MEAR'S

PSYCHROMETRIC CALCULATOR

This instrument determines the properties of moist air: dewpoint, vapour pressure, moisture content etc. from a variety of alternative data i.e.

from 1. Wet and dry bulb temperatures
2. Depression and wet bulb temperature
3. Relative humidity and dry bulb temperature.

Corresponding sections numbered 1, 2 and 3 on the calculator use these three different sets of data and give answers for either screen or aspirated (sling) type psychrometers with the wet bulb filmed with water (above 0°C) or filmed with ice (below 0°C).

Other sections numbered 4 and 5 correct for low barometer (high altitude) and calculate enthalpy and specific volume so that the instrument can be used equally well for meteorological or for air conditioning calculations.

DESIGN BASIS

The various formulae and definitions on which the calculator is based are as follows:

Vapour Pressure from Wet & Dry bulb Temperatures

The calculator solves the empirical equation:

$p = p'_w - p_{at}A(t - t')$ when wet bulb is covered with liquid water film.

$p = p'_i - p_{at}A(t - t')$ when wet bulb is covered with a film of ice.

where:

p = vapour pressure of the air, mb
p'_w = saturation vapour pressure over water at the wet bulb temperature, mb
p'_i = saturation vapour pressure over ice at the ice bulb temperature, mb
p'_{at} = barometric pressure. (The calculator is calibrated for 1013.25 mb)
t = dry bulb temperature, °C
t' = wet bulb temperature, °C
A = a constant having the following values:

	Wet bulb ⩾ 0°C	Wet bulb < 0°C
Sling or Aspirated psychrometer. . .	6.66×10^{-4}	5.94×10^{-4}
Screen psychrometer	7.99×10^{-4}	7.20×10^{-4}

Saturation Vapour Pressure over Water (p'_w)

$$\log p'_w = 31.59051 - 8.2 \log T + 0.0024804T - \frac{3142.31}{T}$$

where T = absolute air temperature °K

Saturation Vapour Pressure over Ice (p'_i)

$$\log p'_i = 13.5380997 - \frac{2663.91}{T}$$

Dew Point

The Dew Point is that temperature to which the moist air must be cooled for it to be saturated with respect to water.

Frost Point

The Frost Point is that temperature to which the moist air must be cooled for it to be saturated with respect to ice.

Relative Humidity

$$\text{Relative humidity} = \frac{p}{p_w} \times 100 \quad \text{per cent}$$

where p_w = saturation vapour pressure over water at t^oC

The Relative Humidity below 0^oC is usually expressed relative to the saturation vapour pressure over water, but the calculator does permit the saturation vapour pressure over ice to be used.

Moisture Content

This is given on the calculator at the standard barometric pressure of 1013.25 mb and is in grammes of moisture associated with 1 kg of dry air. If the moisture content is required at low barometers the Mixing Ratio which is identical can be read instead from section 3.

Vapour Density (Absolute Humidity)

$$\text{Vapour Density} = \frac{216.7p}{T}$$ grammes of moisture per cubic metre of moist air at any pressure.

Mixing Ratio

$$\text{Mixing Ratio} = \frac{622\,p}{p_{at} - p}$$ grammes of moisture per kg of dry air.

Specific Humidity

$$\text{Specific Humidity} = \frac{622\,p}{p_{at}}$$ grammes of moisture per kg of moist air

Note: Sometimes the terms Mixing Ratio and Specific Humidity are defined slightly differently.

Latent Heat

The evaluation of the latent heat in moist air depends slightly upon the temperature at which it is considered to have been evaporated. Thus the latent heat of evaporation of water at 0^oC is 2501 kJ/kg and the calculator is based on this. At 20^oC it is 2454, a reduction of about 2% and a mark showing this value is shown on the latent heat window of section 3.

Sensible Heat of Dry Air

Sensible Heat of dry air = $1.007t - 0.026$ kJ/kg of dry air approximately and is zero at 0^oC.

Sensible Heat of Moisture Content of Air

Sensible Heat of Water Vapour = $1.84t$ kJ/kg of moisture.

