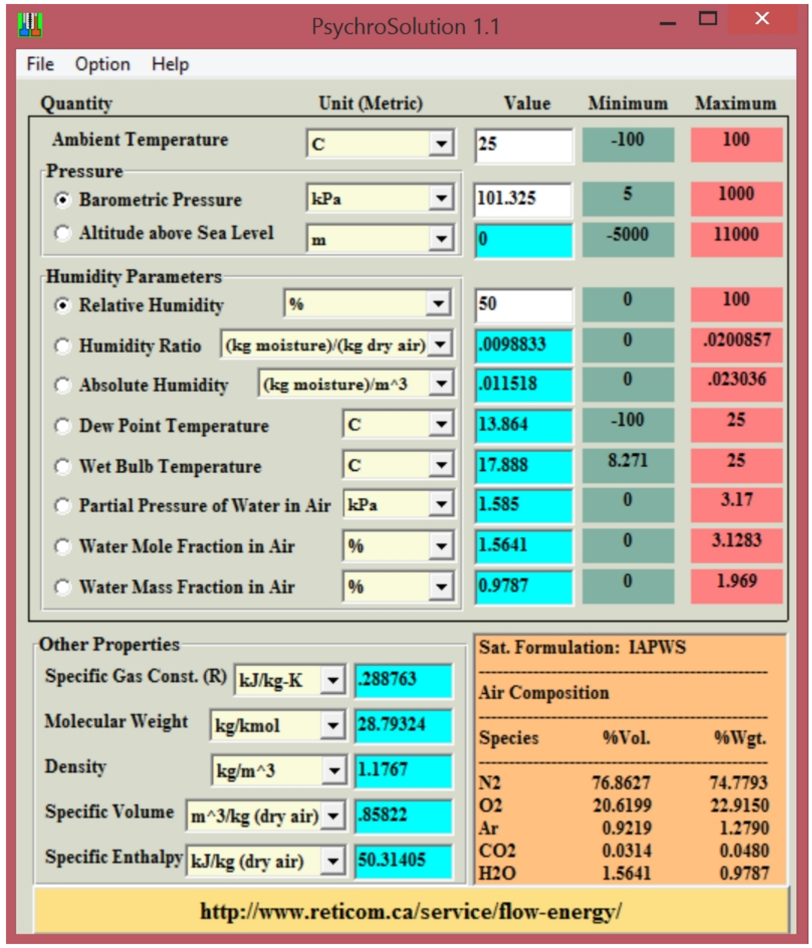
➢ What Features Does *Psychrosolution 1.1* Have?

Psychrosolution 1.1 is a program to calculate the psychrometric properties of water-air mixture for ambient temperature in the range of -100 °C to 100 °C and barometric pressure of 5 kPa to 1000 kPa.

Psychrosolution 1.1 is extremely fast, accurate and user-friendly that provides users with a wide range of engineering units to measure psychrometric quantities. Users not only can select between *Metric* and *British* systems of units, but also are able to change the unit of each quantity individually. Also, a Unit Convertor has been provided for users.

Psychrosolution 1.1 uses two different standards for calculating saturation condition of water namely, IAPWS and Hyland-Wexler's formulations to meet different references. Users also can directly calculate and compare the saturation condition of water for two standards.



Psychrosolution 1.1 calculates the properties of moist air just by inputting one of eight quantities. Other quantities will be extracted by the program.

Psychrosolution 1.1 also gives the composition of species of moist air in mole or mass fractions.

Psychrosolution 1.1 provides the maximum and minimum values of each quantity for the user at any condition and also any unit. A complete and brief report can be provided by the program.

Psychrosolution 1.1 Gives the overall properties of the moist air including specific gas const., molecular weight, density, specific volume and specific enthalpy.

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Definition and Range of Quantities

- **Ambient Temperature (T_{db}, T_{amb})**

The temperature of ambient that can be considered as ***Dry Bulb Temperature***.

Table (1): Range and Units of Ambient Temperature

Unit	Unit Conversion	Min	Max
Degrees Celsius (C)	C	-100	100
Kelvin (K)	C+273.15	173.15	373.15
Degrees Fahrenheit (F)	9/5×C+32	-148	212
Rankin (R)	9/5×C+491.67	311.67	671.67

Note! Users can change units of different quantities individually or select between *British* and *Metric* system of units from the following path.

Option>> System of Units

In addition, a unit convertor is in the program to help users about different units of quantities that is in the following path.

