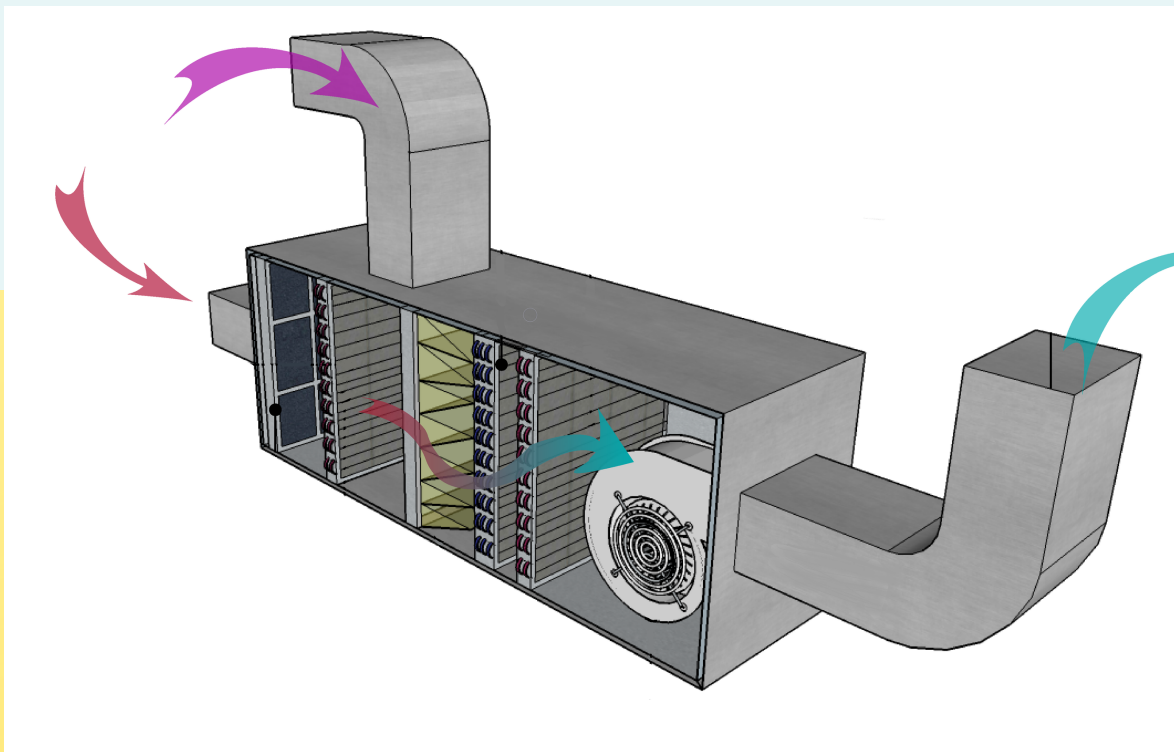


# HVAC Psychrometry, Air Handling System and Duct Selection

Summary, Charts and Formula List

---





---

**1**

**INTRODUCTION TO AIR  
HANDLING SYSTEM**

---

**4**

**SPACE COOLING LOAD**

---

**9**

**PSYCHROMETRY**

---

**14**

**AHU AND DUCT SELECTION**

---

**16**

**PSYCHROMETRY CHART**

Simplified  
Metric Units  
Imperial Units

---

**19**

**FRICITION LOSS CHART, DUCT  
CONVERSION TABLE, DAMPERS  
CHART**

---

**23**

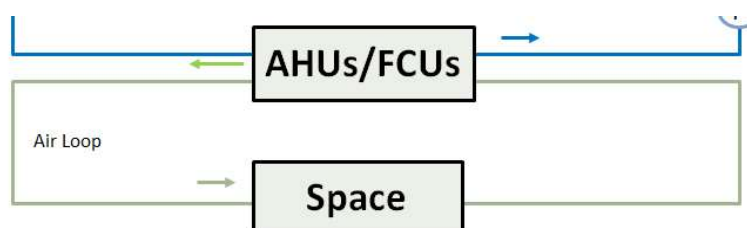
**FORMULA LIST**

# INTRODUCTION TO AIR HANDLING SYSTEM

---

## Air Distribution Systems

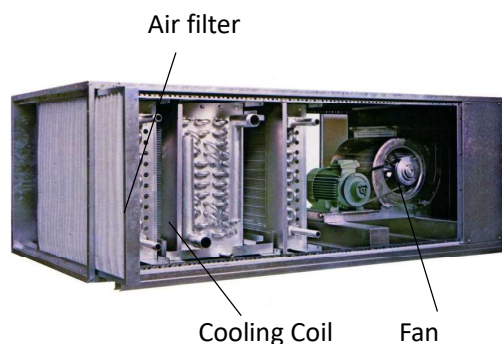
- For a central AC system providing cool air to several spaces, an air distribution system is required
- The main “driver” of the cooled air is
  1. Air Handling Unit (AHU)
  2. Fan Coil Unit (FCU)



## Air Distribution Systems – AHU/FCU

- AHU/FCU consists of a

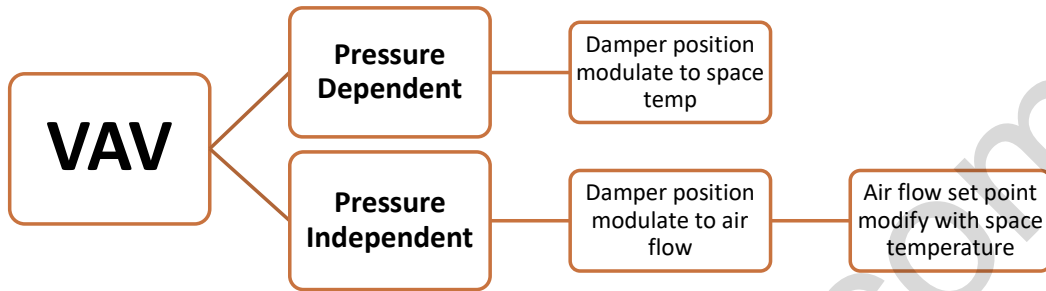
1. Fan
2. Cooling coil
3. Air Filter



### AHU vs FCU major differences

AHU	FCU
1. AHUs are located in <b>plant room</b> separate from or outside the occupied space that they serve.	1. FCUs are located in the <b>ceiling</b> of the occupied space(s) that they serve.
2. Since the chilled water coil (ie. AHU) is located <b>outside</b> the occupied space to be cooled, the space is cooled by the cold air produced outside the space.	2. In an all-water system, the chilled water coil (ie. FCU) is located <b>within</b> the space to be cooled, so the space is cooled by the cold air produced within the space.
3. Maintenance of AHU can thus be carried out without interfering with the tenant's business or operations.	3. Maintenance of FCUs may only be carried out at possible risk of interfering with the tenant's business or operations.
4. A single AHU can serve a reasonably <b>large zone</b> , so a larger fan operated at a lower speed can be provided, resulting in lower sound power level.	4. Several FCUs may be required to serve the same size of zone, so <b>multiple</b> fans operating at various speeds may result in higher sound power level.
5. Fan noise can be largely confined to the AHU room.	5. Fan noise in occupied space may be significant, especially at MED & HI speed.
6. Intake of outdoor air at AHU can be achieved so long as the AHU room has at least 1 external wall for fixed louvres.	6. A separate outdoor air intake system is usually required to distribute OA to the multiple FCUs serving the zone(s).