Specific Enthalpy

This is simply obtained on the calculator from the wet bulb temperature only and is correct for 50% RH (agreeing with the I.H.V.E. tables) and is within 1% over a range of 25% to 100% Relative Humidity.

Specific Volume

This is the volume occupied by 1 kg of dry air together with its associated moisture at its dry bulb temperature. The figure given by the calculator is correct for air at 50% RH, 1 to 2 % high for 100% RH and 1 to 2% low for 20% RH.

CONSTRUCTION and USE

Details of the various sections of the calculator are as follows:

SECTION 1. Using WET and DRY BULB TEMPERATURES

Dew Point, Vapour Pressure, Moisture Content and the Latent Heat of this moisture content are obtained by a single setting of the Dry Bulb to the Wet Bulb Temperature, separate scales being provided for sling type and screen type psychrometers. Below 0°C the dew point scale is calibrated as the frost point as is the practice in the IHVE guide.

An additional scale gives the sensible heat of dry air according to its temperature. The sensible heat of the water vapour is obtainable from section 3, and these together with the latent heat give the total enthalpy of the moist air which is also given directly as a total in section 5.

SECTION 2. Using DEPRESSION and WET BULB TEMPERATURE

Dew Point, Vapour Pressure, Moisture Content and Frost Point are obtained by a single setting of the Wet Bulb Depression to the Wet Bulb Temperature, separate scales being provided for aspirated and for screen type psychrometers and also for wet bulb depressions above and below 0°C, the latter being referred to as the Ice Bulb temperature since the bulb is filmed with ice.

For temperatures below 0°C the Dew Point is given as well as the Frost Point as for such temperatures the Relative Humidity is normally evaluated with respect to super-cooled water and not with respect to ice.

Reduced Barometric Pressures: At low barometers the Wet Bulb DEPRESSION will be high and require correction. This can be done using section 4.

SECTION 3. Using RELATIVE HUMIDITY and DRY BULB TEMPERATURE

A single setting of Dry Bulb Temperature to Relative Humidity gives the Dew Point, Frost Point, Vapour Pressure, Moisture Content, Latent Heat of moisture, Specific Humidity, Mixing Ratio, Vapour Density and Sensible Heat of vapour. Alternatively, if any one or perhaps two of these is known the calculator can be set accordingly and the remainder found.

Barometer. The Moisture Content, Latent Heat and Sensible Heat of the moisture are correct for the standard barometric pressure of 1013.25 mb only.

The Relative Humidity, Dry Bulb Temperature, Dew Point, Frost Point and Vapour Density are independent of changes in barometer.

The Specific Humidity and the Mixing Ratio are read off against a barometric scale and are therefore correct for any barometer.

Corrections for Low Barometer or for Altitude

1. MOISTURE CONTENT. The Mixing Ratio is the Moisture Content at any barometer so instead of reading moisture content simply read the Mixing Ratio as instructed opposite Barometric Pressure minus Vapour Pressure. This is the Moisture Content.
2. LATENT HEAT. Set the Moisture Content arrow to the corrected Moisture Content (Mixing Ratio) obtained as in 1 above and read Latent Heat opposite the Latent Heat arrow.
3. SENSIBLE HEAT of MOISTURE. Proceed as for Latent Heat reading Sensible Heat opposite Dry Bulb Temperature.

SECTION 4. ALTITUDE CORRECTION – CONDITION of AIR MIXTURES

This section allows the wet bulb DEPRESSION to be corrected for the lowered barometers prevailing at altitude. It also enables the Dry Bulb Temperature, Vapour Pressure, Moisture Content etc. of mixtures of two or more streams of air to be obtained from the properties of the component streams.

SECTION 5. SPECIFIC ENTHALPY and SPECIFIC VOLUME

Both Specific Enthalpy and Specific Volume are very closely tied to the wet bulb temperature with very small variations according to Relative Humidity and this section gives them and also indicates the small error involved in using this simple method.

Barometer: They are correct for 1013.25 mb barometer only. Specific enthalpy at low barometers is best obtained by totalling the constituent items from sections 1 and 3, namely Latent Heat and Sensible Heat of moisture and Sensible Heat of dry air.

