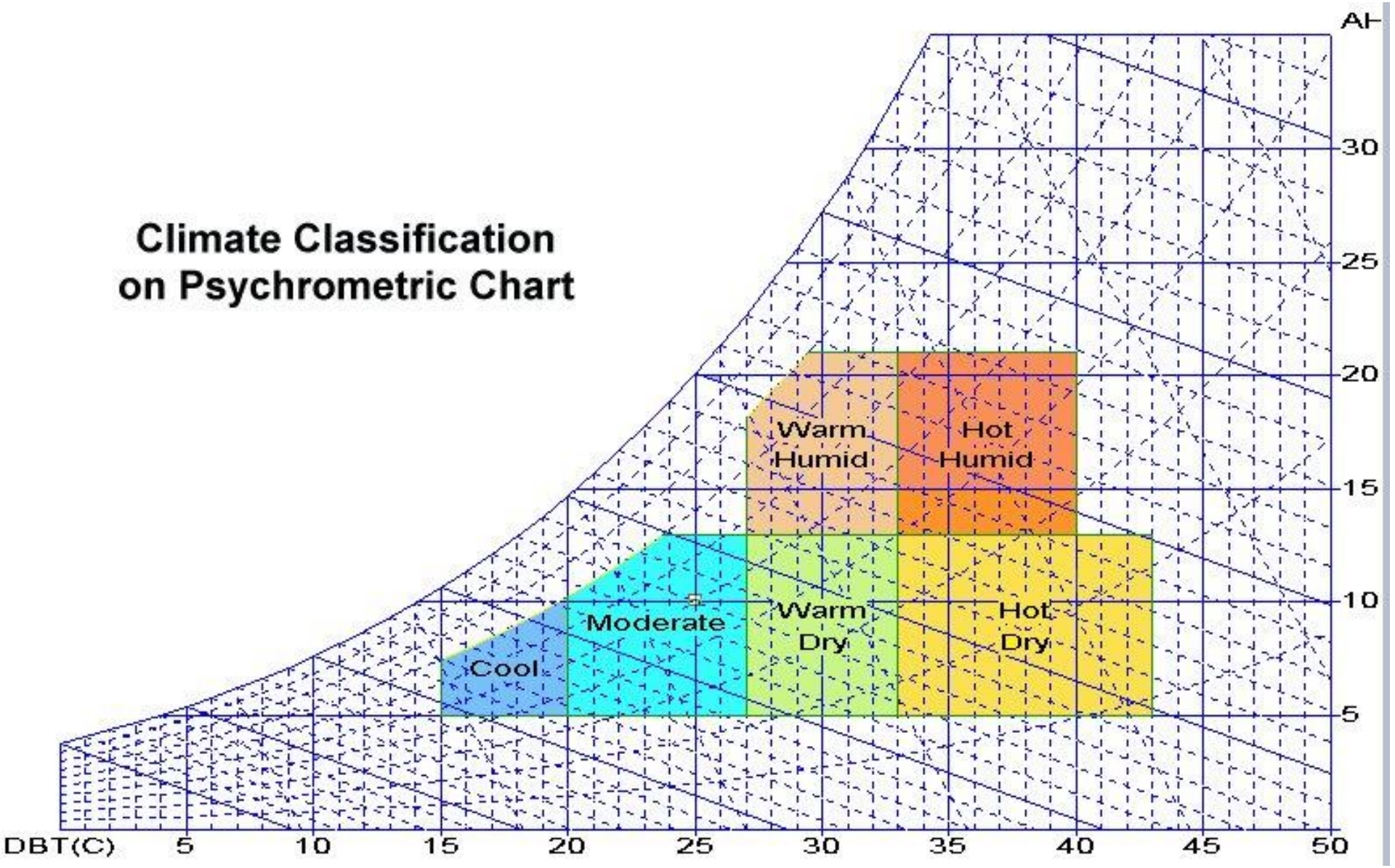
Reproduced courtesy of Carrier Corporation


PSYCHROMETRIC CHART
BAROMETRIC PRESSURE 101.325 kPa
By Mr. S. K. Wang
kJ/kg
ENTHALPY kJ/kg
RELATIVE HUMIDITY
THERMODYNAMIC WET-BULB TEMPERATURE
MOIST VOLUME m³/kg
COOLING AND DEHUMIDIFYING PROCESS
HUMIDITY RATIO
SENSIBLE HEAT RATIO
DRY-BULB TEMPERATURE °C
ENTHALPY kJ/kg


湿空气焓湿图
大气压 101325 Pa
760 mmHg
$i=1.01t+0.001d(2500+1.84t)$ kJ／kg 干空气
$i=0.24t+0.001d(597.3+0.44t)$kcal／kg 干空气
含湿量 d g/kg干空气
焓 i kJ/kg干空气 kcal/kg干空气
干球温度 t ℃
湿
kJ/kg
kcal/kg
$1000\times\frac{\Delta i}{\Delta d}$
d

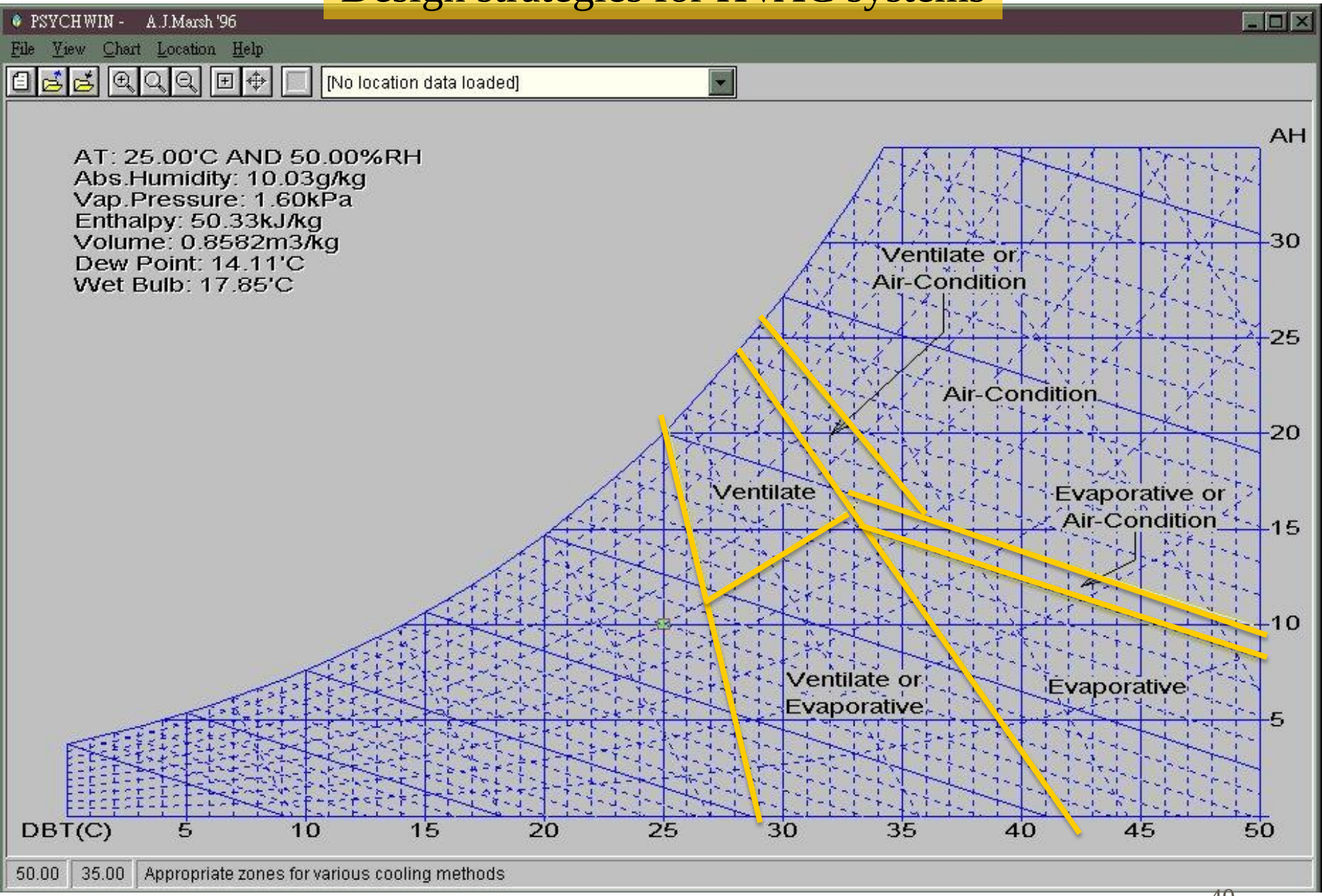
Psychrometric Software

- ASHRAE Psychrometric Analysis CD-ROM (2002) [AV 697 P97]
- ArchiSci software – PSYCHWIN
- CYTSoft Psychrometric Chart
- PsychroGen software
- Psychrometric Chart (PSY) software
- Daikin Psychrometric Diagram Viewer



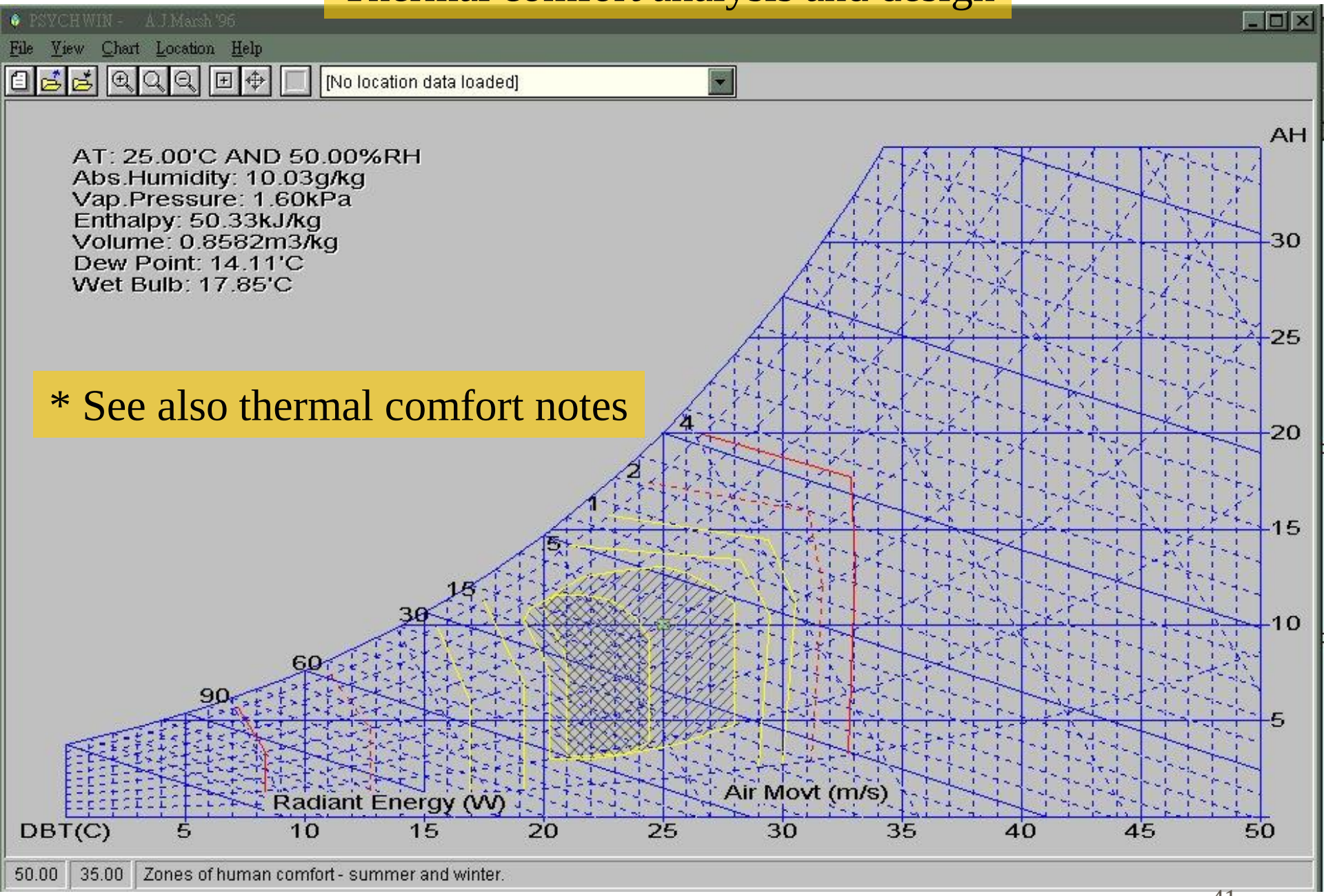
(Source: ArchiSci Software - PSYCHWIN)