## Variable Air Volume (VAV) Classification



## Building Management System Schematic

**System Parameters:**

- OA TempSp: 24.0 °C
- OA Temp: 24.4 °C
- Damper On Sp: 1000 ppm
- Damper Off Sp: 700 ppm
- RA CO2: 446 ppm
- RA Temp: 22.7 °C
- RA Hum: 52.2 %
- Smoke: Normal
- Filter Power: Power On
- Filter Status: Clean
- OffCoil Temp: 10.6 °C
- Fan Status: Running
- SA Temp: 13.8 °C
- SA Static: 177 pa
- SA Temp Sp: 13.0 °C
- SA Static Sp: 180 pa
- Flow Rate: 5.57 L/s
- VSD Fbk: 34.9 Hz
- VSD Cmd: 34.5 Hz
- Power: 5.0 kW
- Status: On

**Control Elements:**

- OA Damper: Close
- PCC Vlv Fbk: 17.3 %
- PCC Vlv Cmd: 7.7 %
- CHWR Temp: 11.28 °C
- CHWS Temp: 10.48 °C
- Valve Fbk: 100.0 %
- Valve Cmd: 99.4 %

**System Status:**

- Schedule: On
- Occupied Mode: Auto
- Switch Mode: Auto
- Trip Alarm: Normal
- Mismatch: Normal
- Alarm Reset: Normal
- System Alarm: Normal
- Maintenance: Off

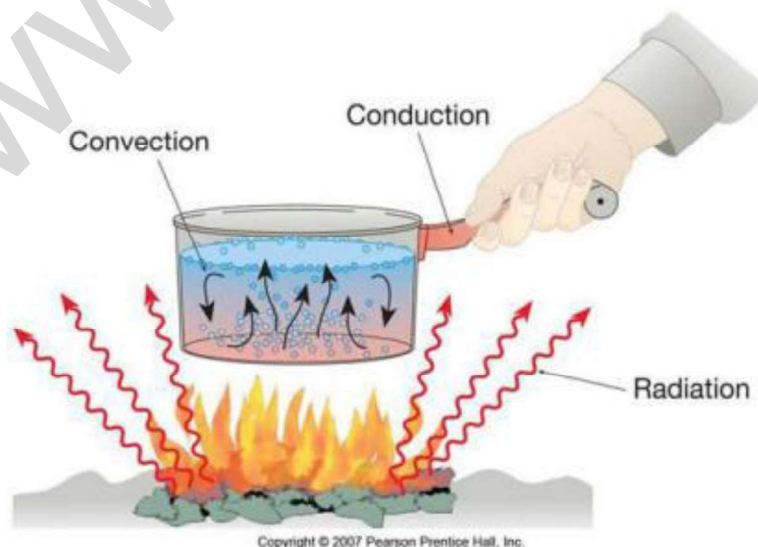
**Notes:**

- Pre-cool coil valve controlled by outside air temperature
- Chilled water valve controlled by supply air temperature
- Variable speed drive controlled by static pressure

# SPACE COOLING LOAD

---

## Heat Transfer - Conduction, Convection and Radiation



## Heat Transfer by Conduction

- Conduction occurs in a solid, or between objects in physical contact
- Heat is transmitted through collisions between particles through molecular movements (vibrations and rotations)
- Governed by Fourier's Law

If the conduction is primarily along one dimension, say  $x$ , then it is stated that

$$\dot{Q} = -kA \frac{dT}{dx}$$

where  $\dot{Q}$  = heat transfer rate (W)  
 $k$  = thermal conductivity (W/m.K)  
 $A$  = area perpendicular to heat flow (m<sup>2</sup>)  
 $\frac{dT}{dx}$  = temperature gradient (K/m)



Joseph Fourier

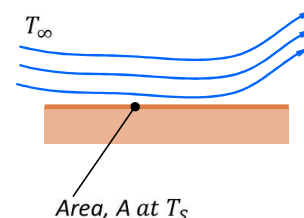
## Heat Transfer by Convection

- Governed by Newton's Law of cooling

The rate of convective heat transfer,  $\dot{Q}$ , is defined by Newton as:

$$\dot{Q} = hA(T_S - T_\infty) \quad (\text{W})$$

where  $h$  = heat transfer coefficient (W/m<sup>2</sup>.K)  
 $A$  = area (m<sup>2</sup>)  
 $T_S$  = temperature of surface (K)  
 $T_\infty$  = temperature of surrounding fluid (K)



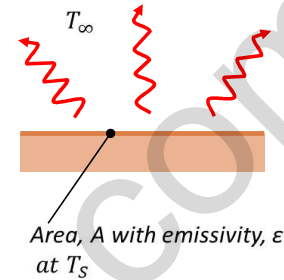
## Heat Transfer by Radiation

- Radiation to or from an object occurs through the absorption or emission of electromagnetic radiation
- The only mechanism able to transfer heat through vacuum

The rate of radiation heat transfer,  $\dot{Q}$ , is defined as:

$$\dot{Q} = \varepsilon \sigma A (T_S^4 - T_\infty^4) \quad (\text{W})$$

where  $\varepsilon$  = emissivity of surface ( $0 < \varepsilon < 1$ )  
 $\sigma$  = Stefan-Boltzmann constant  
 ( $5.67 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$ )  
 $A$  = area ( $\text{m}^2$ )  
 $T_S$  = temperature of surface (**K**)  
 $T_\infty$  = temperature of surrounding fluid (**K**)



## Heat Gains in a Building Space

- External heat gains:
  - a) Solar radiation through glass
  - b) Conduction through glass
  - c) Conduction through external walls / roof
- Internal heat gains:
  - a) occupants
  - b) lighting
  - c) equipment
  - d) Infiltration heat gain

## Solar Heat Gain (SHG)

- To design for the peak cooling load throughout the year
- Based on assumption that solar heat gain is the dominant heat gain

The total solar heat gain through windows is given by

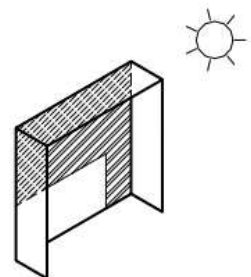
$$TSHG = \sum (SHG \times A_f)$$

where  $TSHG$  = total solar heat gain (W)  
 $SHG$  = solar heat gain (per unit area) ( $W/m^2$ )  
 $A_f$  = total area of windows for each façade ( $m^2$ )

## Factors affecting External Heat Gains

### Building Envelope Design/materials

- Thicker, or tinted glass will result in lower Shading Coefficient ( $SC_1$ ).
- Windows with sun shading devices increases the “shadow area” and reduces heat gained through radiation. ( $SC_2$ )



$$SC = SC_1 \times SC_2$$

$$SC_1 = \frac{SHG \text{ of any glass}}{SHG \text{ through a 3 mm unshaded clear glass}}$$

$$SC_2 = \frac{A_{\text{exposed}} \times I_{\text{Direct rad}} + A \times I_{\text{diffused rad}}}{A \times I_{\text{total rad}}}$$

## Solar Heat Gain Through Glass

- Caused by the sun's radiation passing through the windows
- Radiation causes the temperature of interior surfaces and furnishings to increase, thereby releasing heat

The solar heat gain through a window,  $Q_s$ , is given by

$$Q_s = SHG \times A_w \times SC \times CLF \quad (W)$$

where  $SHG$  = solar heat gain (per unit area) ( $W/m^2$ )  
 $A_w$  = area of window ( $m^2$ )  
 $SC$  = shading coefficient of glass  
 $CLF$  = cooling load factor

To find  $SGH$ , use available weather data such as Table 1.1.

## Conduction Heat Gain Through Envelope

- Caused by temperature difference across outer and inner surface
- Have to consider the heat storage effect (mainly for walls)
- Heat storage effect in glass is considered negligible

The conduction heat gain through a layer of material,  $Q_c$ , is given by

$$Q_c = U \times A_w \times \Delta T \quad (W)$$

where  $U$  = thermal transmittance / U-value of window ( $W/m^2.K$ )  
 $A_w$  = area of window ( $m^2$ )  
 $\Delta T$  = temperature difference between indoor and outdoor air (K)

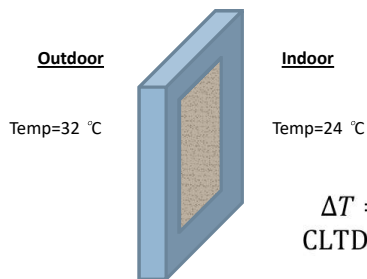
## Conduction Heat Gain Through Envelope

- The cooling load temperature difference (*CLTD*) is used to account for the heat storage effect in the wall / roof materials

The conduction heat gain through a wall / roof,  $Q_c$ , is given by

$$Q_c = U \times A \times CLTD \quad (W)$$

where  $CLTD$  = cooling load temperature difference across wall / roof (K)



$CLTD$  depends on the material of the wall, and the thickness of the wall.