For Specific Volume multiply by: $\frac{1013.25 - \text{vapour pressure}}{\text{barometer} - \text{vapour pressure}}$

EXAMPLE 1.

AIR PROPERTIES AT STANDARD BAROMETER of 1013.25mb

What are the complete properties of air at 20°C wet bulb, 25°C dry bulb and 1013.25 mb , measurements taken with a sling psychrometer.

Using section 1 set 25°C dry bulb to 20°C wet bulb and read:
Dew Point = 17.5°C
Vapour Pressure = 20.0 mbar
Moisture Content = 12.6 g/kg
Latent Heat = 31.6 kJ/kg *
and setting 25°C dry bulb to Sensible Heat arrow read:
Sensible Heat of dry air = 25.1 kJ/kg *

or Using section 2 set 5°C depression to 20°C wet bulb and read:
Dew Point = 17.5°C
Vapour Pressure = 20.0 mbar
Moisture Content = 12.6 g/kg

Using section 3 set Dew Point arrow to 17.5°C and read:
Relative Humidity = 63% (reading opposite 25°C dry bulb)
Vapour Pressure = 20 mbar
Moisture Content = 12.6 g/kg
Latent Heat = 31.6 kJ/kg
Specific Humidity = 12.25 g/kg (opposite 1013.25 mbar pressure)
Mixing Ratio = 12.6 g/kg " 993.25 " "
Vapour Density = 14.5 g/m^3
Sensible Heat of Vapour = 0.58 kJ/kg *
Total Enthalpy = 31.6 + 25.1 + 0.58 = 57.28 kJ/kg by totalling the starred items above.

Using section 5 set arrow to 20°C wet bulb and read:
Specific Enthalpy = 57.2 kJ/kg
Specific Volume = 0.867 m^3/kg

EXAMPLE 2.

AIR PROPERTIES AT ALTITUDE or at LOW BAROMETER

Exactly as example 1 i.e. 20°C wet bulb 25°C dry bulb, sling psychrometer but for a barometer of 800 mb.

The Depression is 5°C

Using section 4

Corrected Depression = 3.95°C

Using section 2 set 3.95°C depression to 20°C wet bulb and read:

Dew Point = 18.05°C
Vapour Pressure = 20.68 mbar

Using section 3 set Dew Point to 18.05°C and read:

Relative Humidity = 65.5%
Specific Humidity = 16.1 g/kg of moist air (read opposite 800 mb)
Mixing Ratio = 16.5 g/kg of dry air (read opposite 779.32 mb)
Vapour Density = 15.1 g/m^3 of moist air (read opposite 25°C)
Moisture Content = Mixing Ratio = 16.5 g/kg of dry air

Setting Moisture Content arrow to 16.5 :-

Latent Heat = 41.2 kJ/kg of dry air
Sensible Heat of moisture = 0.76 kJ/kg of dry air

Using section 1 set 25°C dry bulb to Sensible Heat arrow and read:

Sensible Heat of dry air = 25.1 kJ/kg of dry air. (This is independent of the barometer)

Using section 5 set arrow to 20°C and read:

$$\text{Specific Volume} = 0.867 \times \text{barometer correction} = 0.867 \times \frac{(1013.25 - 20.68)}{(800 - 20.68)}$$

$$= 1.11 \text{ m}^3/\text{kg of dry air}$$

Alternatively the barometer correction can be applied using section 4 by setting 779 mb to 0.867 and reading opposite 992 mb.

Specific Enthalpy: No simple correction factor is applicable, therefore simply total the constituent items obtained above i.e.

= Latent Heat + Sensible Heat of moisture + Sensible Heat of air
= 41.2 + 0.76 + 25.1
= 67.06 kJ/kg of dry air

EXAMPLE 3.

AIR HEATING

Air at 20°C dry bulb, 15°C wet bulb and 1013.25 mb barometer is heated to 40°C. Its volume is 20 m^3/s (measured at 20°), what is the total heat requirement and the final condition of the air?

Consider first 1 kg of dry air: The heat required is in two parts, the sensible heat of the dry air and the sensible heat of the associated moisture.