Design strategies for HVAC systems



(Source: ArchiSci Software - PSYCHWIN)

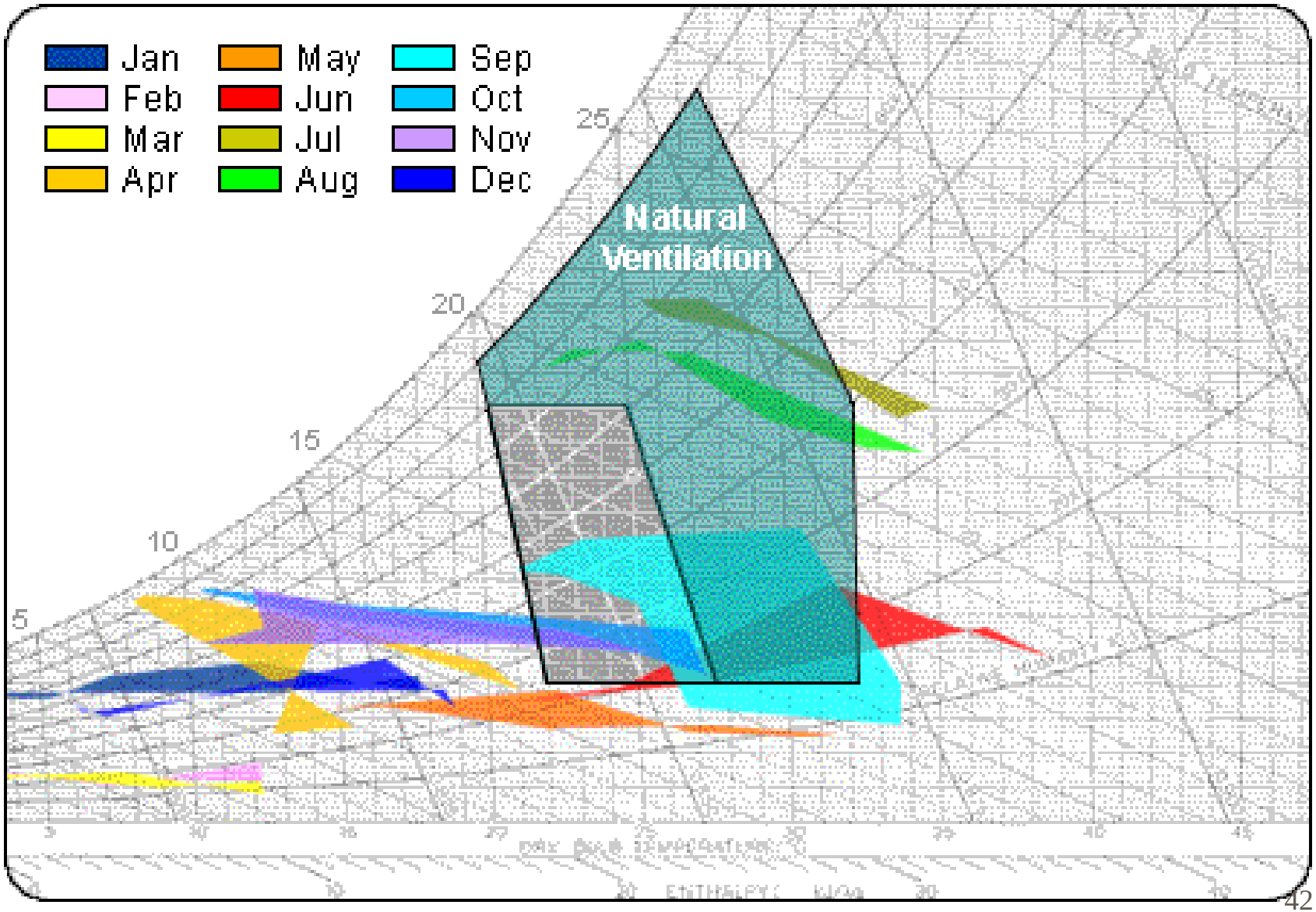
Thermal comfort analysis and design



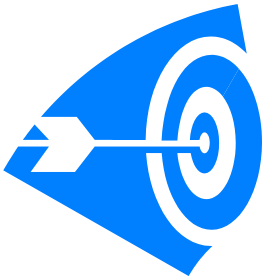
* See also thermal comfort notes

(Source: ArchiSci Software - PSYCHWIN)