Option>> Unit Convertor

- **Barometric Pressure (P_{amb})**

Atmospheric pressure, absolute ambient pressure of any location on the earth.

Note! The Barometric Pressure will be decreased by increasing the altitude above sea level.

Table (2): Range and Units of Barometric Pressure

Unit	Unit Conversion	Min	Max
Pa	1	5000	1000000
kPa	1000	5	1000
Bar	100000	0.05	10
mBar	100	50	10000
mm H_2O	9.8638	506.9	101380.8
mm Hg	133.322	37.503	7500.638
Atmosphere	101325	0.04935	9.86923
Pound per square inch (PSI)	6894.757	0.7252	145.0356

- **Altitude above Sea Level (Z)**

The Altitude of a location above the Mean Sea Level that is used to calculate the average barometric pressure of any location.

Table (3): Range and Units of Altitude above Sea Level

Unit	Unit Conversion	Min	Max
m	1	-5000	11000
km	1000	-5	11
mile	1609.34	-3.107	6.835
ft	0.3048	-16405	36089

- **Relative Humidity (RH, φ)**

The ratio of partial water vapor pressure in moist air to the saturated vapor pressure of water at a prescribed temperature.

Table (4): Range and Units of Relative Humidity

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
%	1	0	100

- **Humidity Ratio (ω)**

The ratio of water vapor mass to unit mass of dry air in air-water mixture. It is also known as *moisture content or mixing ratio.*

Table (5): Range and Units of Humidity Ratio

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
(kg moisture)/(kg dry air)	1	0	eq. (7)
(g moisture)/(kg dry air)	0.001	0	eq. (7)
(lb moisture)/(lb dry air)	1	0	eq. (7)

- **Absolute Humidity (AH)**

The amount of water vapor presents in a unit volume of air.

Table (6): Range and Units of Absolute Humidity

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
(kg moisture)/m^3	1	0	eq. (17)
(g moisture)/m^3	0.001	0	eq. (17)
(lb moisture)/ft^3	16.018463	0	eq. (17)

- **Dew Point Temperature (T_{dp})**

The temperature at which the water vapor in moist air at constant barometric pressure condenses into liquid water at the same rate at which it evaporates. At temperature below dew point, water will leave the air.

Table (7): Range and Units of Dew Point Temperature

Unit	Unit Conversion	Min (dry Air)*	Max (Saturated Air)
Degrees Celsius (C)	C	-100	T_{db}
Kelvin (K)	C+273.15	173.15	T_{db}
Degrees Fahrenheit (F)	9/5×C+32	-148	T_{db}
Rankin (R)	9/5×C+491.67	311.67	T_{db} in
* By decreasing the amount of moisture in air, the value of dew point temperature decreases unboundedly. The mentioned results in this table indicate the restricted values by the software.			

- **Wet Bulb Temperature (T_{wb})**

The temperature a parcel of air would have if it were cooled to saturation by the evaporation of water into it, with the latent heat being supplied by the parcel. The wet bulb temperature is the lowest temperature that can be reached under current ambient conditions by the evaporation of water only. It is the temperature felt when the skin is wet and exposed to moving air.

Table (8): Range and Units of Wet Bulb Temperature

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
Degrees Celsius (C)	C	Eq. (30)	T_{db}
Kelvin (K)	C+273.15	Eq. (30)	T_{db}
Degrees Fahrenheit (F)	9/5×C+32	Eq. (30)	T_{db}
Rankin (R)	9/5×C+491.67	Eq. (30)	T_{db}

- **Partial Pressure of Water in Air (P_v)**

In mixtures of gases, the partial pressure of water in air is the pressure water vapor would exert if it alone occupied the volume of the moist air.

Note! The maximum partial pressure of water vapor in air is equal to the saturated pressure of water at the ambient temperature.

Table (9): Range and Units of Partial Pressure of Water in Air

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
Pa	1	0	P_g, eq. (6)
kPa	1000	0	P_g, eq. (6)
Bar	100000	0	P_g, eq. (6)
mBar	100	0	P_g, eq. (6)
mm H_2O	9.8638	0	P_g, eq. (6)
mm Hg	133.322	0	P_g, eq. (6)
Atmosphere	101325	0	P_g, eq. (6)
Pound per square inch (PSI)	6894.757	0	P_g, eq. (6)

- **Water Mole Fraction in Air (X_{H2O})**

The mole fraction of water vapor in the moist air. It is also equal to volume fraction of water vapor in moist air.

