Moist Air & Thermal Comfort

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ME 415: Refrigeration & Building Mechanical Systems

Properties of Moist Air

If air and water vapour are present together in a confined space, a balanced condition will be reached where the air has become saturated with water vapour. If the temperature of the mixture is known, then the pressure of saturated vapour will be the pressure of steam at this temperature.

$T(^{\circ}C)$	$P_{sat}(kPa)$
0	0.610
10	1.224
15	1.704
20	2.337
25	3.166
30	4.246
35	5.628
40	7.384
45	9.593
50	12.35

$$P = P_a + P_v \quad : \quad \omega = \frac{m_v}{m_a}$$

$P \equiv$ Total (standard) pressure
$P_a \equiv$ Partial pressure of dry air
$P_v \equiv$ Partial pressure of water vapour
$\omega \equiv$ **Humidity ratio**
$m_a \equiv$ Mass of dry air
$m_v \equiv$ Mass of water vapour

$$\omega = \frac{m_v}{m_a} = \frac{P_v V/R_v T}{P_a V/R_a T} = 0.622\,\frac{P_v}{P_a} = 0.622\,\frac{p_v}{P - P_v}$$

For air at 25°C: $P_v = 3.166$ kPa $\longrightarrow$ $P_a = 97.159$ kPa: saturated air.

$\Rightarrow$ $\omega_s = 0.622\left(\frac{3.166}{97.159}\right) = 0.02026$ kg water/kg dry air.

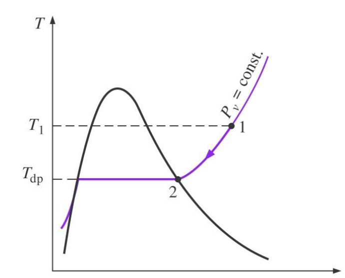
- If $m_v = 0.01013$ kg water/kg dry air $\longrightarrow \mu = 0.5$.

$$\text{saturation or degree of saturation, } \mu \equiv \frac{\omega}{\omega_s}$$

- The proportions of moisture can also be expressed as the ratio of the vapour pressures, and is then termed **relative humidity**:

$$\text{relative humidity, } \phi \equiv \frac{P_v}{P_{v,sat}}$$

$\Rightarrow$ $\omega = 0.01013 \longrightarrow P_v = 1.65$ kPa $\Rightarrow \phi = 1.65/3.166 = 52$



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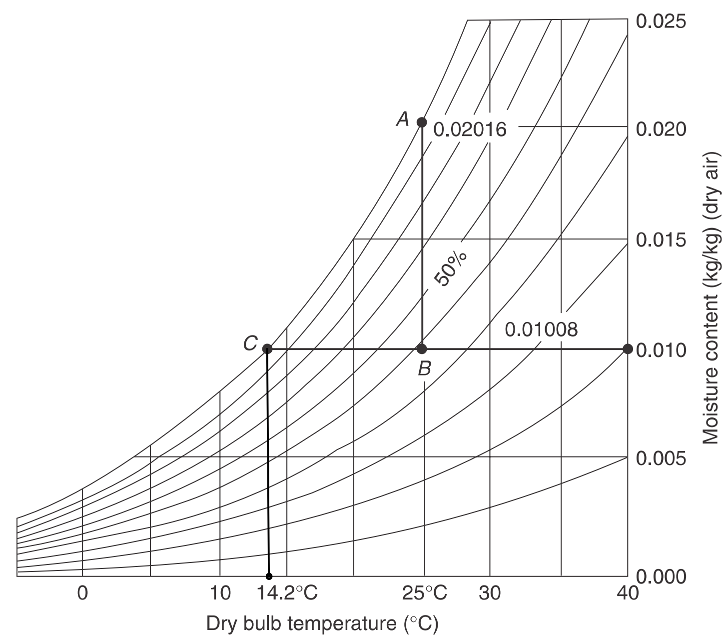
Dew-point temperature, T_{dp} is defined as the temperature at which condensation begins when the air is cooled at constant pressure.



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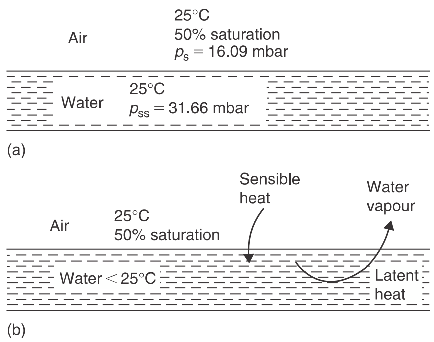
Wet Bulb/Dry Bulb Temperatures



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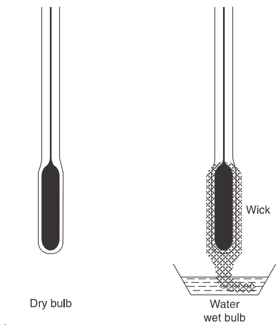

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If unsaturated air comes in contact with water at the same temperature, there will be change in vapour pressures. As a result, some of the water will evaporate. The resultant water temperature drop will provide a temperature difference, and a thermal balance will be reached where the flow of sensible heat from the air to the water provides the latent heat to evaporate a part of it. The equilibrium temperature is **Wet-bulb Temperature.**