Analysis of external climate

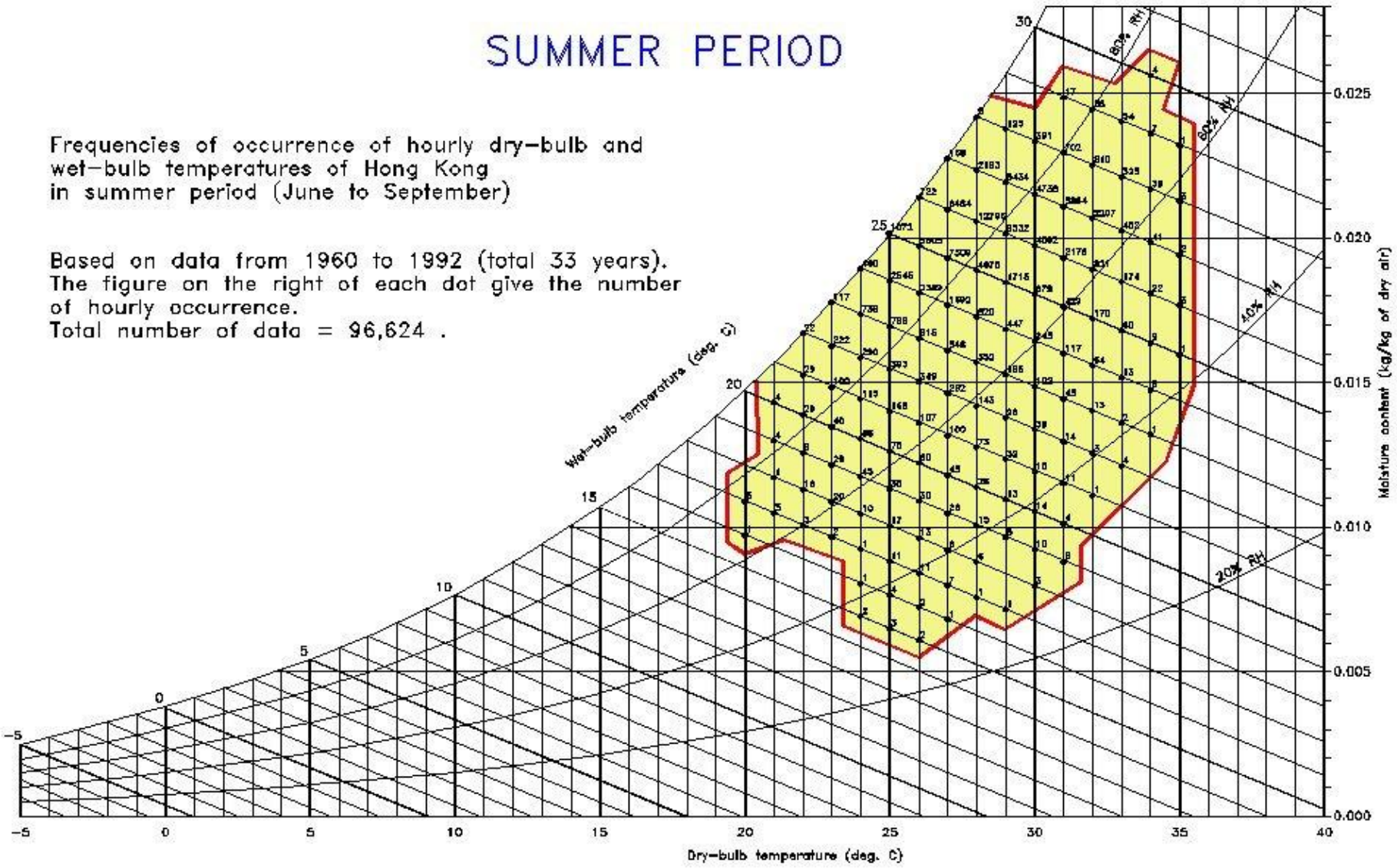


Psychrometric Analysis

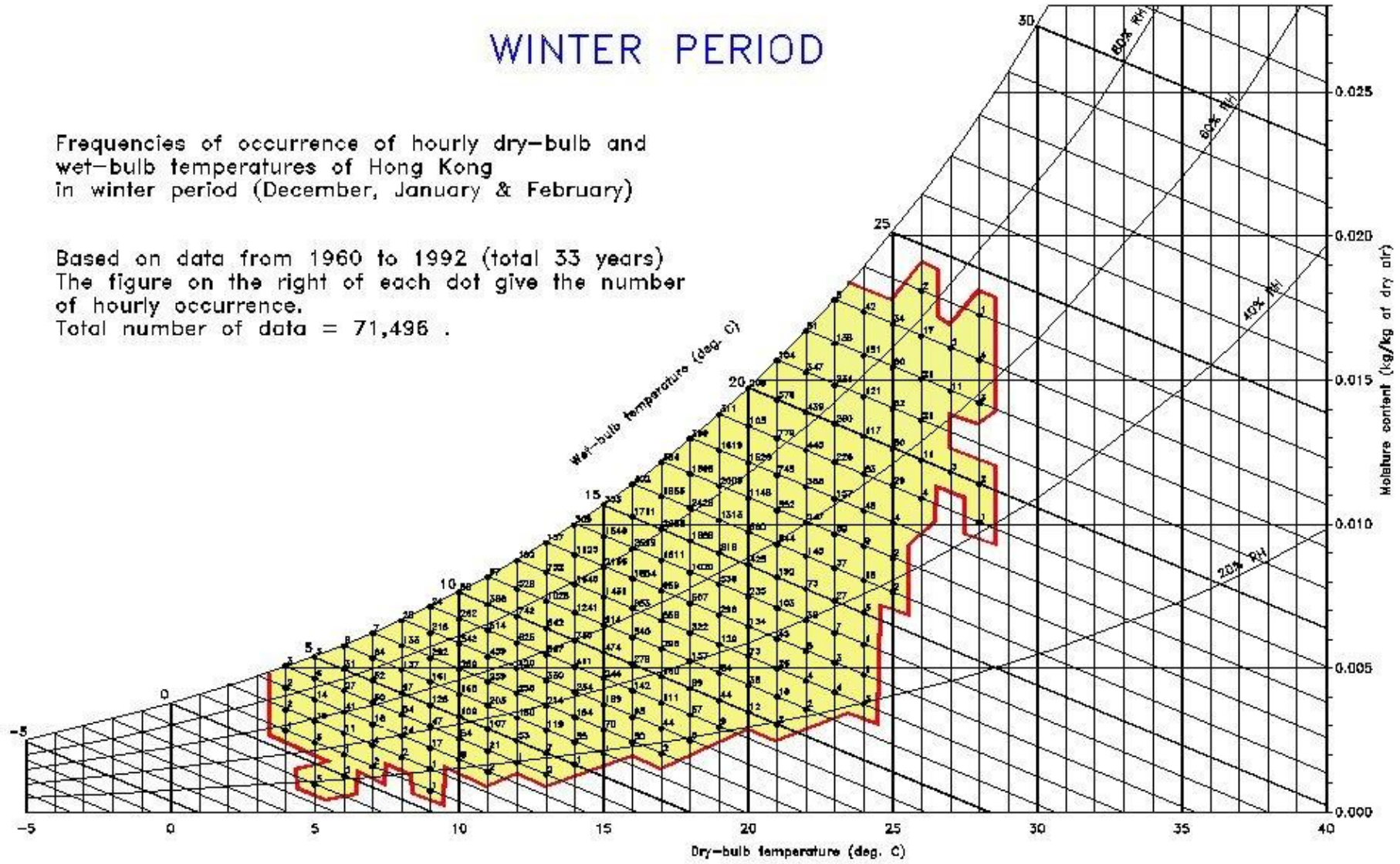


- Psychrometrics and Bioclimatic Analysis for Hong Kong http://arch.hku.hk/~cmhui/teach/65156-7e.htm
  - Cooling strategies
  - Thermal comfort zones
  - Frequency distribution on psychrometric charts

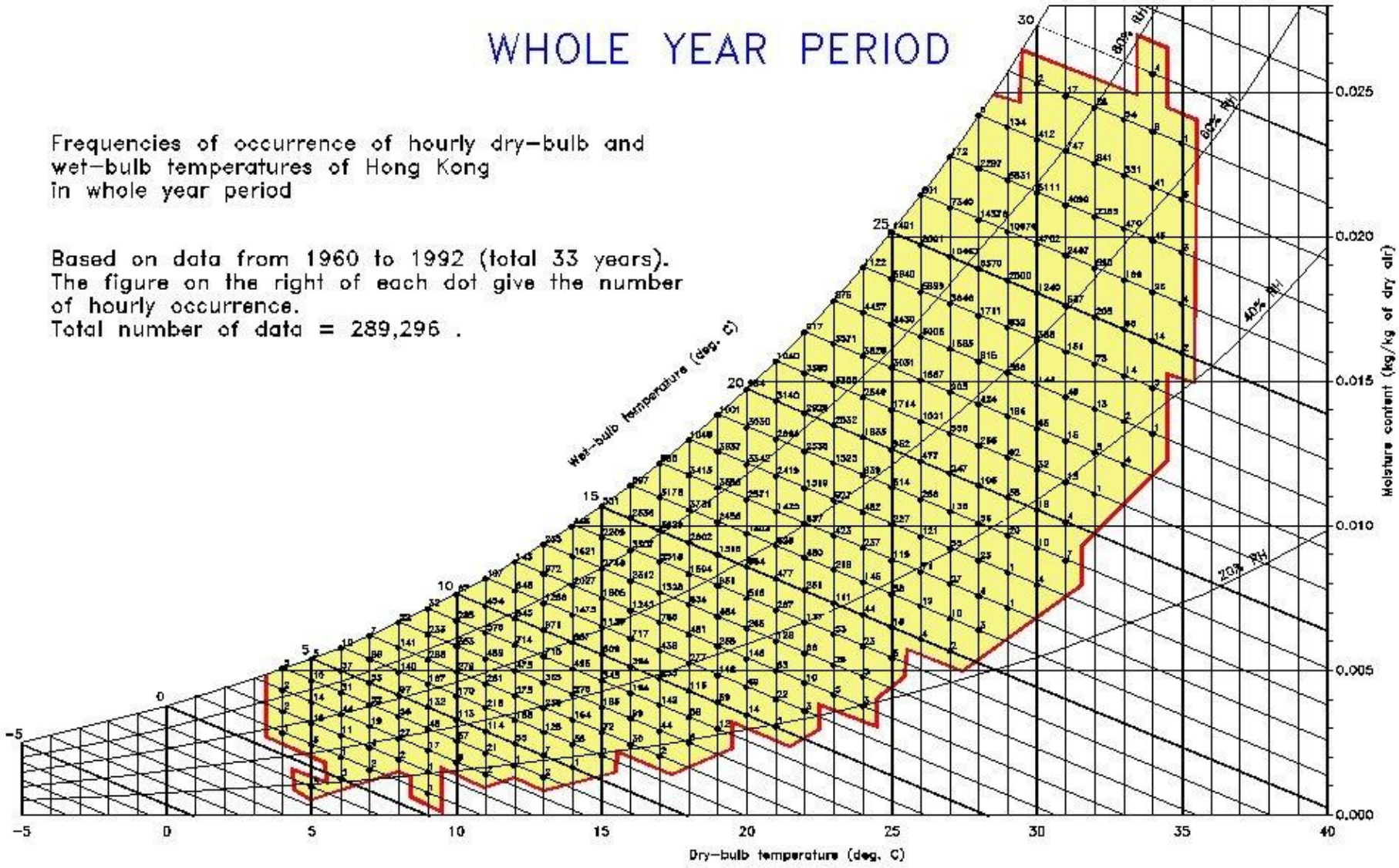
Analysis of weather conditions in Hong Kong



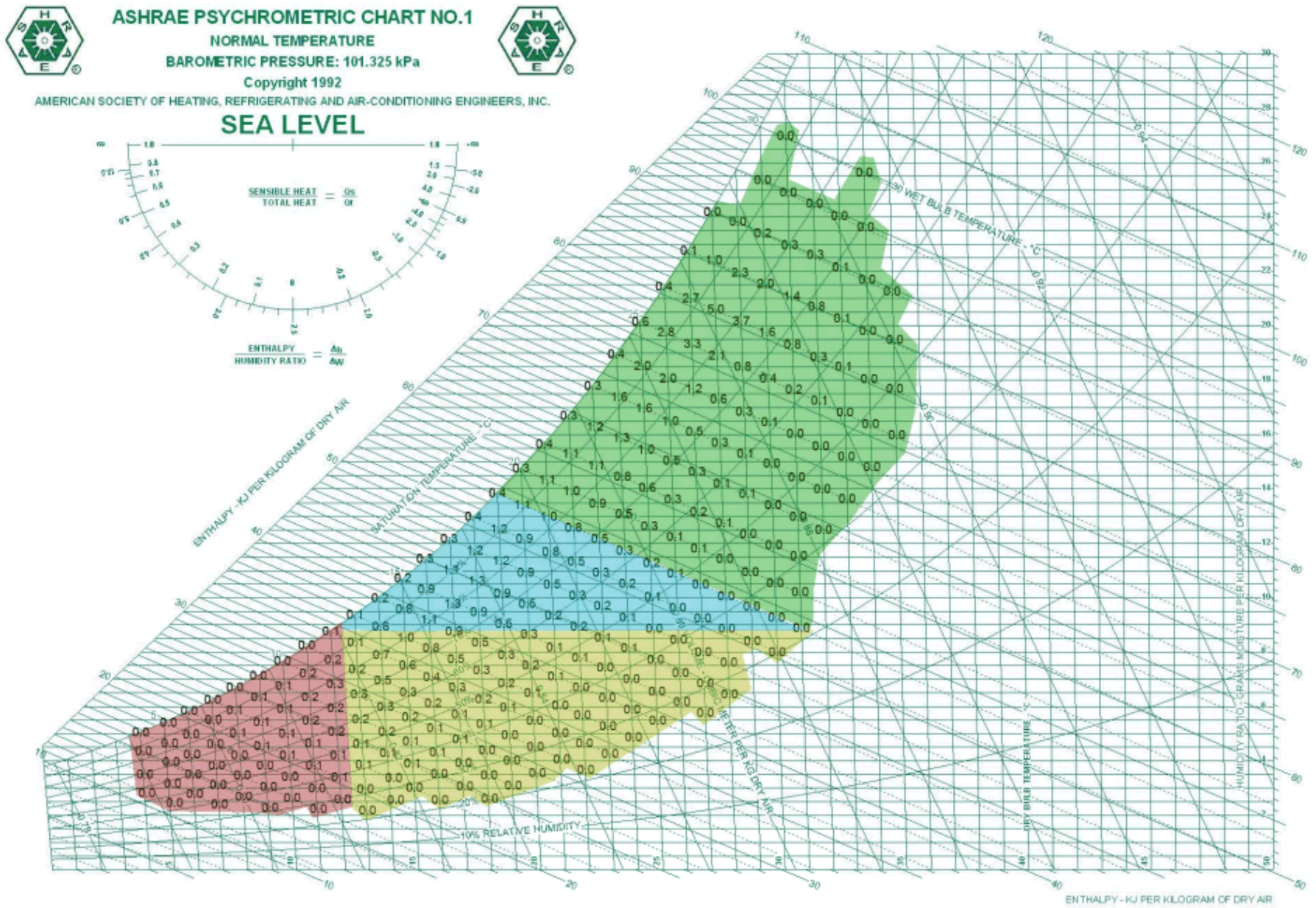
Analysis of weather conditions in Hong Kong



Analysis of weather conditions in Hong Kong



Analysis of weather conditions in Hong Kong



* The number represents the possibility of occurrence.