A denser and thicker material will have a better storage effect, thus result in a lower  $CLTD$  (smaller temp difference)

$$\Delta T = 8^{\circ}C$$

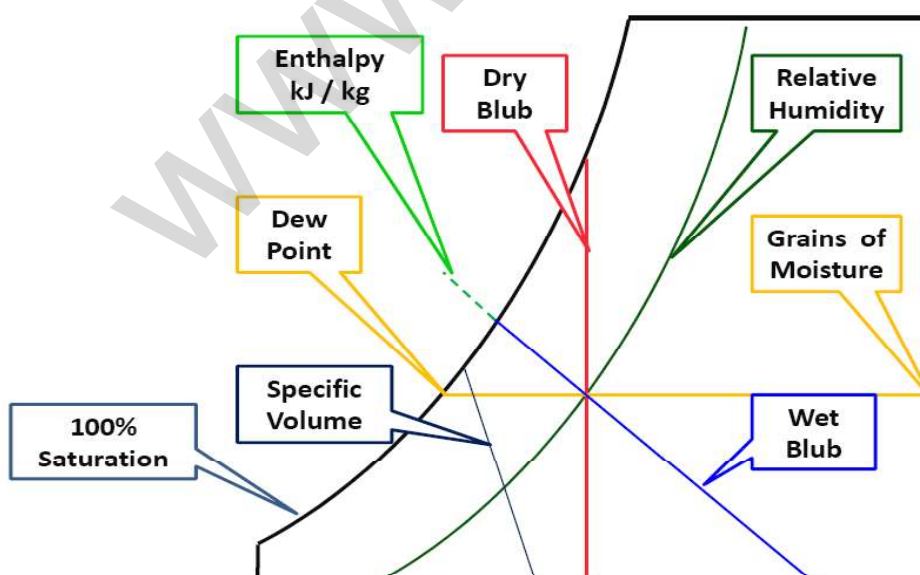
$$CLTD = 6^{\circ}C \text{ to } 15^{\circ}C$$

## PSYCHROMETRY

## Thermophysical Properties of Air

- Dry-bulb temperature,  $T_{DB}$
- Wet-bulb temperature,  $T_{WB}$
- Dew point,  $T_{Dew}$
- Humidity ratio,  $w$
- Relative humidity, RH
- Specific volume,  $v$
- Specific enthalpy,  $h$

## The Psychrometric Chart



## Air Treatment Processes

### Process 0 – 1

- Sensible heating



### Process 0 – 2

- Sensible cooling



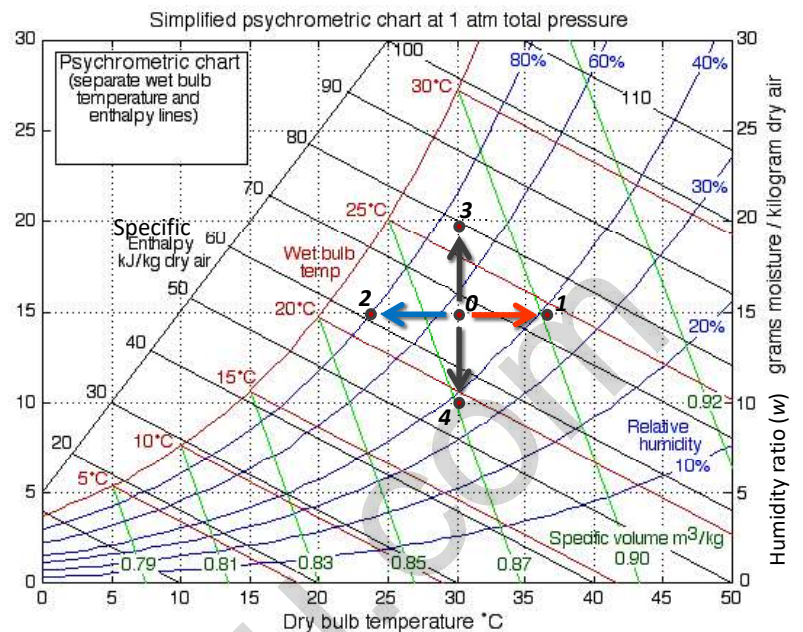
### Process 0 – 3

- Humidification



### Process 0 – 4

- Dehumidification



## Air Mixing Process

- The exact location of the mixed air point can be determined by finding the resultant temp.,  $T_{DB3}$ , from two equations:

$$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$$

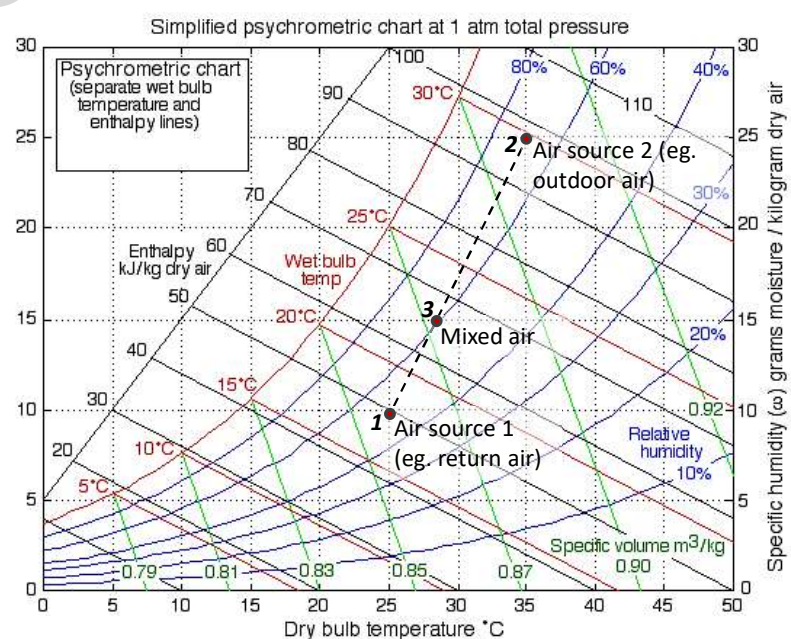
$$\dot{m}_1 T_{DB1} + \dot{m}_2 T_{DB2} = \dot{m}_3 T_{DB3}$$

where

$\dot{m}$  = mass flow rate (kg/s)

$T_{DB}$  = dry bulb temp. (°C)

- Alternatively,  $T_{DB3}$  can be determined if the mixing proportion in **ratio** or **percentage** is known.



## Sensible Heating and Cooling Equation

After a sensible heating or cooling process, the new dry bulb temp.,  $T_{DB'}$ , can be calculated from:

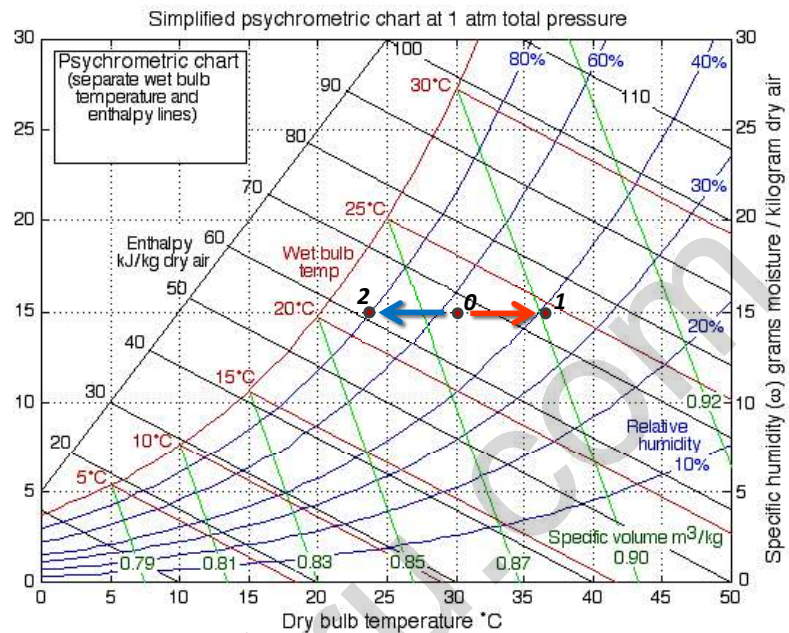
$$Q_S = \dot{m}c_{air}\Delta T \\ = \dot{m}c_{air}(T_{DB} - T_{DB0})$$

where

$Q_S$  = sensible heat transfer (kW)

$\dot{m}$  = mass flow rate of air (kg/s)

$c_{air}$  = specific heat capacity of air (= 1.005 kJ/kg.K)



## Humidification and Dehumidification Equation

After a humidification or dehumidification process, the new humidity ratio,  $w$ , can be found from:

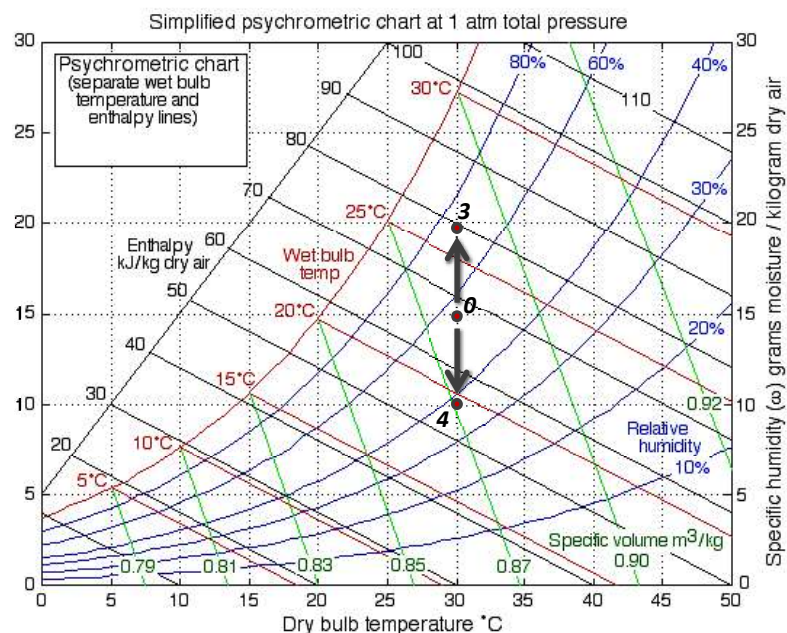
$$Q_L = \dot{m}l_{h2o}\Delta w \\ = \dot{m}l_{h2o}(w - w_0)$$

where

$Q_L$  = latent heat transfer (kW)

$\dot{m}$  = mass flow rate of air (kg/s)

$l_{h2o}$  = latent heat of vaporization of water (= 2,260 kJ/kg)



## Heat Equation

The amount of heat gained or lost by the air can be calculated from:

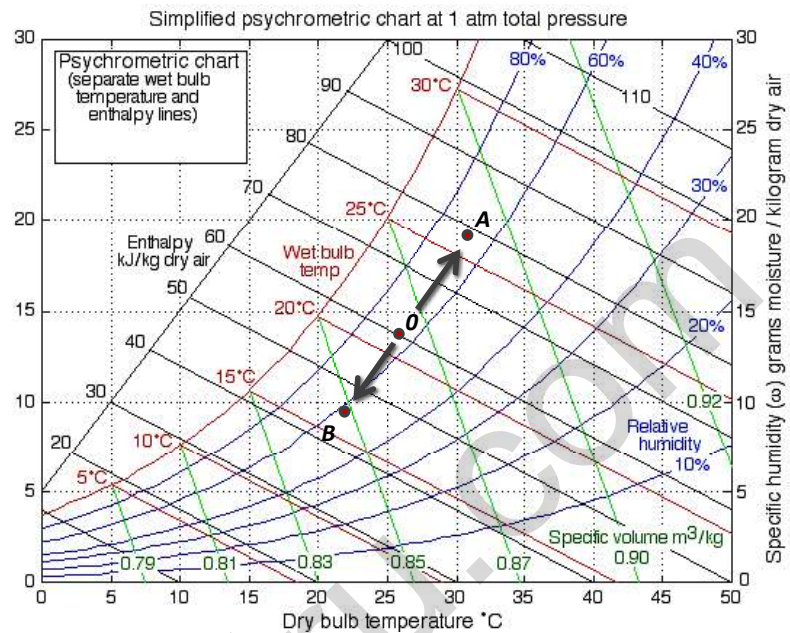
$$Q_T = \dot{m}\Delta h \\ = \dot{m}(h - h_0)$$

where

$Q_T$  = Total heat transfer (kW)

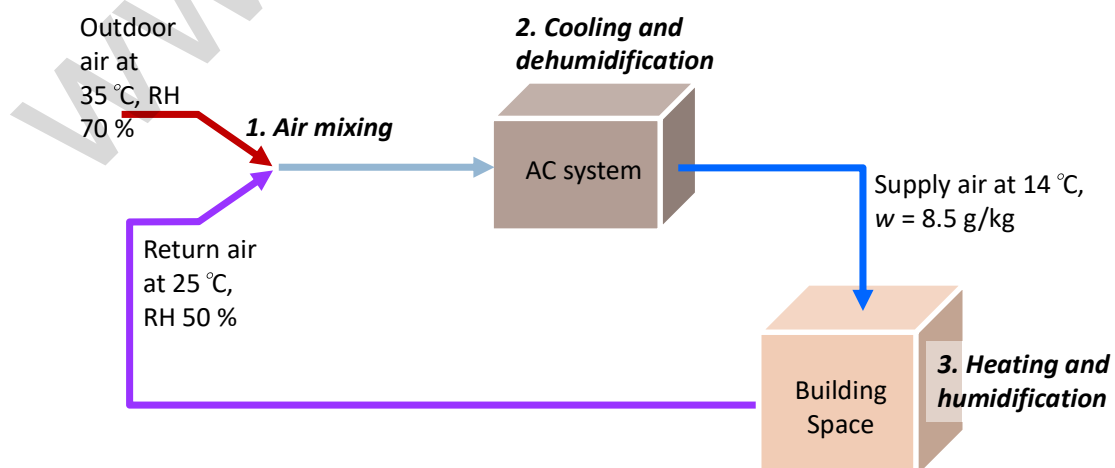
$\dot{m}$  = mass flow rate of air (kg/s)

$h$  = Specific enthalpy of air (kJ/kg)



## Air-Conditioning Processes

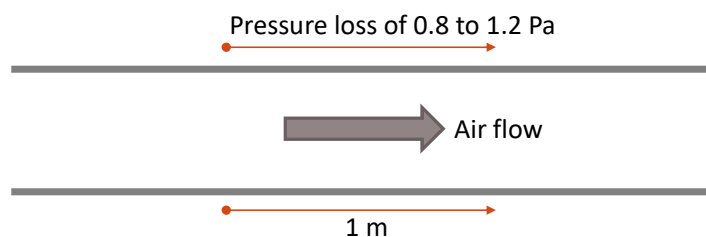
- In the AC system, three air treatment processes take place:



# AHU AND DUCT SELECTION

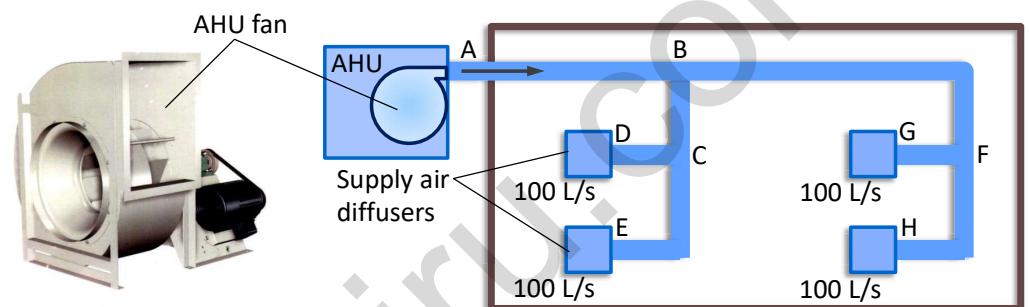
## Equal Friction Method

- A simplified method of duct sizing, named 'equal friction method', is commonly used by the industry
- Based on the assumption that pressure loss per meter remains constant
- The pressure loss per meter is named 'friction loss' and a value of 0.8 to 1.2 Pa/m is normally used.
- In some cases, the friction loss value is deduced from the designed outlet velocity of AHU



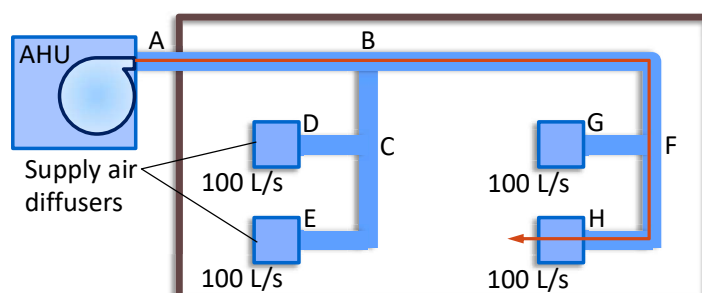
## AHU Selection

- Other than sizing of the air ducting, the other crucial step would be to select suitable AHU fan to deliver the desired airflow.
- Selection of AHU is largely based on two requirements:
  - 1) Air flow rate
  - 2) Cooling Capacity
- The air flow rate and cooling capacity are usually determined using specialized software such as E20 or HAP.