ASHRAE-1989 Correlations

$$\phi = \frac{P_{sat}(T_{wb}) - P_m}{P_{sat}(T_{db})}$$

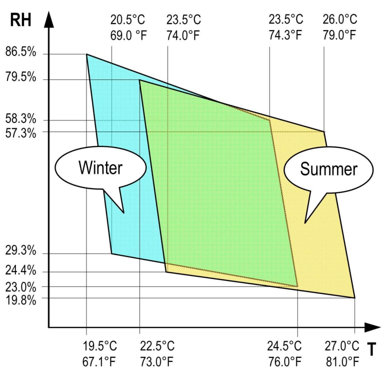
- $P_{sat}(T_{db}) \equiv$ saturated pressure corresponding to T_{db}
- $P_{sat}(T_{wb}) \equiv$ saturated pressure corresponding to T_{wb}
- $P_m \equiv$ partial pressure of vapour due to depression of T_{wb} below T_{db}.

$$P_m = P\left(\frac{T_{db} - T_{wb}}{1514}\right)\left(1 + \frac{T_{wb} - 273.2}{873}\right)$$

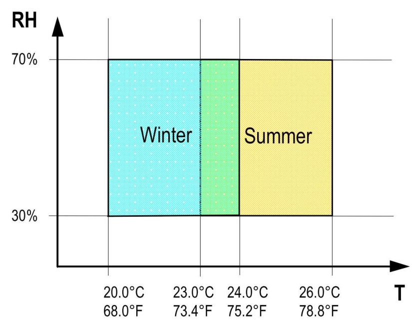
▷ Estimate relative humidity of air if T_{db} = 30°C & T_{wb} = 25°C.

▷ Atmospheric air at 30°C and 50% RH is compressed isothermally to 1.0 MPa. Estimate the psychrometric conditions of the compressed air.

Thermal Comfort



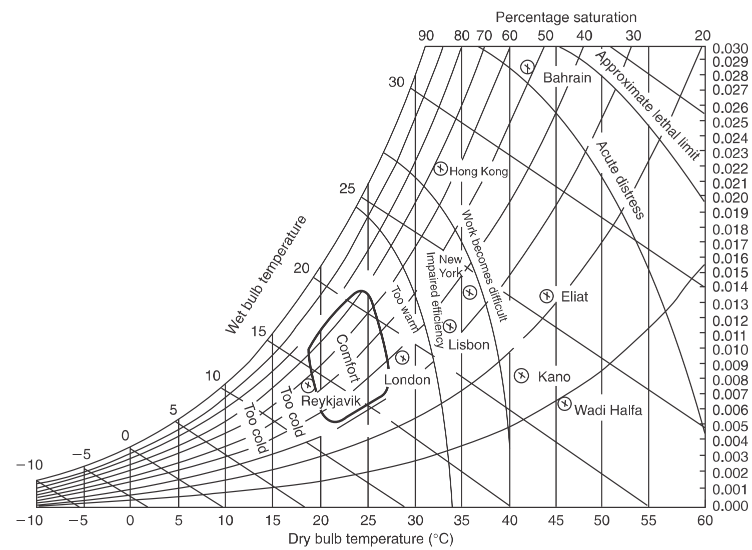
Comfort zone according to ASHRAE 55-1992



Comfort zone according to ISO 7730

Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment. Factors affecting thermal comfort are: temperature, thermal radiation, humidity, air speed, personal activity and clothing.

Typical Climate Conditions



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Bangladesh Outdoor Design Condition

Country	City	Latitude	Longitude	Altitude	Winter Design			Summer Design				Design wet bulb		
					Annual Extreme	99% DB	97.5% DB	1% DB	2.5% DB	5% DB	Daily Range	1%	2.5%	5%
Bangladesh	Chittagong	22.35°N	91.83°E	27 m	9°C	11°C	12°C	34°C	33°C	32°C	11°C	28°C	27°C	27°C

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- Summer design is based on 4 summer month from June to September (Total = (30+ 31+ 31+ 30)* 24 = 2928 hrs.)
- 2.5% means that temperature exceeds the value (33°C) only 2.5% of all the hrs in 4 months = 73.2 hr.
- Winter: December to January (Total 2160 hrs).
- 97.5% means temperature falls below the value for 54 hrs.
- For ordinary buildings, it is customary to design based on level of 2.5% in summer and 97.5% in winter.

$\Rightarrow$ $T_{o,max} = 33°$C, DR = 11°C $\Longrightarrow T_{o,av} = T_{o,max} - DR/2 = 27.5°$C.

Ventilation: Outdoor Air Requirements

- To meet metabolic requirements of occupants.
- To dilute the indoor air contaminants, odours and pollutants to maintain an acceptable air quality.
- To support any combustion process or replace the amount of exhaust air required in laboratories, manufacturing processes or rest rooms.
- To provide make-up of amount of ex-filtrated air required when positive pressure is to be maintained at the conditioned space.
- To add to or remove heat/moisture from the space.