Analysis of HVAC operation strategy

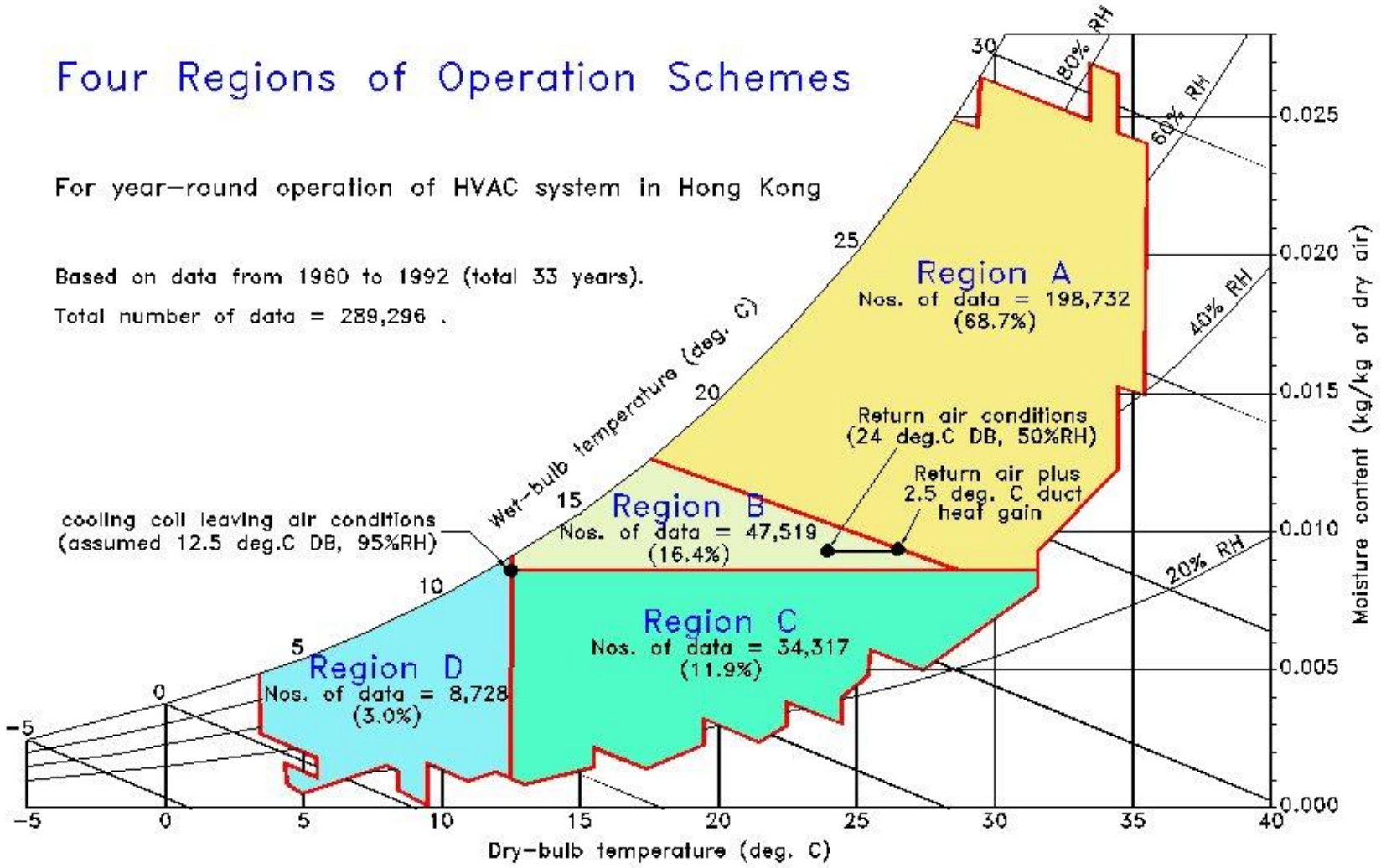


Table 2 Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 101.325 kPa

Temp., °C	Humidity Ratio	Specific Volume, m^3/kg_{da}			Specific Enthalpy, kJ/kg_{da}			Specific Entropy, $kJ/(kg_{da}\cdot K)$		Temp., °C
t	W_s, kg_w/kg_{da}	v_{da}	v_{as}	v_s	h_{da}	h_{as}	h_s	s_{da}	s_s	t
−60	0.0000067	0.6027	0.0000	0.6027	−60.341	0.016	−60.325	−0.2494	−0.2494	−60
−59	0.0000076	0.6055	0.0000	0.6055	−59.335	0.018	−59.317	−0.2447	−0.2446	−59
−58	0.0000087	0.6084	0.0000	0.6084	−58.329	0.021	−58.308	−0.2400	−0.2399	−58
−57	0.0000100	0.6112	0.0000	0.6112	−57.323	0.024	−57.299	−0.2354	−0.2353	−57
−56	0.0000114	0.6141	0.0000	0.6141	−56.317	0.027	−56.289	−0.2307	−0.2306	−56
−55	0.0000129	0.6169	0.0000	0.6169	−55.311	0.031	−55.280	−0.2261	−0.2260	−55
−54	0.0000147	0.6198	0.0000	0.6198	−54.305	0.035	−54.269	−0.2215	−0.2213	−54
−53	0.0000167	0.6226	0.0000	0.6226	−53.299	0.040	−53.258	−0.2169	−0.2167	−53
−52	0.0000190	0.6255	0.0000	0.6255	−52.293	0.046	−52.247	−0.2124	−0.2121	−52
−51	0.0000215	0.6283	0.0000	0.6283	−51.287	0.052	−51.235	−0.2078	−0.2076	−51
−50	0.0000243	0.6312	0.0000	0.6312	−50.281	0.059	−50.222	−0.2033	−0.2030	−50
−49	0.0000275	0.6340	0.0000	0.6340	−49.275	0.066	−49.209	−0.1988	−0.1985	−49
−48	0.0000311	0.6369	0.0000	0.6369	−48.269	0.075	−48.194	−0.1943	−0.1940	−48
−47	0.0000350	0.6397	0.0000	0.6397	−47.263	0.085	−47.179	−0.1899	−0.1895	−47
−46	0.0000395	0.6425	0.0000	0.6426	−46.257	0.095	−46.162	−0.1854	−0.1850	−46
−45	0.0000445	0.6454	0.0000	0.6454	−45.252	0.107	−45.144	−0.1810	−0.1805	−45
−44	0.0000500	0.6482	0.0001	0.6483	−44.246	0.121	−44.125	−0.1766	−0.1761	−44
−43	0.0000562	0.6511	0.0001	0.6511	−43.240	0.136	−43.104	−0.1722	−0.1716	−43
−42	0.0000631	0.6539	0.0001	0.6540	−42.234	0.153	−42.081	−0.1679	−0.1672	−42
−41	0.0000708	0.6568	0.0001	0.6568	−41.229	0.172	−41.057	−0.1635	−0.1628	−41
−40	0.0000793	0.6596	0.0001	0.6597	−40.223	0.192	−40.031	−0.1592	−0.1583	−40
−39	0.0000887	0.6625	0.0001	0.6626	−39.217	0.215	−39.002	−0.1549	−0.1539	−39
−38	0.0000992	0.6653	0.0001	0.6654	−38.212	0.241	−37.970	−0.1506	−0.1495	−38
−37	0.0001108	0.6682	0.0001	0.6683	−37.206	0.269	−36.936	−0.1464	−0.1451	−37
−36	0.0001237	0.6710	0.0001	0.6711	−36.200	0.301	−35.899	−0.1421	−0.1408	−36
−35	0.0001379	0.6738	0.0001	0.6740	−35.195	0.336	−34.859	−0.1379	−0.1364	−35
−34	0.0001536	0.6767	0.0002	0.6769	−34.189	0.374	−33.815	−0.1337	−0.1320	−34
−33	0.0001710	0.6795	0.0002	0.6797	−33.183	0.417	−32.766	−0.1295	−0.1276	−33
−32	0.0001902	0.6824	0.0002	0.6826	−32.178	0.464	−31.714	−0.1253	−0.1232	−32
−31	0.0002113	0.6852	0.0002	0.6855	−31.172	0.516	−30.656	−0.1211	−0.1189	−31
−30	0.0002345	0.6881	0.0003	0.6883	−30.167	0.573	−29.593	−0.1170	−0.1145	−30
−29	0.0002602	0.6909	0.0003	0.6912	−29.161	0.636	−28.525	−0.1129	−0.1101	−29
−28	0.0002883	0.6938	0.0003	0.6941	−28.156	0.706	−27.450	−0.1088	−0.1057	−28
−27	0.0003193	0.6966	0.0004	0.6970	−27.150	0.782	−26.368	−0.1047	−0.1013	−27
−26	0.0003532	0.6994	0.0004	0.6998	−26.144	0.866	−25.278	−0.1006	−0.0969	−26
−25	0.0003905	0.7023	0.0004	0.7027	−25.139	0.958	−24.181	−0.0965	−0.0924	−25
−24	0.0004314	0.7051	0.0005	0.7056	−24.133	1.059	−23.074	−0.0925	−0.0880	−24
−23	0.0004761	0.7080	0.0005	0.7085	−23.128	1.170	−21.958	−0.0884	−0.0835	−23
−22	0.0005251	0.7108	0.0006	0.7114	−22.122	1.291	−20.831	−0.0844	−0.0790	−22
−21	0.0005787	0.7137	0.0007	0.7143	−21.117	1.424	−19.693	−0.0804	−0.0745	−21
−20	0.0006373	0.7165	0.0007	0.7172	−20.111	1.570	−18.542	−0.0765	−0.0699	−20
−19	0.0007013	0.7193	0.0008	0.7201	−19.106	1.728	−17.377	−0.0725	−0.0653	−19
−18	0.0007711	0.7222	0.0009	0.7231	−18.100	1.902	−16.198	−0.0685	−0.0607	−18
−17	0.0008473	0.7250	0.0010	0.7260	−17.095	2.091	−15.003	−0.0646	−0.0560	−17
−16	0.0009303	0.7279	0.0011	0.7290	−16.089	2.298	−13.791	−0.0607	−0.0513	−16
−15	0.0010207	0.7307	0.0012	0.7319	−15.084	2.523	−12.560	−0.0568	−0.0465	−15
−14	0.0011191	0.7336	0.0013	0.7349	−14.078	2.769	−11.310	−0.0529	−0.0416	−14
−13	0.0012261	0.7364	0.0014	0.7378	−13.073	3.036	−10.037	−0.0490	−0.0367	−13
−12	0.0013425	0.7392	0.0016	0.7408	−12.067	3.326	−8.741	−0.0452	−0.0317	−12
−11	0.0014689	0.7421	0.0017	0.7438	−11.062	3.642	−7.419	−0.0413	−0.0267	−11
−10	0.0016062	0.7449	0.0019	0.7468	−10.056	3.986	−6.070	−0.0375	−0.0215	−10
−9	0.0017551	0.7478	0.0021	0.7499	−9.050	4.358	−4.692	−0.0337	−0.0163	−9
−8	0.0019166	0.7506	0.0023	0.7529	−8.045	4.763	−3.282	−0.0299	−0.0110	−8
−7	0.0020916	0.7534	0.0025	0.7560	−7.039	5.202	−1.838	−0.0261	−0.0055	−7
−6	0.0022812	0.7563	0.0028	0.7591	−6.034	5.677	−0.356	−0.0223	0.0000	−6
−5	0.0024863	0.7591	0.0030	0.7622	−5.028	6.193	1.164	−0.0186	0.0057	−5
−4	0.0027083	0.7620	0.0033	0.7653	−4.023	6.750	2.728	−0.0148	0.0115	−4
−3	0.0029482	0.7648	0.0036	0.7684	−3.017	7.354	4.337	−0.0111	0.0175	−3
−2	0.0032076	0.7677	0.0039	0.7716	−2.011	8.007	5.995	−0.0074	0.0236	−2
−1	0.0034877	0.7705	0.0043	0.7748	−1.006	8.712	7.707	−0.0037	0.0299	−1
0	0.0037900	0.7733	0.0047	0.7780	0.000	9.475	9.475	0.0000	0.0364	0
1	0.004076	0.7762	0.0051	0.7813	1.006	10.198	11.203	0.0037	0.0427	1
2	0.004382	0.7790	0.0055	0.7845	2.011	10.970	12.981	0.0073	0.0492	2
3	0.004708	0.7819	0.0059	0.7878	3.017	11.794	14.811	0.0110	0.0559	3
4	0.005055	0.7847	0.0064	0.7911	4.023	12.673	16.696	0.0146	0.0627	4
5	0.005425	0.7875	0.0068	0.7944	5.029	13.611	18.639	0.0182	0.0697	5
6	0.005819	0.7904	0.0074	0.7978	6.034	14.610	20.644	0.0219	0.0769	6
7	0.006238	0.7932	0.0079	0.8012	7.040	15.674	22.714	0.0254	0.0843	7
8	0.006684	0.7961	0.0085	0.8046	8.046	16.807	24.853	0.0290	0.0919	8
9	0.007158	0.7989	0.0092	0.8081	9.052	18.013	27.065	0.0326	0.0997	9
10	0.007663	0.8017	0.0098	0.8116	10.058	19.297	29.354	0.0362	0.1078	10
11	0.008199	0.8046	0.0106	0.8152	11.063	20.661	31.724	0.0397	0.1162	11
12	0.008768	0.8074	0.0113	0.8188	12.069	22.111	34.181	0.0432	0.1248	12
13	0.009372	0.8103	0.0122	0.8224	13.075	23.653	36.728	0.0468	0.1337	13
14	0.010013	0.8131	0.0131	0.8262	14.081	25.290	39.371	0.0503	0.1430	14