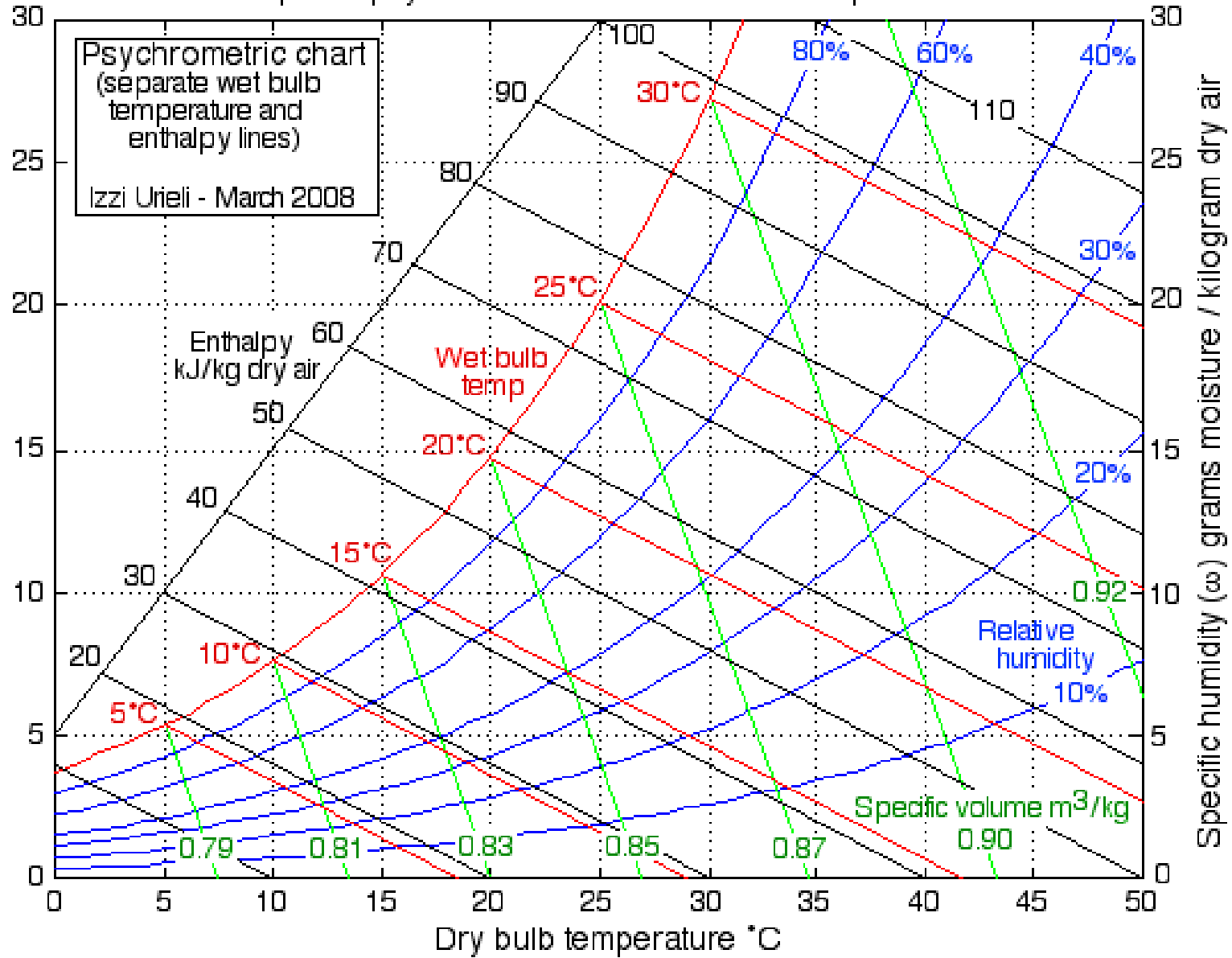


## External Static Pressure Loss Calculation

- In the calculation of the total pressure loss, the air flow stream with the **largest pressure loss** has to be considered.
- For example, amongst flow streams ABCD, ABCE, ABFG and ABFH, it is likely that **ABFH** will have the largest pressure loss.
- Along ABFH, the pressure losses due to friction, junctions, elbows and the diffuser must be accounted for.



Simplified psychrometric chart at 1 atm total pressure

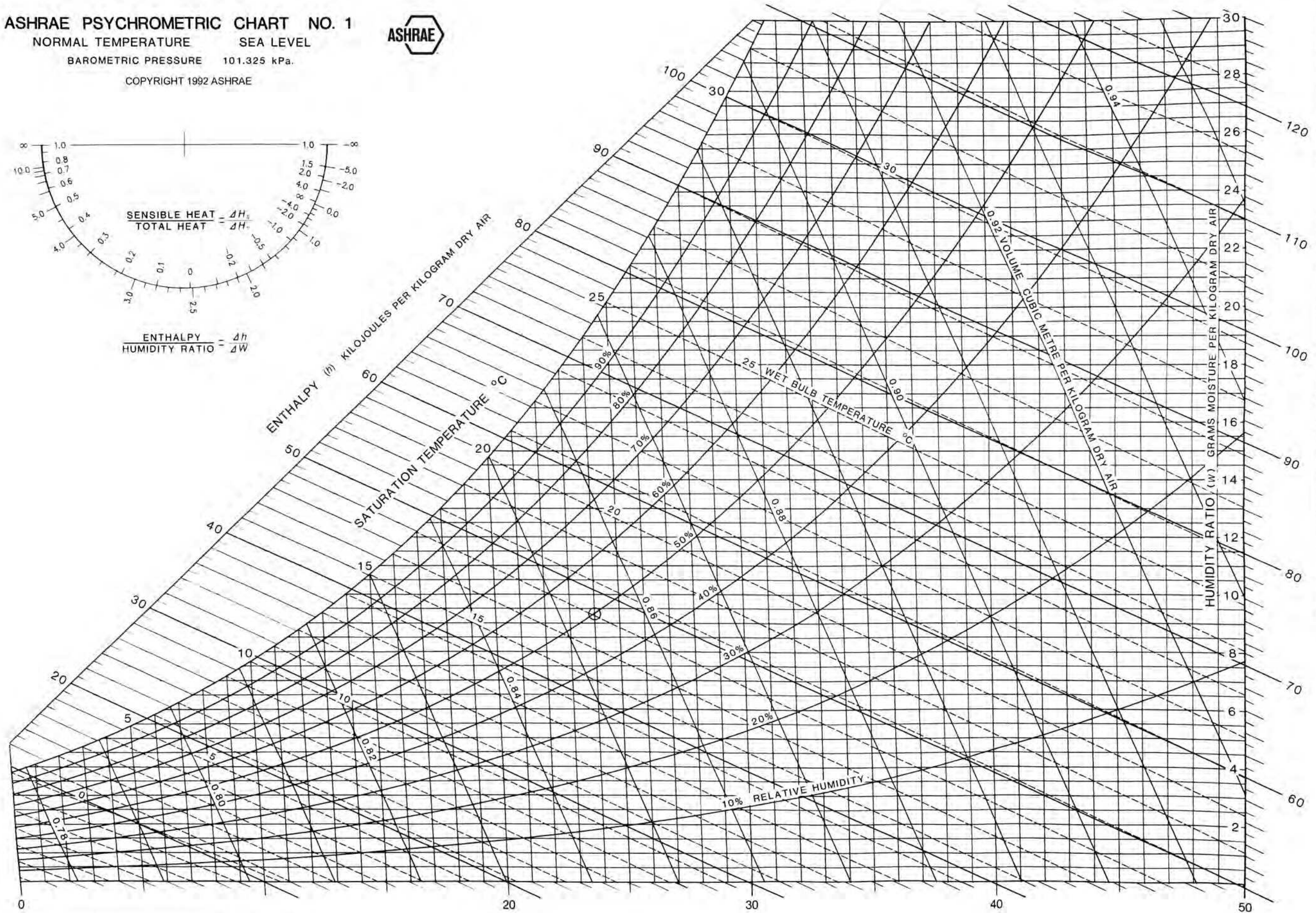
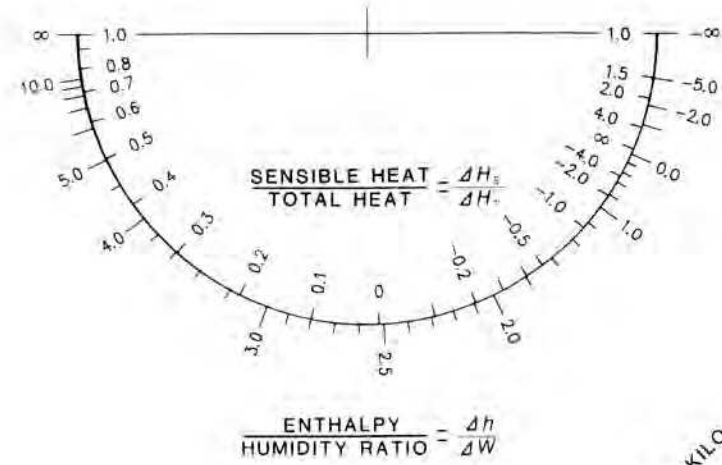


# ASHRAE PSYCHROMETRIC CHART NO. 1

NORMAL TEMPERATURE SEA LEVEL

BAROMETRIC PRESSURE 101.325 kPa.