Steady State Thermal Equilibrium

$$M = W + C + R + E_{sk} + E_{res}$$

M = Metabolic rate (W/m^2)
W = Mechanical work performed
$C + R$ = Convective + radiative, or sensible heat loss from skin
E_{sk} = Evaporative heat loss from skin surface
E_{res} = Evaporative heat loss from respiration

In an air conditioned space, a steady-state thermal equilibrium is usually maintained between the human body and the indoor environment.

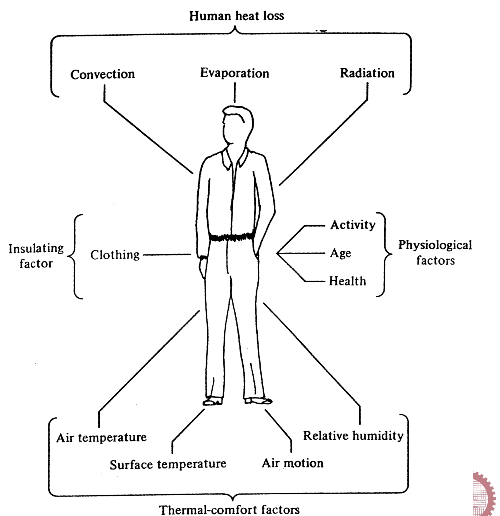
Metabolic Rate, M

- Energy release per unit area of skin surface as a result of oxidative process in the living cell is the metabolic rate. It depends on the intensity of physical activities.
- 1 met = 58.24 W/m^2
- Mechanical work, $W = \mu M$, μ = 0.2 to 0.24

Activity	met
Sleeping	0.7
Office work, reading or writing or seated	1.0
Domestic work, cooking	1.6 - 2.0
Walking, 2 mph	2.0
Walking, 4 mph	3.7
Heavy machine work	4.0

Seven Factors Influencing Thermal Comfort

1. Activity level
2. Clothing
3. Expectation
4. Air temperature
5. Radiant temperature
6. Humidity
7. Air speed



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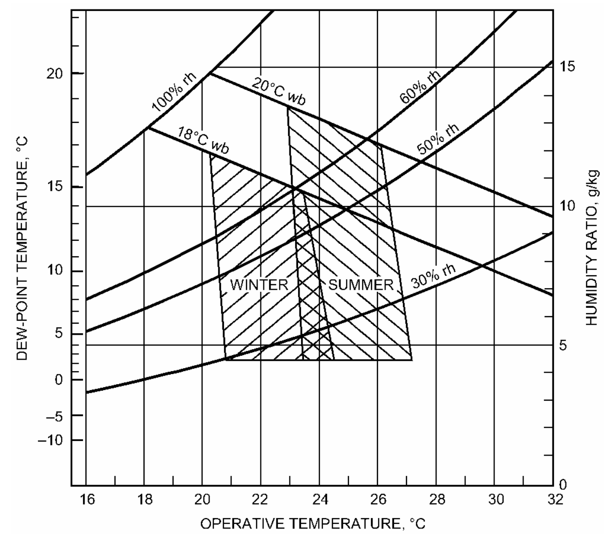
ASHRAE Comfort Zone



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Indoor Design Conditions

As per ASHRAE 55-1992 & 90.1-1999

	T (^{o}C)	ϕ (%)
Summer	23.5 to 26.0	30 to 65
Winter		
1. Commercial & public bld.	20.5 to 23.5	20 to 65
2. Health care bld.	20.5 to 23.5	30 to 65

Outdoor Air Requirements

- to meet metabolic requirements of occupants
- to dilute the indoor air contraminants, odors and pollutants to maintain an acceptable air quality.
- to support any combustion process or replace the amount of exhaust air required in laboratories, manufacturing processes or rest rooms.
- to provide makeup of amount of exfiltrated air required when positive pressure is to be maintained at the conditioned space.

Outdoor Air as per ASHRAE 62-1992

Application	L/s per person
Dining/conference room, office spaces, lounges	10
Retail stores, transport waiting rooms, class rooms	7
Hospitial patient rooms, residences	15
Smoking lounges	30

Thermal Comfort

Common Air Contaminants

Contaminants	Major Source
Particles (particulates)	Dust (generated inside and outside), smoking, cooking
Allergens (a substance that can cause an allergic reaction)	Molds, pets, many other sources
Bacteria and Viruses	People, moisture, pets
Carbon Dioxide (CO_2)	Occupants breathing, combustion
Odoriferous chemicals	People, cooking, molds, chemicals, smoking
Volatile Organic Compounds (VOCs)	Construction materials, furnishings, cleaning products
Tobacco Smoke	Smoking
Carbon Monoxide (CO)	Incomplete and/or faulty combustion, smoking
Radon (Rn)	Radioactive decay of radium in the soil
Formaldehyde (HCHO)	Construction materials, furniture, smoking
Oxides of Nitrogen	Combustion, smoking
Sulphur Dioxide	Combustion
Ozone	Photocopiers, electrostatic air cleaners

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Thermal Comfort

Filters for Air Cleaning Devices

1. Viscous impingment type
2. Dry screen type
3. Electrostatic precipitators
4. Air washers