Table 2 Thermodynamic Properties of Moist Air at Standard Atmospheric Pressure, 101.325 kPa (*Concluded*)

Temp., °C	Humidity Ratio	Specific Volume, m^3/kg_{da}			Specific Enthalpy, kJ/kg_{da}			Specific Entropy, $kJ/(kg_{da} \cdot K)$		Temp., °C
t	W_s, kg_w/kg_{da}	v_{da}	v_{as}	v_s	h_{da}	h_{as}	h_s	s_{da}	s_s	t
15	0.010694	0.8159	0.0140	0.8299	15.087	27.028	42.115	0.0538	0.1525	15
16	0.011415	0.8188	0.0150	0.8338	16.093	28.873	44.966	0.0573	0.1624	16
17	0.012181	0.8216	0.0160	0.8377	17.099	30.830	47.929	0.0607	0.1726	17
18	0.012991	0.8245	0.0172	0.8416	18.105	32.906	51.011	0.0642	0.1832	18
19	0.013851	0.8273	0.0184	0.8457	19.111	35.107	54.219	0.0676	0.1942	19
20	0.014761	0.8301	0.0196	0.8498	20.117	37.441	57.558	0.0711	0.2057	20
21	0.015724	0.8330	0.0210	0.8540	21.124	39.914	61.037	0.0745	0.2175	21
22	0.016744	0.8358	0.0224	0.8583	22.130	42.533	64.663	0.0779	0.2298	22
23	0.017823	0.8387	0.0240	0.8626	23.136	45.308	68.444	0.0813	0.2426	23
24	0.018965	0.8415	0.0256	0.8671	24.142	48.245	72.388	0.0847	0.2560	24
25	0.020173	0.8443	0.0273	0.8716	25.148	51.355	76.503	0.0881	0.2698	25
26	0.021451	0.8472	0.0291	0.8763	26.155	54.646	80.801	0.0915	0.2842	26
27	0.022802	0.8500	0.0311	0.8811	27.161	58.128	85.289	0.0948	0.2992	27
28	0.024229	0.8529	0.0331	0.8860	28.167	61.812	89.979	0.0982	0.3148	28
29	0.025738	0.8557	0.0353	0.8910	29.174	65.708	94.882	0.1015	0.3311	29
30	0.027333	0.8585	0.0376	0.8961	30.180	69.829	100.009	0.1048	0.3481	30
31	0.029018	0.8614	0.0400	0.9014	31.187	74.185	105.372	0.1081	0.3658	31
32	0.030797	0.8642	0.0426	0.9069	32.193	78.791	110.985	0.1115	0.3843	32
33	0.032677	0.8671	0.0454	0.9124	33.200	83.660	116.860	0.1147	0.4035	33
34	0.034663	0.8699	0.0483	0.9182	34.207	88.806	123.013	0.1180	0.4236	34
35	0.036760	0.8727	0.0514	0.9241	35.213	94.245	129.458	0.1213	0.4447	35
36	0.038975	0.8756	0.0547	0.9302	36.220	99.993	136.213	0.1246	0.4666	36
37	0.041313	0.8784	0.0581	0.9365	37.227	106.068	143.294	0.1278	0.4895	37
38	0.043783	0.8813	0.0618	0.9430	38.233	112.487	150.720	0.1311	0.5135	38
39	0.046391	0.8841	0.0657	0.9498	39.240	119.270	158.510	0.1343	0.5386	39
40	0.049145	0.8869	0.0698	0.9567	40.247	126.438	166.685	0.1375	0.5649	40
41	0.052053	0.8898	0.0741	0.9639	41.254	134.014	175.268	0.1407	0.5923	41
42	0.055124	0.8926	0.0788	0.9714	42.261	142.021	184.282	0.1439	0.6211	42
43	0.058368	0.8955	0.0837	0.9791	43.268	150.483	193.751	0.1471	0.6512	43
44	0.061795	0.8983	0.0888	0.9871	44.275	159.429	203.704	0.1503	0.6828	44
45	0.065416	0.9011	0.0943	0.9955	45.282	168.887	214.169	0.1535	0.7159	45
46	0.069242	0.9040	0.1002	1.0041	46.289	178.889	225.178	0.1566	0.7507	46
47	0.073286	0.9068	0.1063	1.0131	47.297	189.466	236.763	0.1598	0.7871	47
48	0.077561	0.9096	0.1129	1.0225	48.304	200.656	248.960	0.1629	0.8254	48
49	0.082081	0.9125	0.1198	1.0323	49.311	212.497	261.808	0.1660	0.8655	49
50	0.086863	0.9153	0.1272	1.0425	50.319	225.030	275.349	0.1692	0.9078	50
51	0.091922	0.9182	0.1350	1.0531	51.326	238.300	289.627	0.1723	0.9522	51
52	0.097278	0.9210	0.1433	1.0643	52.334	252.357	304.690	0.1754	0.9989	52
53	0.102949	0.9238	0.1521	1.0759	53.341	267.251	320.592	0.1785	1.0481	53
54	0.108958	0.9267	0.1614	1.0881	54.349	283.041	337.389	0.1816	1.0999	54
55	0.115326	0.9295	0.1714	1.1009	55.356	299.788	355.144	0.1846	1.1545	55
56	0.122080	0.9324	0.1819	1.1143	56.364	317.560	373.924	0.1877	1.2121	56
57	0.129248	0.9352	0.1932	1.1284	57.372	336.431	393.803	0.1908	1.2729	57
58	0.136858	0.9380	0.2051	1.1432	58.380	356.482	414.862	0.1938	1.3371	58
59	0.144945	0.9409	0.2179	1.1587	59.388	377.800	437.188	0.1968	1.4050	59
60	0.153545	0.9437	0.2315	1.1752	60.396	400.484	460.880	0.1999	1.4769	60
61	0.162697	0.9465	0.2460	1.1925	61.404	424.641	486.044	0.2029	1.5530	61
62	0.172446	0.9494	0.2615	1.2108	62.412	450.388	512.799	0.2059	1.6337	62
63	0.182842	0.9522	0.2780	1.2302	63.420	477.856	541.276	0.2089	1.7194	63
64	0.193937	0.9551	0.2957	1.2508	64.428	507.192	571.620	0.2119	1.8105	64
65	0.205794	0.9579	0.3147	1.2726	65.436	538.557	603.993	0.2149	1.9074	65
66	0.218478	0.9607	0.3350	1.2957	66.445	572.131	638.576	0.2179	2.0107	66
67	0.232067	0.9636	0.3568	1.3204	67.453	608.118	675.572	0.2208	2.1209	67
68	0.246645	0.9664	0.3803	1.3467	68.462	646.746	715.208	0.2238	2.2386	68
69	0.262309	0.9692	0.4056	1.3748	69.470	688.271	757.741	0.2268	2.3646	69
70	0.279167	0.9721	0.4328	1.4049	70.479	732.985	803.464	0.2297	2.4997	70
71	0.297343	0.9749	0.4622	1.4372	71.488	781.220	852.707	0.2326	2.6449	71
72	0.316979	0.9778	0.4941	1.4719	72.496	833.353	905.850	0.2356	2.8011	72
73	0.338237	0.9806	0.5287	1.5093	73.505	889.821	963.326	0.2385	2.9697	73
74	0.361304	0.9834	0.5663	1.5497	74.514	951.124	1025.638	0.2414	3.1520	74
75	0.386399	0.9863	0.6072	1.5935	75.523	1017.843	1093.367	0.2443	3.3496	75
76	0.413774	0.9891	0.6520	1.6411	76.532	1090.659	1167.191	0.2472	3.5645	76
77	0.443727	0.9919	0.7010	1.6930	77.542	1170.366	1247.907	0.2501	3.7989	77
78	0.476610	0.9948	0.7550	1.7497	78.551	1257.907	1336.458	0.2529	4.0553	78
79	0.512842	0.9976	0.8145	1.8121	79.560	1354.402	1433.962	0.2558	4.3371	79
80	0.552926	1.0005	0.8805	1.8809	80.569	1461.196	1541.765	0.2587	4.6478	80
81	0.597470	1.0033	0.9539	1.9572	81.579	1579.917	1661.496	0.2615	4.9920	81
82	0.647218	1.0061	1.0360	2.0421	82.589	1712.556	1795.145	0.2644	5.3754	82
83	0.703089	1.0090	1.1283	2.1373	83.598	1861.573	1945.171	0.2672	5.8047	83
84	0.766233	1.0118	1.2328	2.2446	84.608	2030.041	2114.649	0.2701	6.2885	84
85	0.838105	1.0146	1.3519	2.3665	85.618	2221.858	2307.476	0.2729	6.8376	85
86	0.920580	1.0175	1.4887	2.5062	86.628	2442.035	2528.662	0.2757	7.4660	86
87	1.016105	1.0203	1.6473	2.6676	87.638	2697.127	2784.764	0.2785	8.1919	87
88	1.127952	1.0232	1.8332	2.8564	88.648	2995.880	3084.528	0.2813	9.0396	88
89	1.260579	1.0260	2.0539	3.0799	89.658	3350.228	3439.885	0.2841	10.0421	89
90	1.420235	1.0288	2.3198	3.3487	90.668	3776.888	3867.556	0.2869	11.2458	90