COPYRIGHT 1992 ASHRAE





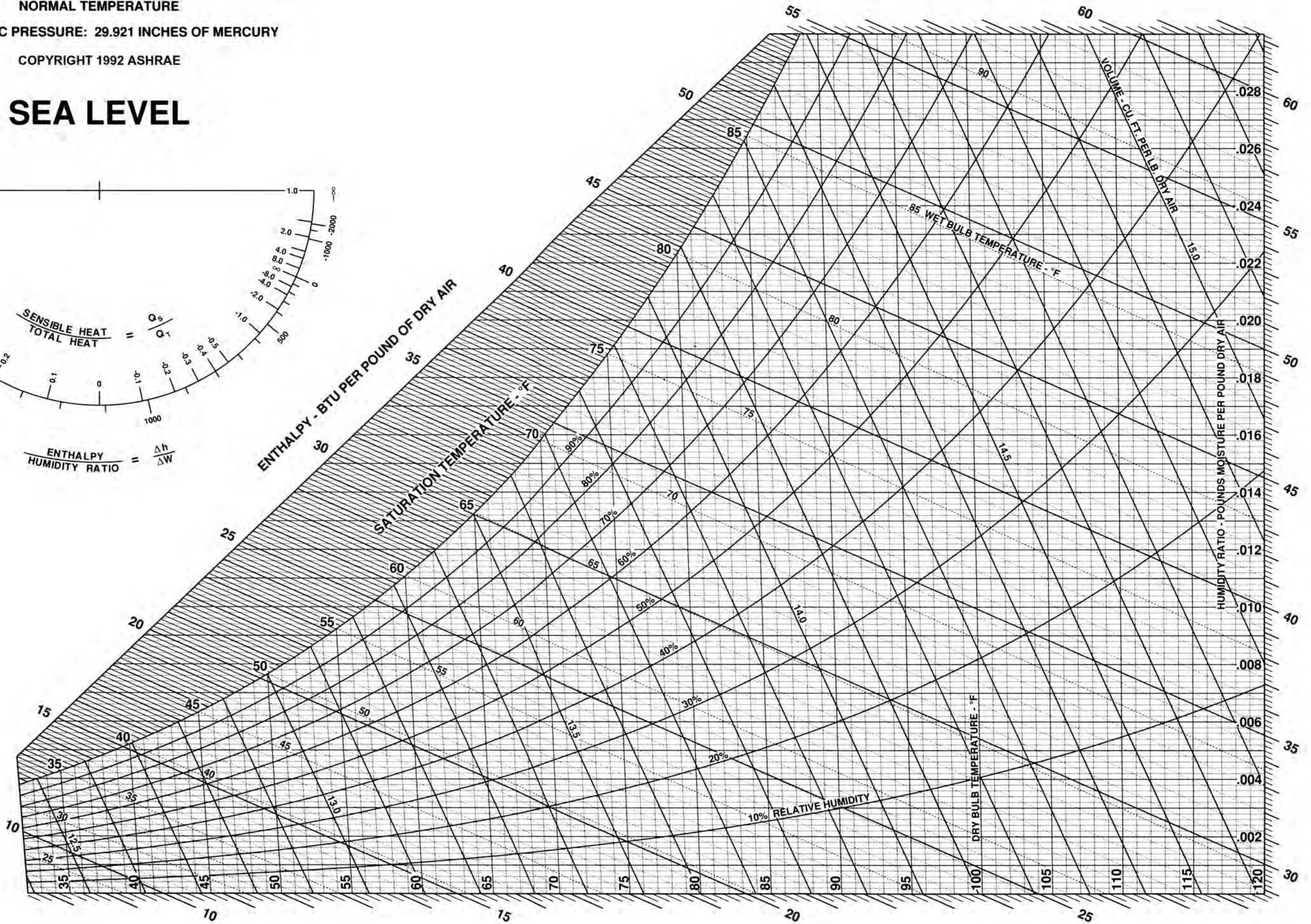
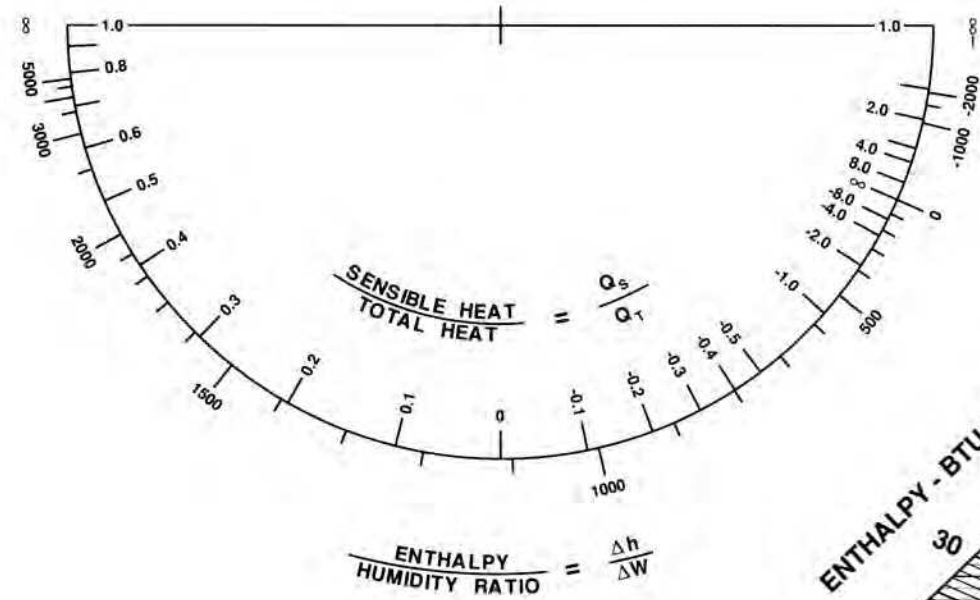
# ASHRAE PSYCHROMETRIC CHART NO. 1