Table (10): Range and Units of Water Mole Fraction in Air

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
%	1	0	eq. (11)

- **Water Mass Fraction in Air (Y_{H2O})**

The mass fraction of water vapor in the moist air. It is also equal to weight fraction of water vapor in moist air.

Table (11): Range and Units of Water Mass Fraction in Air

Unit	Unit Conversion	Min (dry Air)	Max (Saturated Air)
%	1	0	eq. (13)

- **Specific Gas Constant (R)**

A unique constant of gaseous materials that is obtained by dividing the ***Universal Gas Constant*** into molecular weight of material. It is also known as the ***Individual Gas Constant***.

Table (12): Units of Specific Gas Constant

Unit	Unit Conversion
J/kg	1
kJ/kg	1000
cal/kg	4.1868
kcal/kg	4186.8
btu/lb	4186.8

Note! According to ASHRAE standard, the value of the ***Universal Gas Constant*** in different units can be found in table below.

Table (13): Value of Universal Gas Constant in Different Units

Unit	R_u
kJ/kmol-K	8.31441
kcal/kmol-K	1.98584
Btu/lbmol-R	1.98584
lbf-ft/lbmol-R	1545.32

- **Molecular Weight (MW)**

Refers to the mass of one mole of a substance. It is also called *Molecular Mass*.

Table (14): Units of Molecular Weight

Unit	Unit Conversion
kg/kmol	1
lbm/lbmol	1

- **Density (ρ)**

The mass per unit volume. Here, it is measured at the actual pressure and temperature of moist air.

Table (15): Units of Density

Unit	Unit Conversion
kg/m^3	1
g/cm^3	1000
lb/ft^3	16.01846

- **Specific Volume (v)**

The volume of moist air per unit mass of dry air.

Table (16): Units of Specific Volume

Unit	Unit Conversion
m^3/kg (dry air)	1
cm^3/g (dry air)	0.001
ft^3/lb (dry air)	0.0624265

- **Specific Enthalpy (h)**

The summation of individual enthalpies of water vapor and dry air per unit mass of dry air. In ***Psychrosolution 1.1***, the value of enthalpy is set to be zero at triple point of water, T=0.01 °C.

Table (17): Units of Specific Enthalpy

Unit	Unit Conversion
kJ/kg (dry air)	1
kcal/kg (dry air)	4.1868
btu/lb (dry air)	2.326014

Calculation Procedure

- **Barometric Pressure vs. Altitude Above Sea Level**

The barometric pressure of each location is a function of its altitude above sea level which is calculated by eq. (1).

$$P_a = 101.325 \times (1 - 2.25577 \times 10^{-5} \times Z)^{5.2} \quad (1)$$

where P_a indicates barometric pressure in *kPa* and Z is the altitude of location above sea level in *m*. It should be noted that eq. (1) is valid for -5 km ≤ Z ≤ 11 km.

- **Saturation Condition of Water Vapor**

In ***Psychrosolution 1.1***, there are two independent methods for finding the saturation conditions of water, namely, IAPWS and Hyland-Wexler.
IAPWS (International Association for the Properties of Water and Steam) has released a series of documents for computing all properties of water/steam at different conditions, including the properties of water at saturation conditions. Further information can be found in IAPWS's documents [1, 2].
On the other hand, the Hyland-Wexler formulation is a relatively simple equation which is engaged to find the saturation pressure of water by its temperature. This formulation has also been used in ASHRAE fundamental handbook for psychrometric calculations [3].
Although the mentioned formulations have almost the same results, ***Psychrosolution 1.1*** has provided its users with the possibility of changing the method of calculating the saturation conditions to meet the different references. The ***Psychrosolution 1.1***'s users can choose the method of calculating of saturation condition from the following path:

Option>> Method of Calculating Saturation Condition

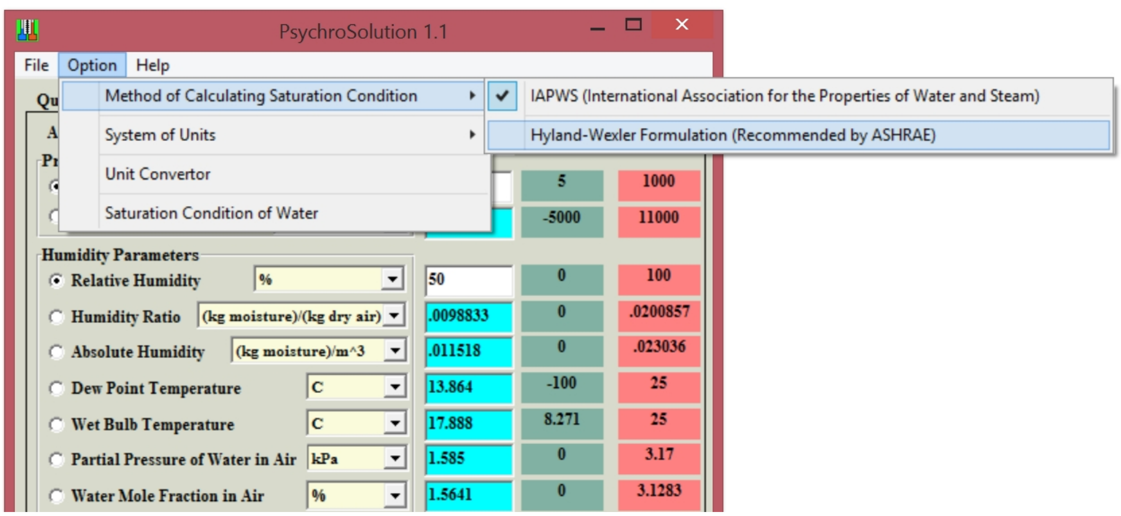

Fig. (1): Selecting method of calculation for saturation condition

In addition, the user can directly find and compare the saturation condition of water for both IAPWS and Hyland-Wexler's methods from the following path:

Option>> Saturation Condition of Water

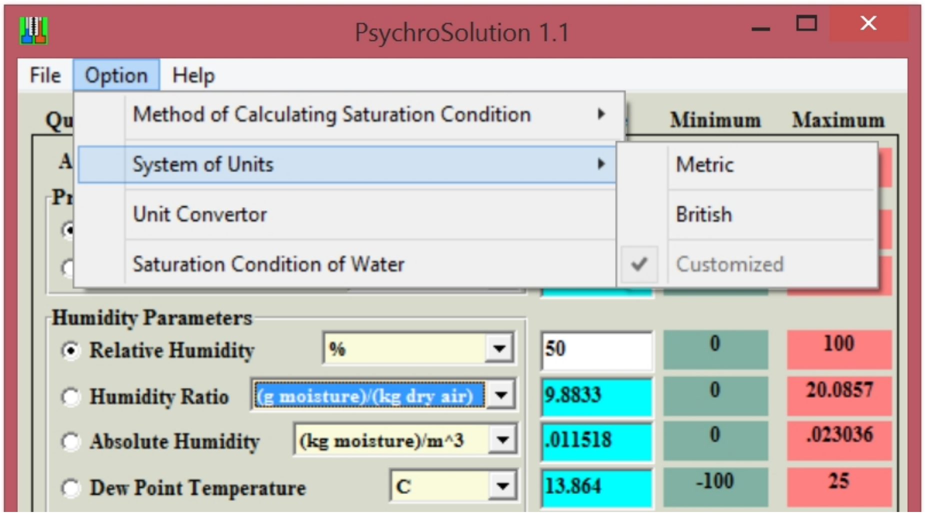

Fig. (2): Selecting method of calculation for saturation condition

- **Calculation of Humidity Parameters**

  The molecular weights of water and dry air are MW_w=18.01528 and MW_{da} =28.9645, respectively. Consequently, the gas constant (R) values for these two materials can be computed as follows.

$R_w = \frac{R_u}{M\ \ _w} = \frac{8.31441}{18.01528} = 0.46152\ (\frac{k}{k\ \ .K})$	(2)
$R_d\ \ = \frac{R_u}{M\ \ _d} = \frac{8.31441}{28.9645} = 0.287055\ (\frac{k}{k\ \ .K})$	(3)

The humidity ratio (ω) is defined as the amount of mass of water in a unit mass of dry air and can be calculated by eq. (4).

$\omega = \frac{m_w}{m_d} = \frac{M\ \ _w}{M\ \ _d} \times \frac{P_v}{P_d} = \frac{0.62198 \times P_v}{P_a\ \ \ - P_v}$	(4)

where P_v is the partial pressure of water vapor in the moist air.