Table 3 Thermodynamic Properties of Water at Saturation

Temp., °C t	Absolute Pressure p_{ws}, kPa	Specific Volume, m^3/kg_w			Specific Enthalpy, kJ/kg_w			Specific Entropy, $kJ/(kg_w \cdot K)$			Temp., °C t
		Sat. Solid v_i/v_f	Evap. v_{ig}/v_{fg}	Sat. Vapor v_g	Sat. Solid h_i/h_f	Evap. h_{ig}/h_{fg}	Sat. Vapor h_g	Sat. Solid s_i/s_f	Evap. s_{ig}/s_{fg}	Sat. Vapor s_g	
−60	0.00108	0.001081	90971.58	90971.58	−446.12	2836.27	2390.14	−1.6842	13.3064	11.6222	−60
−59	0.00124	0.001082	79885.31	79885.31	−444.46	2836.45	2391.99	−1.6764	13.2452	11.5687	−59
−58	0.00141	0.001082	70235.77	70235.78	−442.79	2836.63	2393.85	−1.6687	13.1845	11.5158	−58
−57	0.00161	0.001082	61826.23	61826.24	−441.11	2836.81	2395.70	−1.6609	13.1243	11.4634	−57
−56	0.00184	0.001082	54488.28	54488.28	−439.42	2836.97	2397.55	−1.6531	13.0646	11.4115	−56
−55	0.00209	0.001082	48077.54	48077.54	−437.73	2837.13	2399.40	−1.6453	13.0054	11.3601	−55
−54	0.00238	0.001082	42470.11	42470.11	−436.03	2837.28	2401.25	−1.6375	12.9468	11.3092	−54
−53	0.00271	0.001082	37559.49	37559.50	−434.32	2837.42	2403.10	−1.6298	12.8886	11.2589	−53
−52	0.00307	0.001083	33254.07	33254.07	−432.61	2837.56	2404.95	−1.6220	12.8310	11.2090	−52
−51	0.00348	0.001083	29474.87	29474.87	−430.88	2837.69	2406.81	−1.6142	12.7738	11.1596	−51
−50	0.00394	0.001083	26153.80	26153.80	−429.16	2837.81	2408.66	−1.6065	12.7171	11.1106	−50
−49	0.00445	0.001083	23232.03	23232.04	−427.42	2837.93	2410.51	−1.5987	12.6609	11.0622	−49
−48	0.00503	0.001083	20658.70	20658.70	−425.68	2838.04	2412.36	−1.5909	12.6051	11.0142	−48
−47	0.00568	0.001083	18389.75	18389.75	−423.93	2838.14	2414.21	−1.5832	12.5498	10.9666	−47
−46	0.00640	0.001083	16387.03	16387.03	−422.17	2838.23	2416.06	−1.5754	12.4950	10.9196	−46
−45	0.00720	0.001084	14617.39	14617.39	−420.40	2838.32	2417.91	−1.5677	12.4406	10.8729	−45
−44	0.00810	0.001084	13052.07	13052.07	−418.63	2838.39	2419.76	−1.5599	12.3867	10.8267	−44
−43	0.00910	0.001084	11666.02	11666.02	−416.85	2838.47	2421.62	−1.5522	12.3331	10.7810	−43
−42	0.01022	0.001084	10437.46	10437.46	−415.06	2838.53	2423.47	−1.5444	12.2801	10.7356	−42
−41	0.01146	0.001084	9347.38	9347.38	−413.27	2838.59	2425.32	−1.5367	12.2274	10.6907	−41
−40	0.01284	0.001084	8379.20	8379.20	−411.47	2838.64	2427.17	−1.5289	12.1752	10.6462	−40
−39	0.01437	0.001085	7518.44	7518.44	−409.66	2838.68	2429.02	−1.5212	12.1234	10.6022	−39
−38	0.01607	0.001085	6752.43	6752.43	−407.85	2838.72	2430.87	−1.5135	12.0720	10.5585	−38
−37	0.01795	0.001085	6070.08	6070.08	−406.02	2838.74	2432.72	−1.5057	12.0210	10.5152	−37
−36	0.02004	0.001085	5461.68	5461.68	−404.19	2838.76	2434.57	−1.4980	11.9704	10.4724	−36
−35	0.02234	0.001085	4918.69	4918.69	−402.36	2838.78	2436.42	−1.4903	11.9202	10.4299	−35
−34	0.02489	0.001085	4433.64	4433.64	−400.51	2838.78	2438.27	−1.4825	11.8703	10.3878	−34
−33	0.02771	0.001085	3999.95	3999.95	−398.66	2838.78	2440.12	−1.4748	11.8209	10.3461	−33
−32	0.03081	0.001086	3611.82	3611.82	−396.80	2838.77	2441.97	−1.4671	11.7718	10.3047	−32
−31	0.03423	0.001086	3264.15	3264.16	−394.94	2838.75	2443.82	−1.4594	11.7231	10.2638	−31
−30	0.03801	0.001086	2952.46	2952.46	−393.06	2838.73	2445.67	−1.4516	11.6748	10.2232	−30
−29	0.04215	0.001086	2672.77	2672.77	−391.18	2838.70	2447.51	−1.4439	11.6269	10.1830	−29
−28	0.04672	0.001086	2421.58	2421.58	−389.29	2838.66	2449.36	−1.4362	11.5793	10.1431	−28
−27	0.05173	0.001086	2195.80	2195.80	−387.40	2838.61	2451.21	−1.4285	11.5321	10.1036	−27
−26	0.05724	0.001087	1992.68	1992.68	−385.50	2838.56	2453.06	−1.4208	11.4852	10.0644	−26
−25	0.06327	0.001087	1809.79	1809.79	−383.59	2838.49	2454.91	−1.4131	11.4386	10.0256	−25
−24	0.06989	0.001087	1644.99	1644.99	−381.67	2838.42	2456.75	−1.4054	11.3925	9.9871	−24
−23	0.07714	0.001087	1496.36	1496.36	−379.75	2838.35	2458.60	−1.3977	11.3466	9.9489	−23
−22	0.08508	0.001087	1362.21	1362.21	−377.81	2838.26	2460.45	−1.3899	11.3011	9.9111	−22
−21	0.09376	0.001087	1241.03	1241.03	−375.88	2838.17	2462.29	−1.3822	11.2559	9.8736	−21
−20	0.10324	0.001087	1131.49	1131.49	−373.93	2838.07	2464.14	−1.3745	11.2110	9.8365	−20
−19	0.11360	0.001088	1032.38	1032.38	−371.98	2837.96	2465.98	−1.3668	11.1665	9.7996	−19
−18	0.12490	0.001088	942.64	942.65	−370.01	2837.84	2467.83	−1.3591	11.1223	9.7631	−18
−17	0.13722	0.001088	861.34	861.34	−368.05	2837.72	2469.67	−1.3514	11.0784	9.7269	−17
−16	0.15065	0.001088	787.61	787.61	−366.07	2837.59	2471.51	−1.3437	11.0348	9.6910	−16
−15	0.16527	0.001088	720.70	720.70	−364.09	2837.45	2473.36	−1.3360	10.9915	9.6554	−15
−14	0.18119	0.001088	659.94	659.94	−362.10	2837.30	2475.20	−1.3284	10.9485	9.6201	−14
−13	0.19849	0.001089	604.72	604.73	−360.10	2837.14	2477.04	−1.3207	10.9058	9.5851	−13
−12	0.21729	0.001089	554.51	554.51	−358.10	2836.98	2478.88	−1.3130	10.8634	9.5504	−12
−11	0.23771	0.001089	508.81	508.81	−356.08	2836.80	2480.72	−1.3053	10.8213	9.5160	−11
−10	0.25987	0.001089	467.19	467.19	−354.06	2836.62	2482.56	−1.2976	10.7795	9.4819	−10
−9	0.28391	0.001089	429.25	429.26	−352.04	2836.44	2484.40	−1.2899	10.7380	9.4481	−9
−8	0.30995	0.001089	394.66	394.66	−350.00	2836.24	2486.23	−1.2822	10.6967	9.4145	−8
−7	0.33817	0.001090	363.09	363.09	−347.96	2836.03	2488.07	−1.2745	10.6558	9.3812	−7
−6	0.36871	0.001090	334.26	334.26	−345.91	2835.82	2489.91	−1.2668	10.6151	9.3482	−6
−5	0.40174	0.001090	307.92	307.92	−343.86	2835.60	2491.74	−1.2592	10.5747	9.3155	−5
−4	0.43745	0.001090	283.82	283.83	−341.79	2835.37	2493.57	−1.2515	10.5345	9.2830	−4
−3	0.47604	0.001090	261.78	261.78	−339.72	2835.13	2495.41	−1.2438	10.4946	9.2508	−3
−2	0.51770	0.001091	241.60	241.60	−337.64	2834.88	2497.24	−1.2361	10.4550	9.2189	−2
−1	0.56266	0.001091	223.10	223.11	−335.56	2834.63	2499.07	−1.2284	10.4157	9.1872	−1
0	0.61115	0.001091	206.15	206.15	−333.47	2834.36	2500.90	−1.2208	10.3766	9.1558	0

Table 3 Thermodynamic Properties of Water at Saturation (*Continued*)