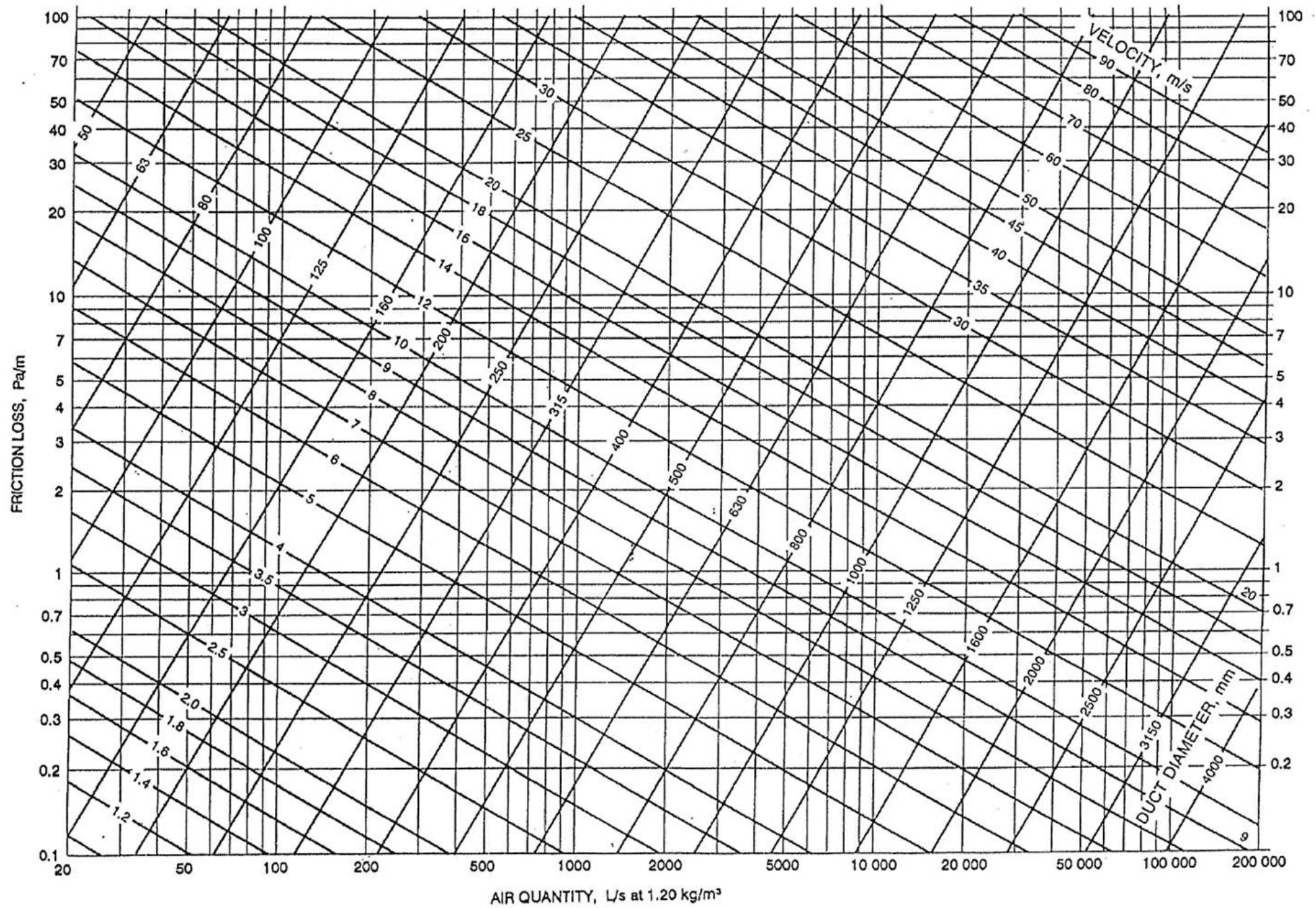
NORMAL TEMPERATURE

BAROMETRIC PRESSURE: 29.921 INCHES OF MERCURY

COPYRIGHT 1992 ASHRAE

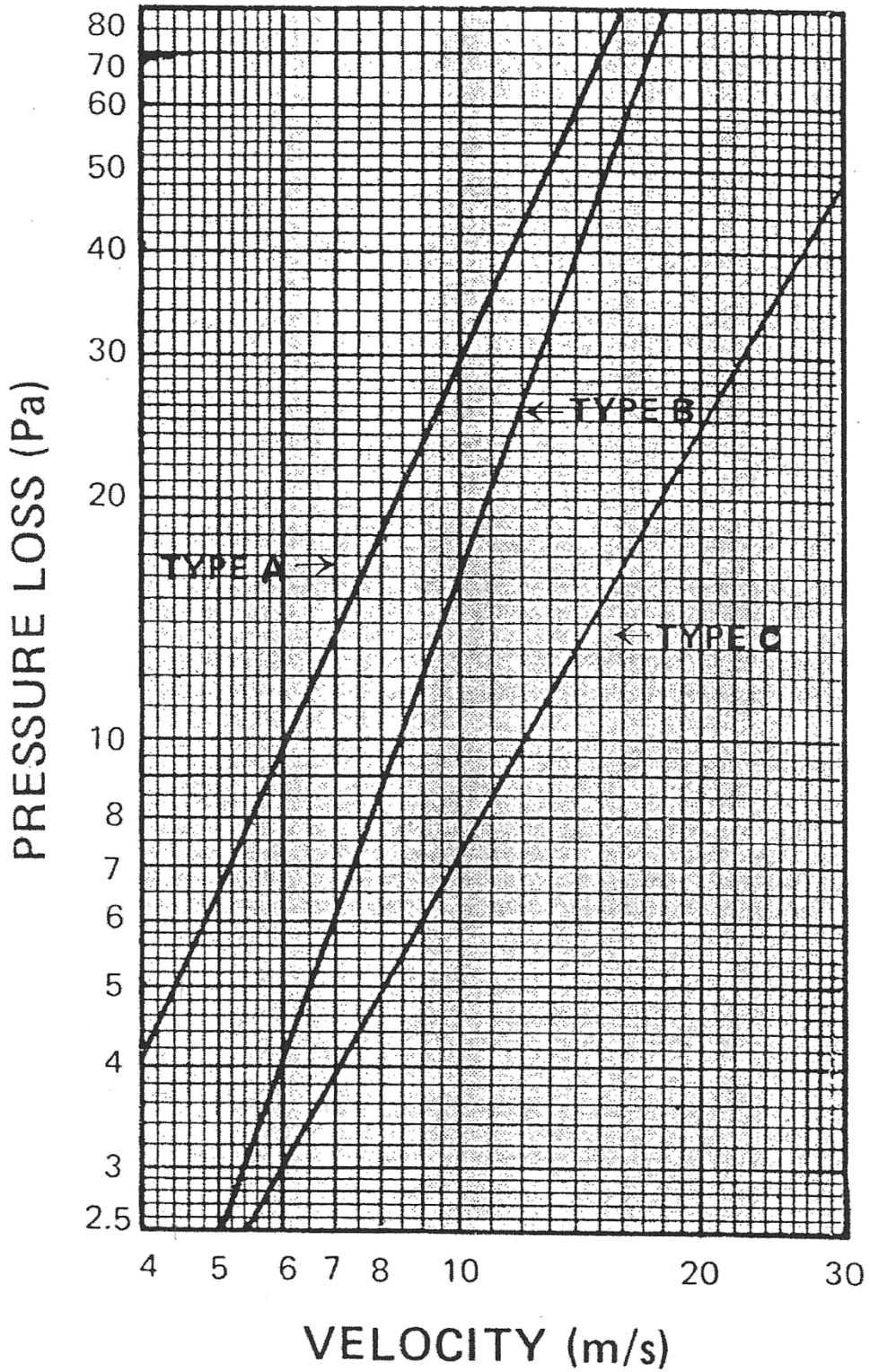
## SEA LEVEL



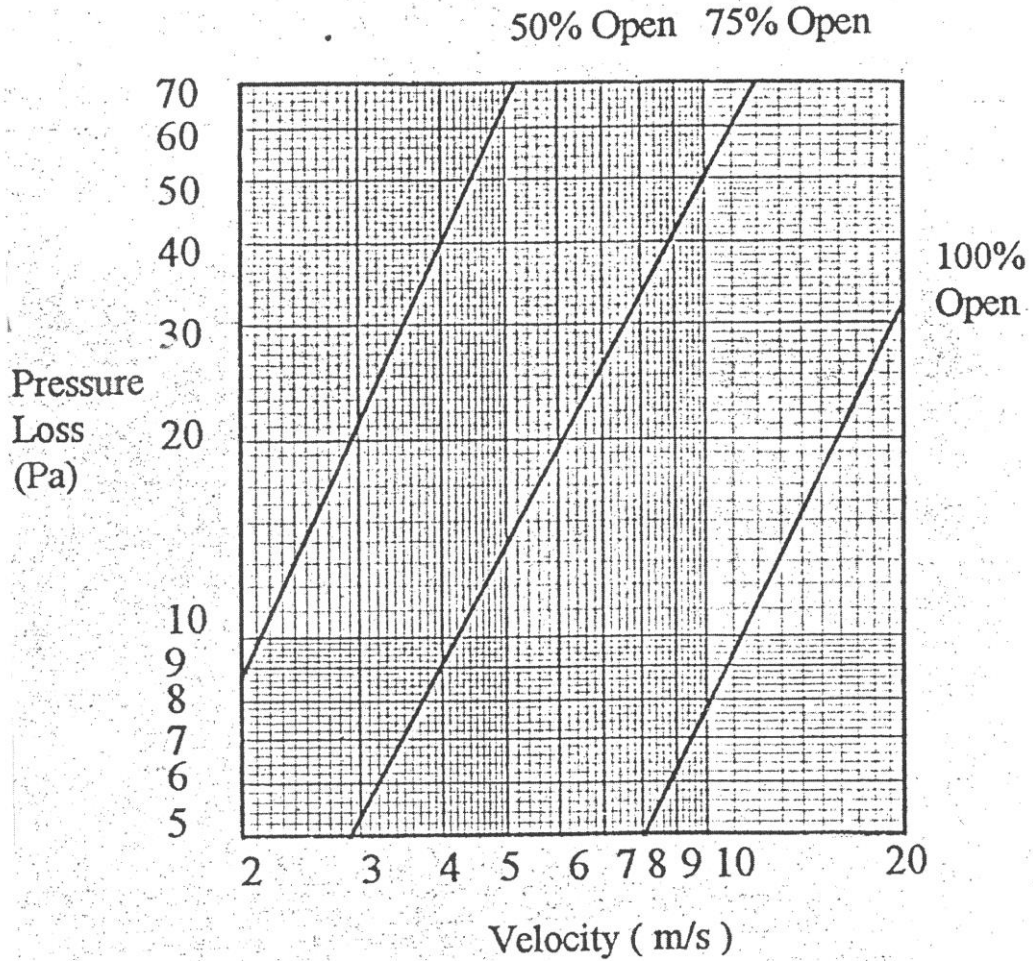


Length of Other Side of Rect. Duct	Length of One Side of Rectangular Duct (mm)																			
	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800	900
	Equivalent Round Duct Diameter (mm)																			
100	109																			
125	122	137																		
150	133	150	164																	
175	143	161	177	191																
200	152	172	189	204	219															
225	161	181	200	216	232	246														
250	169	190	210	228	244	259	273													
275	176	199	220	238	256	272	287	301												
300	183	207	229	248	266	283	299	314	328											
350	195	222	245	267	286	305	322	339	354	383										
400	207	235	260	283	305	325	343	361	378	409	437									
450	217	247	274	299	321	343	363	382	400	433	464	492								
500	227	258	287	313	337	360	381	401	420	455	488	518	547							
550	236	269	299	326	352	375	398	419	439	477	511	543	573	601						
600	245	279	310	339	365	390	414	436	457	496	533	567	598	628	656					
650	253	289	321	351	378	404	429	452	474	515	553	589	622	653	683	711				
700	261	298	331	362	391	418	443	467	490	533	573	610	644	677	708	737	765			
750	268	306	341	373	402	430	457	482	506	550	592	630	666	700	732	763	792	820		
800	275	314	350	383	414	442	470	496	520	567	609	649	687	722	755	787	818	847	875	
900	289	330	367	402	435	465	494	522	548	597	643	686	726	763	799	833	866	897	927	984
1000	301	344	384	420	454	486	517	546	574	626	674	719	762	802	840	876	911	944	976	1037
1100	313	358	399	437	473	506	538	569	598	652	703	751	795	838	878	916	953	988	1022	1086
1200	324	370	413	453	490	525	558	590	620	677	731	780	827	872	914	954	993	1030	1066	1133
1300	334	382	426	468	506	543	577	610	642	701	757	808	857	904	948	990	1031	1069	1107	1177
1400	344	394	439	482	522	559	595	629	662	724	781	835	886	934	980	1024	1066	1107	1146	1220
1500	353	404	452	495	536	575	612	648	681	745	805	860	913	963	1011	1057	1100	1143	1183	1260
1600	362	415	463	508	551	591	629	665	700	766	827	885	939	991	1041	1088	1133	1177	1219	1298
1700	371	425	475	521	564	605	644	682	718	785	849	908	964	1018	1069	1118	1164	1209	1253	1335
1800	379	434	485	533	577	619	660	698	735	804	869	930	988	1043	1096	1146	1195	1241	1286	1371
1900	387	444	496	544	590	663	674	713	751	823	889	952	1012	1068	1122	1174	1224	1271	1318	1405
2000	395	453	506	555	602	646	688	728	767	840	908	973	1034	1092	1147	1200	1252	1301	1348	1438
2100	402	461	516	566	614	659	702	743	782	857	927	993	1055	1115	1172	1226	1279	1329	1378	1470
2200	410	470	525	577	625	671	715	757	797	874	945	1013	1076	1137	1195	1251	1305	1356	1406	1501
2300	417	478	534	587	636	683	728	771	812	890	963	1031	1097	1159	1218	1275	1330	1383	1434	1532
2400	424	486	543	597	647	695	740	784	826	905	980	1050	1116	1180	1241	1299	1355	1409	1461	1561
2500	430	494	552	606	658	706	753	797	840	920	996	1068	1136	1200	1262	1322	1379	1434	1488	1589