At each ambient temperature, the air can hold a limited amount of moisture indicated by saturation condition. Any extra moisture introduced into saturated air will condense. At this condition, the partial pressure of water vapor in the air (indicated by P_g or $P_{v,max}$) would be equal to the saturation pressure of water at the ambient temperature. The relative humidity (φ) is defined as the ratio of the amount of water vapor in the air to the maximum water vapor that the air can hold at the same temperature as defined by eq. (5).

$$\varphi = \frac{P_v}{P_g} \tag{5}$$

where

$$P_g = P_s \quad @\, T_a \tag{6}$$

P_g is the saturation pressure at ambient temperature.
Hence, the maximum specific humidity can be calculated by eq. (7).

$$\omega_m = \frac{0.62198 \times P_g}{P_a - P_g} \tag{7}$$

Water vapor mole fraction in the air can be calculated by the following equation.

$$X_{H_2O} = \frac{P_v}{P_a} \tag{8}$$

The molecular weight of moist air is calculated by eq. (9).

$$M_m = X_{H_2O} \times 18.01528 + (1 - X_{H_2O}) \times 28.96518 \tag{9}$$

Consequently, the mass fraction of water vapor would be computed by eq. (10).

$$Y_{H_2O} = X_{H_2O} \times \frac{18.01528}{M_m} \tag{10}$$

The maximum value of water vapor mole fraction can be obtained by following equation.

$$X_{H_2O,m} = \frac{P_g}{P_a} \tag{11}$$

At saturation condition, the molecular weight of air can be represented by eq. (12).

$$M_{s} = X_{H_2O,m} \times 18.01528 + (1 - X_{H_2O,m}) \times 28.9645 \tag{12}$$

Finally, the maximum mass fraction of water vapor will be calculated by the following equation.

$$Y_{H_2O,m} = X_{H_2O,m} \times \frac{18.01528}{M_{s}} \tag{13}$$

The specific gas constant of moist air is calculated by Eq. (14).

$$R_m = \frac{R_u}{M_{m}} \tag{14}$$

Considering the moist air as an ideal gas, the equation of state can be written as the following equation.

$$\frac{P_a}{\rho_m} = R_m \times T_a \tag{15}$$

where ρ_m is the actual density of moist air. The value of absolute humidity can be extracted by eq. (16).

$$A = \frac{P_v \times 18.01528}{8.31441 \times T_a} \tag{16}$$

where the values of P_v, T_a and AH are measured in kPa, K and (kg moisture)/m^3, respectively. Also, the maximum value of absolute humidity can be computed by eq. (17).

$A_m = \frac{P_g \times 18.01528}{8.31441 \times T_a}$	(17)

where P_g is in kPa.

The specific volume of moist air (v) is defined as the following equation.

$v = \frac{V}{m_d}$	(18)

where V is the volume of moist air which can be calculated from the density by the following equation.

$\rho_m = \frac{m_d + m_w}{V} \Rightarrow V = \frac{m_d + m_w}{\rho_m}$	(19)

Hence, the specific volume of moist air can be estimated by the following equation.

$v = \frac{1 + \omega}{\rho_m}$	(20)

The enthalpy of a mixture of ideal gases is equal to the summation of the individual partial enthalpies of the components. Therefore, the specific enthalpy of moist air can be written as follows.

$h = h_d + \omega h_g$	(21)

where h_d is the specific enthalpy for dry air and h_g is the specific enthalpy for saturated water vapor at the temperature of the mixture. As a good approximation, one can write:

$h_d = 1.006 \times T_d$	(22)
$h_g = 2501 + 1.805 \times T_d$	(23)

where h_d and h_g are in kJ/kg (dry air) and T_d is in ºC.

The composition of dry air usually remains constant during the psychrometric processes and it has been approximately presented in Table (1). Since the amount of water vapor in moist air is variable, the composition of species of air can be changed due to variation of water vapor amount. ***Psychrosolution 1.1*** calculates the composition of moist air for any condition.