Temp., °C t	Absolute Pressure p_{ws}, kPa	Specific Volume, m^3/kg_w			Specific Enthalpy, kJ/kg_w			Specific Entropy, $kJ/(kg_w \cdot K)$			Temp., °C t
		Sat. Solid v_i/v_f	Evap. v_{ig}/v_{fg}	Sat. Vapor v_g	Sat. Solid h_i/h_f	Evap. h_{ig}/h_{fg}	Sat. Vapor h_g	Sat. Solid s_i/s_f	Evap. s_{ig}/s_{fg}	Sat. Vapor s_g	
0	0.6112	0.001000	206.139	206.140	–0.04	2500.93	2500.89	–0.0002	9.1559	9.1558	0
1	0.6571	0.001000	192.444	192.445	4.18	2498.55	2502.73	0.0153	9.1138	9.1291	1
2	0.7060	0.001000	179.763	179.764	8.39	2496.17	2504.57	0.0306	9.0721	9.1027	2
3	0.7581	0.001000	168.013	168.014	12.60	2493.80	2506.40	0.0459	9.0306	9.0765	3
4	0.8135	0.001000	157.120	157.121	16.81	2491.42	2508.24	0.0611	8.9895	9.0506	4
5	0.8726	0.001000	147.016	147.017	21.02	2489.05	2510.07	0.0763	8.9486	9.0249	5
6	0.9354	0.001000	137.637	137.638	25.22	2486.68	2511.91	0.0913	8.9081	8.9994	6
7	1.0021	0.001000	128.927	128.928	29.43	2484.31	2513.74	0.1064	8.8678	8.9742	7
8	1.0730	0.001000	120.833	120.834	33.63	2481.94	2515.57	0.1213	8.8278	8.9492	8
9	1.1483	0.001000	113.308	113.309	37.82	2479.58	2517.40	0.1362	8.7882	8.9244	9
10	1.2282	0.001000	106.308	106.309	42.02	2477.21	2519.23	0.1511	8.7488	8.8998	10
11	1.3129	0.001000	99.792	99.793	46.22	2474.84	2521.06	0.1659	8.7096	8.8755	11
12	1.4028	0.001001	93.723	93.724	50.41	2472.48	2522.89	0.1806	8.6708	8.8514	12
13	1.4981	0.001001	88.069	88.070	54.60	2470.11	2524.71	0.1953	8.6322	8.8275	13
14	1.5989	0.001001	82.797	82.798	58.79	2467.75	2526.54	0.2099	8.5939	8.8038	14
15	1.7057	0.001001	77.880	77.881	62.98	2465.38	2528.36	0.2245	8.5559	8.7804	15
16	1.8188	0.001001	73.290	73.291	67.17	2463.01	2530.19	0.2390	8.5181	8.7571	16
17	1.9383	0.001001	69.005	69.006	71.36	2460.65	2532.01	0.2534	8.4806	8.7341	17
18	2.0647	0.001001	65.002	65.003	75.55	2458.28	2533.83	0.2678	8.4434	8.7112	18
19	2.1982	0.001002	61.260	61.261	79.73	2455.92	2535.65	0.2822	8.4064	8.6886	19
20	2.3392	0.001002	57.760	57.761	83.92	2453.55	2537.47	0.2965	8.3696	8.6661	20
21	2.4881	0.001002	54.486	54.487	88.10	2451.18	2539.29	0.3108	8.3331	8.6439	21
22	2.6452	0.001002	51.421	51.422	92.29	2448.81	2541.10	0.3250	8.2969	8.6218	22
23	2.8109	0.001003	48.551	48.552	96.47	2446.45	2542.92	0.3391	8.2609	8.6000	23
24	2.9856	0.001003	45.862	45.863	100.66	2444.08	2544.73	0.3532	8.2251	8.5783	24
25	3.1697	0.001003	43.340	43.341	104.84	2441.71	2546.54	0.3673	8.1895	8.5568	25
26	3.3637	0.001003	40.976	40.977	109.02	2439.33	2548.35	0.3813	8.1542	8.5355	26
27	3.5679	0.001004	38.757	38.758	113.20	2436.96	2550.16	0.3952	8.1192	8.5144	27
28	3.7828	0.001004	36.674	36.675	117.38	2434.59	2551.97	0.4091	8.0843	8.4934	28
29	4.0089	0.001004	34.718	34.719	121.56	2432.21	2553.78	0.4230	8.0497	8.4727	29
30	4.2467	0.001004	32.881	32.882	125.75	2429.84	2555.58	0.4368	8.0153	8.4521	30
31	4.4966	0.001005	31.153	31.154	129.93	2427.46	2557.39	0.4506	7.9812	8.4317	31
32	4.7592	0.001005	29.528	29.529	134.11	2425.08	2559.19	0.4643	7.9472	8.4115	32
33	5.0351	0.001005	28.000	28.001	138.29	2422.70	2560.99	0.4780	7.9135	8.3914	33
34	5.3247	0.001006	26.561	26.562	142.47	2420.32	2562.79	0.4916	7.8800	8.3715	34
35	5.6286	0.001006	25.207	25.208	146.64	2417.94	2564.58	0.5052	7.8467	8.3518	35
36	5.9475	0.001006	23.931	23.932	150.82	2415.56	2566.38	0.5187	7.8136	8.3323	36
37	6.2818	0.001007	22.728	22.729	155.00	2413.17	2568.17	0.5322	7.7807	8.3129	37
38	6.6324	0.001007	21.594	21.595	159.18	2410.78	2569.96	0.5457	7.7480	8.2936	38
39	6.9997	0.001007	20.525	20.526	163.36	2408.39	2571.75	0.5591	7.7155	8.2746	39
40	7.3844	0.001008	19.516	19.517	167.54	2406.00	2573.54	0.5724	7.6832	8.2557	40
41	7.7873	0.001008	18.564	18.565	171.72	2403.61	2575.33	0.5858	7.6512	8.2369	41
42	8.2090	0.001009	17.664	17.665	175.90	2401.21	2577.11	0.5990	7.6193	8.2183	42
43	8.6503	0.001009	16.815	16.816	180.08	2398.82	2578.89	0.6123	7.5876	8.1999	43
44	9.1118	0.001009	16.012	16.013	184.26	2396.42	2580.67	0.6255	7.5561	8.1816	44
45	9.5944	0.001010	15.252	15.253	188.44	2394.02	2582.45	0.6386	7.5248	8.1634	45
46	10.0988	0.001010	14.534	14.535	192.62	2391.61	2584.23	0.6517	7.4937	8.1454	46
47	10.6259	0.001011	13.855	13.856	196.80	2389.21	2586.00	0.6648	7.4628	8.1276	47
48	11.1764	0.001011	13.212	13.213	200.98	2386.80	2587.77	0.6778	7.4320	8.1099	48
49	11.7512	0.001012	12.603	12.604	205.16	2384.39	2589.54	0.6908	7.4015	8.0923	49
50	12.3513	0.001012	12.027	12.028	209.34	2381.97	2591.31	0.7038	7.3711	8.0749	50
51	12.9774	0.001013	11.481	11.482	213.52	2379.56	2593.08	0.7167	7.3409	8.0576	51
52	13.6305	0.001013	10.963	10.964	217.70	2377.14	2594.84	0.7296	7.3109	8.0405	52
53	14.3116	0.001014	10.472	10.473	221.88	2374.72	2596.60	0.7424	7.2811	8.0235	53
54	15.0215	0.001014	10.006	10.007	226.06	2372.30	2598.35	0.7552	7.2514	8.0066	54
55	15.7614	0.001015	9.5639	9.5649	230.24	2369.87	2600.11	0.7680	7.2219	7.9899	55
56	16.5322	0.001015	9.1444	9.1454	234.42	2367.44	2601.86	0.7807	7.1926	7.9733	56
57	17.3350	0.001016	8.7461	8.7471	238.61	2365.01	2603.61	0.7934	7.1634	7.9568	57
58	18.1708	0.001016	8.3678	8.3688	242.79	2362.57	2605.36	0.8060	7.1344	7.9405	58
59	19.0407	0.001017	8.0083	8.0093	246.97	2360.13	2607.10	0.8186	7.1056	7.9243	59
60	19.9458	0.001017	7.6666	7.6677	251.15	2357.69	2608.85	0.8312	7.0770	7.9082	60
61	20.8873	0.001018	7.3418	7.3428	255.34	2355.25	2610.58	0.8438	7.0485	7.8922	61
62	21.8664	0.001018	7.0328	7.0338	259.52	2352.80	2612.32	0.8563	7.0201	7.8764	62
63	22.8842	0.001019	6.7389	6.7399	263.71	2350.35	2614.05	0.8687	6.9919	7.8607	63
64	23.9421	0.001019	6.4591	6.4601	267.89	2347.89	2615.78	0.8811	6.9639	7.8451	64
65	25.0411	0.001020	6.1928	6.1938	272.08	2345.43	2617.51	0.8935	6.9361	7.8296	65
66	26.1827	0.001020	5.9392	5.9402	276.27	2342.97	2619.23	0.9059	6.9083	7.8142	66
67	27.3680	0.001021	5.6976	5.6986	280.45	2340.50	2620.96	0.9182	6.8808	7.7990	67
68	28.5986	0.001022	5.4674	5.4684	284.64	2338.03	2622.67	0.9305	6.8534	7.7839	68
69	29.8756	0.001022	5.2479	5.2490	288.83	2335.56	2624.39	0.9428	6.8261	7.7689	69

Table 3 Thermodynamic Properties of Water at Saturation (*Concluded*)