Using section 1 and setting 20°C dry bulb to 15°C wet bulb:
read opposite 40°C . . . . Wet Bulb Temperature of heated air = 21.75°C
Moisture Content of heated air = 8.55 g/kg

and setting 20° temperature rise to the Sensible Heat arrow:
Sensible Heat of dry air = 20.1 kJ/kg

Using section 3, setting Moisture Content to 8.55 and reading opposite 20°
Sensible Heat of moisture = 0.31 kJ/kg

Total Heat required = 20.1 + 0.31 = 20.41 kJ/kg of dry air

This must be multiplied by the number of kg of dry air in 20 m^3/s and this is obtained from section 5:

Using section 5 and setting the arrow to 15°C wet bulb temperature:
Specific volume = 0.845 m^3/kg

therefore Mass Flow of Air = $\frac{20}{0.845}$ = 23.65 kg/s

therefore TOTAL HEAT REQUIRED = 20.41 x 23.65
= 483 kJ/s

EXAMPLE 4.

CHANGE OF VOLUME FLOW to MASS FLOW OF DRY AIR

Express 2 m^3/s of moist air at 20°C dry bulb, 15°C wet bulb in kg/s of dry air. The volume of the moist air is as measured at its dry bulb temperature of 20°C.

Using section 5 set arrow to 15°C wet bulb and read the specific volume of 1 kg of dry air : Specific Volume = 0.845

Therefore 2 m^3/s of this air will be equal to 2 ÷ 0.845 = 2.365 kg/s of dry air

As mentioned on the calculator the method used although extremely simple is not completely accurate except at 50% RH but the error is usually small in this instance the correct specific volume being 0.8415 m^3/kg.

EXAMPLE 5.

SENSIBLE & LATENT HEAT EXTRACTION (or addition) & MOISTURE REMOVAL

Air at 25°C dry bulb and 20°C wet bulb (sling) is to have removed 5kJ/kg of sensible heat and 3 kJ/kg of latent heat. What is its final condition?

Using section 5 set arrow to 20°C wet bulb temperature and read:

Specific Enthalpy initially = 57.1 kJ/kg of dry air
less sensible & latent heats to be removed 8.0
Final Specific Enthalpy . . = 49.1 kJ/kg

reset arrow to 49.1:-

Final Wet Bulb Temperature = 17.5°C

Using section 1 set 25°C dry bulb to 20°C wet bulb and read:

Initial Latent Heat = 31.5 kJ/kg
Latent Heat extracted = 3.0
Final Latent Heat = 28.5 kJ/kg

reset Latent Heat arrow to 28.5 and read opposite the Final Wet Bulb Temperature of 17.5° :-

Final Dry Bulb Temperature = 20.2°C

and opposite the Dew Point arrow:

Final Dew Point . . . . = 15.9°C

Moisture Removed.

Using section 3 set the Latent Heat arrow to the 3 kJ/kg of latent heat removed and read opposite the Moisture Content arrow:

Moisture removed . . . . = 1.2 g/kg

EXAMPLE 6.

AIR MIXING

What is the condition of the resulting mixture containing 75% of air at 30°C dry bulb 24°C wet bulb and 25% of air at 23°C dry bulb 50% Relative Humidity?

DRY BULB TEMPERATURE = 75% x 30° + 25% x 23°
= 22.5 + 5.75 from section 4
= 28.25°C

WET BULB TEMPERATURE:

using section 1 set 30°C dry bulb to 24°C wet bulb and read:
Moisture content of component 1 = 16.35 g/kg of dry air

using section 3 set 23°C dry bulb to 50% relative humidity and read:
Moisture content of component 2 = 8.8 g/kg of dry air

Moisture content of mixture = 75% x 16.35 + 25% x 8.8
= 12.2 + 2.2
= 14.4 g/kg of dry air.

setting the Moisture content arrow on section 3 to this moisture content of 14.4 and reading opposite the dry bulb temperature of 28.25°C gives:

Relative Humidity of Mixture = 60%

Similarly from section 1:

Wet Bulb Temperature of Mixture = 22.3°C