2600	437	501	560	616	668	717	764	810	853	935	1012	1085	1154	1220	1283	1344	1402	1459	1513	1617
2700	443	509	569	625	678	728	776	822	866	950	1028	1102	1173	1240	1304	1366	1425	1483	1538	1644
2800	450	516	577	634	688	738	787	834	879	964	1043	1119	1190	1259	1324	1387	1447	1506	1562	1670
2900	456	523	585	643	697	749	798	845	891	977	1058	1135	1208	1277	1344	1408	1469	1529	1586	1696

# Fire Damper Pressure Loss Chart – Reference



VAV Pressure Loss Chart – Reference



# Formula List

## Formulas:

- |  |   |
|--|---|
| <ol style="list-style-type: none"> <li>1. Conduction heat transfer:</li> <li>2. Convection heat transfer:</li> <li>3. Radiation heat transfer:</li> <li>4. Total Solar Heat Gain through windows:</li> <li>5. Shading Coefficient:</li> </ol>  | $\dot{Q} = -kA \frac{dT}{dx}$ $\dot{Q} = hA(T_S - T_\infty)$ $\dot{Q} = \varepsilon\sigma A(T_S^4 - T_\infty^4)$ $TSHG = \sum(SHG \times A_f)$ $SC = SC_1 \times SC_2$ $SC_1 = \frac{SHG \text{ of any glass}}{SHG \text{ through a 3 mm unshaded clear glass}}$ $SC_2 = \frac{A_{exposed} \times I_{Direct \text{ rad}} + A \times I_{dif fused \text{ rad}}}{A \times I_{total \text{ rad}}}$ |
| <ol style="list-style-type: none"> <li>6. Solar Heat Gain through windows:</li> <li>7. Conduction Heat Gain through material:</li> <li>8. Conduction Heat Gain through wall:</li> <li>9. Air mixing process:               <ol style="list-style-type: none"> <li>a. Mass conservation</li> <li>b. Energy conservation (in terms of DB temperature)</li> <li>c. Energy conservation (in terms of humidity ratio)</li> <li>d. Energy conservation (in terms of enthalpy)</li> </ol> </li> </ol> | $Q_S = SHG \times A_w \times SC \times CLF$ $Q_C = U \times A_w \times \Delta T$ $Q_C = U \times A \times CLTD$ $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$ $\dot{m}_1 T_{DB1} + \dot{m}_2 T_{DB2} = \dot{m}_3 T_{DB3}$ $\dot{m}_1 \omega_1 + \dot{m}_2 \omega_2 = \dot{m}_3 \omega_3$ $\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$  |
| <ol style="list-style-type: none"> <li>10. Sensible heat transfer from air at cooling coil</li> <li>11. Latent heat transfer from air at cooling coil</li> <li>12. Sensible Heat Ratio</li> <li>13. Total heat transfer from air at cooling coil</li> <li>14. Coil Bypass Factor:</li> <li>15. Condensate mass:</li> </ol>   | $\dot{Q}_S = \dot{m} c_{air} (\Delta T)$ $\dot{Q}_L = \dot{m} l_{h_2O} (\Delta \omega)$ $SHR = \dot{Q}_S / (\dot{Q}_S + \dot{Q}_L)$ $\dot{Q}_{Total} = \dot{m} (\Delta h)$ $BF = \frac{T_2 - T_3}{T_1 - T_3}$ $\dot{m}_w = \dot{m}_a (\omega_1 - \omega_2)$   |

## Constants and Conversion

- Stefan-Boltzmann constant ( $\sigma$ ) =  $5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$   
 Specific heat capacity for air ( $C_{air}$ ) =  $1.005 \text{ kJ/kgK}$   
 Specific heat capacity for water ( $C_w$ ) =  $4.19 \text{ kJ/kgK}$   
 Latent heat of vaporization ( $l_{h_2O}$ ) =  $2260 \text{ kJ/kg}$   
 Air density ( $\rho$ ) =  $1.2 \text{ kg/m}^3$