Temp., °C t	Absolute Pressure p_{ws}, kPa	Specific Volume, m^3/kg_w			Specific Enthalpy, kJ/kg_w			Specific Entropy, $kJ/(kg_w \cdot K)$			Temp., °C t
		Sat. Solid v_i/v_f	Evap. v_{ig}/v_{fg}	Sat. Vapor v_g	Sat. Solid h_i/h_f	Evap. h_{ig}/h_{fg}	Sat. Vapor h_g	Sat. Solid s_i/s_f	Evap. s_{ig}/s_{fg}	Sat. Vapor s_g	
70	31.2006	0.001023	5.0387	5.0397	293.02	2333.08	2626.10	0.9550	6.7990	7.7540	70
71	32.5750	0.001023	4.8392	4.8402	297.21	2330.60	2627.81	0.9672	6.7720	7.7392	71
72	34.0001	0.001024	4.6488	4.6498	301.40	2328.11	2629.51	0.9793	6.7452	7.7245	72
73	35.4775	0.001025	4.4671	4.4681	305.59	2325.62	2631.21	0.9915	6.7185	7.7100	73
74	37.0088	0.001025	4.2937	4.2947	309.78	2323.13	2632.91	1.0035	6.6920	7.6955	74
75	38.5954	0.001026	4.1281	4.1291	313.97	2320.63	2634.60	1.0156	6.6656	7.6812	75
76	40.2389	0.001026	3.9699	3.9709	318.17	2318.13	2636.29	1.0276	6.6393	7.6669	76
77	41.9409	0.001027	3.8188	3.8198	322.36	2315.62	2637.98	1.0396	6.6132	7.6528	77
78	43.7031	0.001028	3.6743	3.6754	326.56	2313.11	2639.66	1.0516	6.5872	7.6388	78
79	45.5271	0.001028	3.5363	3.5373	330.75	2310.59	2641.34	1.0635	6.5613	7.6248	79
80	47.4147	0.001029	3.4042	3.4053	334.95	2308.07	2643.01	1.0754	6.5356	7.6110	80
81	49.3676	0.001030	3.2780	3.2790	339.15	2305.54	2644.68	1.0873	6.5100	7.5973	81
82	51.3875	0.001030	3.1572	3.1582	343.34	2303.01	2646.35	1.0991	6.4846	7.5837	82
83	53.4762	0.001031	3.0415	3.0426	347.54	2300.47	2648.01	1.1109	6.4592	7.5701	83
84	55.6355	0.001032	2.9309	2.9319	351.74	2297.93	2649.67	1.1227	6.4340	7.5567	84
85	57.8675	0.001032	2.8249	2.8259	355.95	2295.38	2651.33	1.1344	6.4090	7.5434	85
86	60.1738	0.001033	2.7234	2.7244	360.15	2292.83	2652.98	1.1461	6.3840	7.5301	86
87	62.5565	0.001034	2.6262	2.6272	364.35	2290.27	2654.62	1.1578	6.3592	7.5170	87
88	65.0174	0.001035	2.5330	2.5341	368.56	2287.70	2656.26	1.1694	6.3345	7.5039	88
89	67.5587	0.001035	2.4437	2.4448	372.76	2285.14	2657.90	1.1811	6.3099	7.4909	89
90	70.1824	0.001036	2.3581	2.3591	376.97	2282.56	2659.53	1.1927	6.2854	7.4781	90
91	72.8904	0.001037	2.2760	2.2771	381.18	2279.98	2661.16	1.2042	6.2611	7.4653	91
92	75.6849	0.001037	2.1973	2.1983	385.38	2277.39	2662.78	1.2158	6.2368	7.4526	92
93	78.5681	0.001038	2.1217	2.1228	389.59	2274.80	2664.39	1.2273	6.2127	7.4400	93
94	81.5420	0.001039	2.0492	2.0502	393.81	2272.20	2666.01	1.2387	6.1887	7.4275	94
95	84.6089	0.001040	1.9796	1.9806	398.02	2269.60	2667.61	1.2502	6.1648	7.4150	95
96	87.7711	0.001040	1.9128	1.9138	402.23	2266.98	2669.22	1.2616	6.1411	7.4027	96
97	91.0308	0.001041	1.8486	1.8497	406.45	2264.37	2670.81	1.2730	6.1174	7.3904	97
98	94.3902	0.001042	1.7870	1.7880	410.66	2261.74	2672.40	1.2844	6.0938	7.3782	98
99	97.8518	0.001043	1.7277	1.7288	414.88	2259.11	2673.99	1.2957	6.0704	7.3661	99
100	101.4180	0.001043	1.6708	1.6719	419.10	2256.47	2675.57	1.3070	6.0471	7.3541	100
101	105.0910	0.001044	1.6161	1.6171	423.32	2253.83	2677.15	1.3183	6.0238	7.3421	101
102	108.8735	0.001045	1.5635	1.5645	427.54	2251.18	2678.72	1.3296	6.0007	7.3303	102
103	112.7678	0.001046	1.5129	1.5140	431.76	2248.52	2680.28	1.3408	5.9777	7.3185	103
104	116.7765	0.001047	1.4642	1.4653	435.99	2245.85	2681.84	1.3520	5.9548	7.3068	104
105	120.9021	0.001047	1.4174	1.4185	440.21	2243.18	2683.39	1.3632	5.9320	7.2951	105
106	125.1472	0.001048	1.3724	1.3734	444.44	2240.50	2684.94	1.3743	5.9092	7.2836	106
107	129.5145	0.001049	1.3290	1.3301	448.67	2237.81	2686.48	1.3854	5.8866	7.2721	107
108	134.0065	0.001050	1.2873	1.2883	452.90	2235.12	2688.02	1.3965	5.8641	7.2607	108
109	138.6261	0.001051	1.2471	1.2481	457.13	2232.41	2689.55	1.4076	5.8417	7.2493	109
110	143.3760	0.001052	1.2083	1.2094	461.36	2229.70	2691.07	1.4187	5.8194	7.2380	110
111	148.2588	0.001052	1.1710	1.1721	465.60	2226.99	2692.58	1.4297	5.7972	7.2268	111
112	153.2775	0.001053	1.1351	1.1362	469.83	2224.26	2694.09	1.4407	5.7750	7.2157	112
113	158.4348	0.001054	1.1005	1.1015	474.07	2221.53	2695.60	1.4517	5.7530	7.2047	113
114	163.7337	0.001055	1.0671	1.0681	478.31	2218.78	2697.09	1.4626	5.7310	7.1937	114
115	169.1770	0.001056	1.0349	1.0359	482.55	2216.03	2698.58	1.4735	5.7092	7.1827	115
116	174.7678	0.001057	1.0038	1.0049	486.80	2213.27	2700.07	1.4844	5.6874	7.1719	116
117	180.5090	0.001058	0.9739	0.9750	491.04	2210.51	2701.55	1.4953	5.6658	7.1611	117
118	186.4036	0.001059	0.9450	0.9461	495.29	2207.73	2703.02	1.5062	5.6442	7.1504	118
119	192.4547	0.001059	0.9171	0.9182	499.53	2204.94	2704.48	1.5170	5.6227	7.1397	119
120	198.6654	0.001060	0.8902	0.8913	503.78	2202.15	2705.93	1.5278	5.6013	7.1291	120
122	211.5782	0.001062	0.8392	0.8403	512.29	2196.53	2708.82	1.5494	5.5587	7.1081	122
124	225.1676	0.001064	0.7916	0.7927	520.80	2190.88	2711.69	1.5708	5.5165	7.0873	124
126	239.4597	0.001066	0.7472	0.7483	529.32	2185.19	2714.52	1.5922	5.4746	7.0668	126
128	254.4813	0.001068	0.7058	0.7068	537.85	2179.47	2717.32	1.6134	5.4330	7.0465	128
130	270.2596	0.001070	0.6670	0.6681	546.39	2173.70	2720.09	1.6346	5.3918	7.0264	130
132	286.8226	0.001072	0.6308	0.6318	554.93	2167.89	2722.83	1.6557	5.3508	7.0066	132
134	304.1989	0.001074	0.5969	0.5979	563.49	2162.04	2725.53	1.6767	5.3102	6.9869	134
136	322.4175	0.001076	0.5651	0.5662	572.05	2156.15	2728.20	1.6977	5.2698	6.9675	136
138	341.5081	0.001078	0.5353	0.5364	580.62	2150.22	2730.84	1.7185	5.2298	6.9483	138
140	361.5010	0.001080	0.5074	0.5085	589.20	2144.24	2733.44	1.7393	5.1900	6.9293	140
142	382.4271	0.001082	0.4813	0.4823	597.79	2138.22	2736.01	1.7600	5.1505	6.9105	142
144	404.3178	0.001084	0.4567	0.4577	606.39	2132.15	2738.54	1.7806	5.1112	6.8918	144
146	427.2053	0.001086	0.4336	0.4346	615.00	2126.04	2741.04	1.8011	5.0723	6.8734	146
148	451.1220	0.001088	0.4118	0.4129	623.62	2119.88	2743.50	1.8216	5.0335	6.8551	148
150	476.1014	0.001091	0.3914	0.3925	632.25	2113.67	2745.92	1.8420	4.9951	6.8370	150
152	502.1771	0.001093	0.3722	0.3733	640.89	2107.41	2748.30	1.8623	4.9569	6.8191	152
154	529.3834	0.001095	0.3541	0.3552	649.55	2101.10	2750.64	1.8825	4.9189	6.8014	154
156	557.7555	0.001097	0.3370	0.3381	658.21	2094.74	2752.95	1.9027	4.8811	6.7838	156
158	587.3287	0.001100	0.3209	0.3220	666.89	2088.32	2755.21	1.9228	4.8436	6.7664	158
160	618.1392	0.001102	0.3057	0.3068	675.57	2081.86	2757.43	1.9428	4.8063	6.7491	160

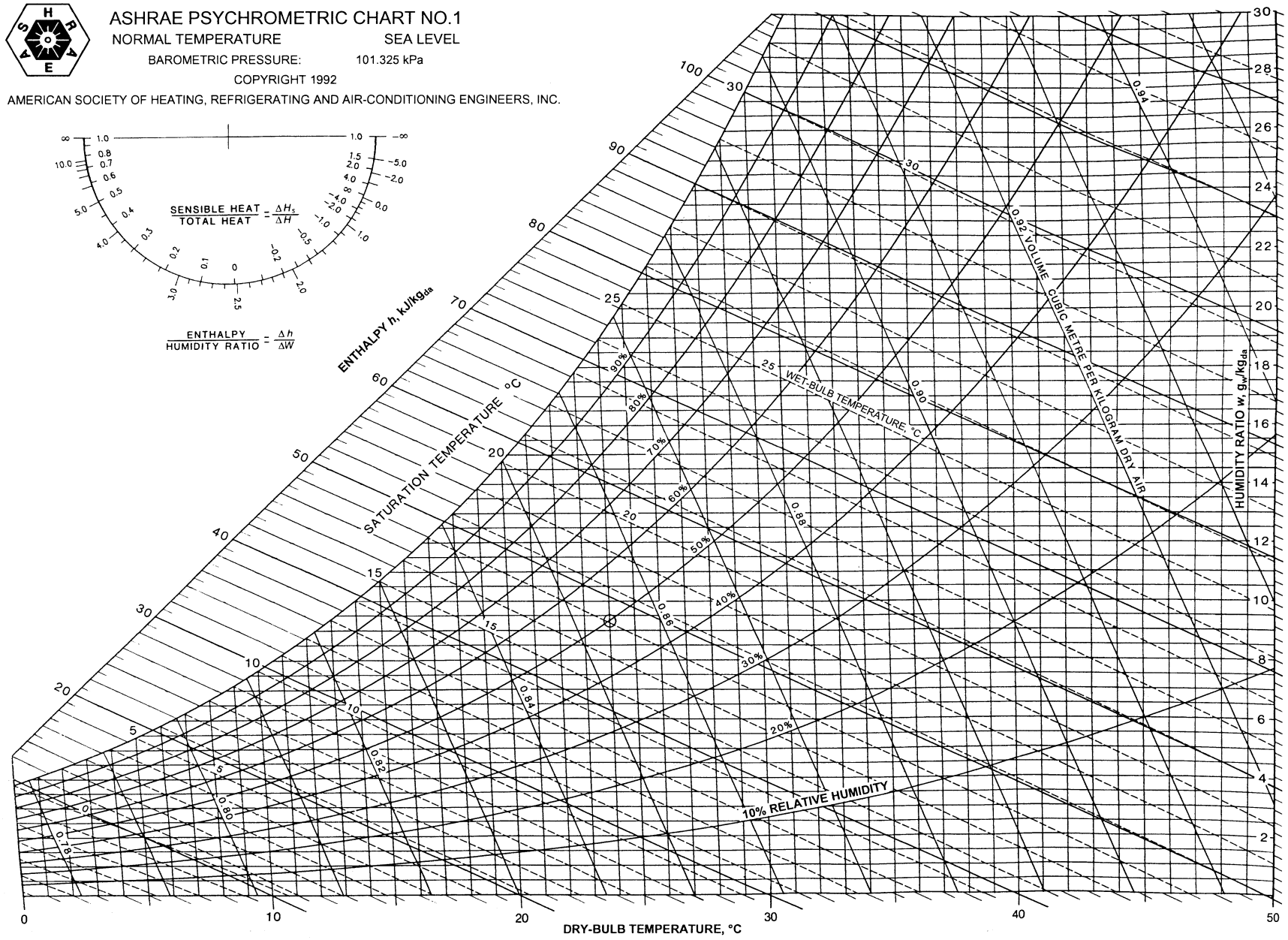


Fig. 1 ASHRAE Psychrometric Chart No. 1