Table (18): Composition of dry air

Species	$X_{i,da}$	$Y_{i,da}$
N_2	0.780840	0.755184
O_2	0.209476	0.231415
Ar	0.009365	0.012916
CO_2	.000319	0.000485

The mole and mass fractions of species of dry air in table (1) for moist air can be calculated by Eq. (24) and Eq. (25), respectively.

$$X_{i,m} = X_{i,d} \times (1 - X_{H_2O}) \tag{24}$$

$$Y_{i,m} = Y_{i,d} \times (1 - Y_{H_2O}) \tag{25}$$

To evaluate the value of dew point temperature, one can find the temperature in which the saturation pressure of water would be equal to the partial pressure of water vapor in current air temperature. Hence for saturated air, the dew point temperature is equal to the ambient temperature. The process depicted in Fig. (3) schematically shows the idea of dew point temperature. Also, eq. (6) presents the value of dew point temperature. It should be noted that for dry air (φ=0%), the dew point temperature reaches to $(-\infty)$ while it is limited in ***Psychrosolution 1.1*** to the value of -100 °C. Dew point temperature can be calculated by Eq. (26).

$$T_d = T_s \ @ \ P_v \tag{26}$$

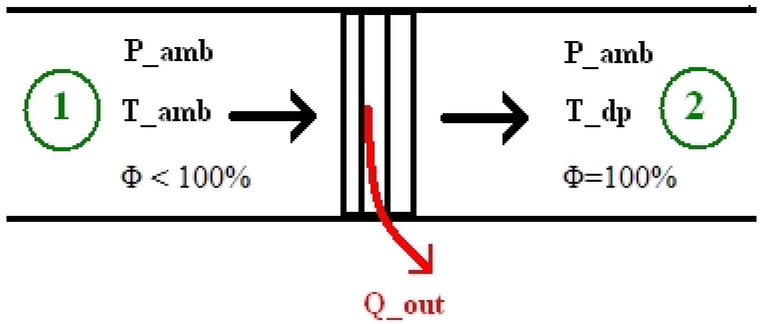

Fig. (3): Description of dew point temperature

Wet bulb temperature indicates the minimum temperature that a certain amount of air can reach only by an evaporative cooling process which involves no heat or work interaction. Fig. (4) demonstrates the definition of wet bulb temperature schematically.

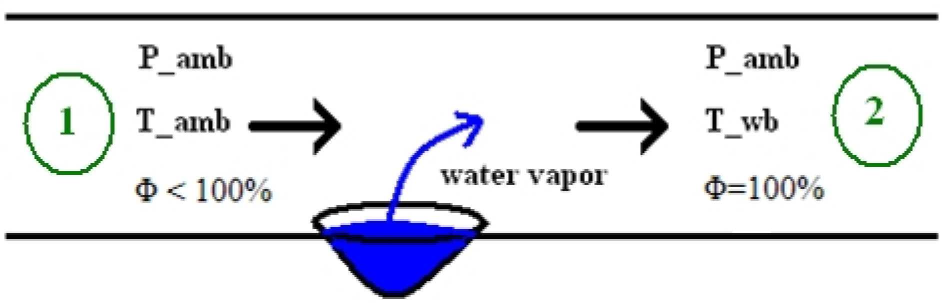

Fig. (4): Description of wet bulb temperature

Since the process indicated in Fig. (4) is an adiabatic one, the enthalpy of state 2 (h_2) is the summation of the enthalpy of state 1 (h_1) and the enthalpy of water added into the moist air ($h_w^* \times (\omega_2 - \omega_1)$). Also, h_w^* is the specific enthalpy of the water added into the moist air at the temperature T_{wb} that can be approximately found by the following equation.

$h_w^* = 4.186 \times T_w$	(27)

where h_w^* and T_w are in kJ/kg (dry air) and ^oC, respectively.

Therefore, one can write:

$h_1 + h_w^* \times (\omega_2 - \omega_1) = h_2$	(28)

By engaging Eq. (27) and Eq. (28), the following equation can be used to calculate the humidity ratio as a function of wet bulb temperature.

$$\omega_1 = \frac{\omega_2(2501 + 2.381 \times T_w) - 1.006(T_d - T_w)}{2501 + 1.805 \times T_d - 4.186 \times T_w} \quad (29)$$

where ω_2 is the saturated humidity ratio at ambient pressure and wet bulb temperature and can be found by Eq. (6) and Eq. (7) for T_{wb} instead of T_{db}. Also, T_{wb} and T_{db} are in ^oC.

For dry air which yields to the minimum wet bulb temperature, the humidity ratio (ω_1) is equal to zero. Hence, one can write:

$$T_{w,m} = \frac{1.006 \times T_d - 2501 \times \omega_2}{2.381 \times \omega_2 + 1.006} \quad (30)$$

Note! Regarding this fact that ω_2 depends on the wet bulb temperature, Eq. (30) should be solved by a *try-and-error* method to find out the wet bulb temperature.

➢ Other facilities

- **Saturation Condition of Water Vapor**

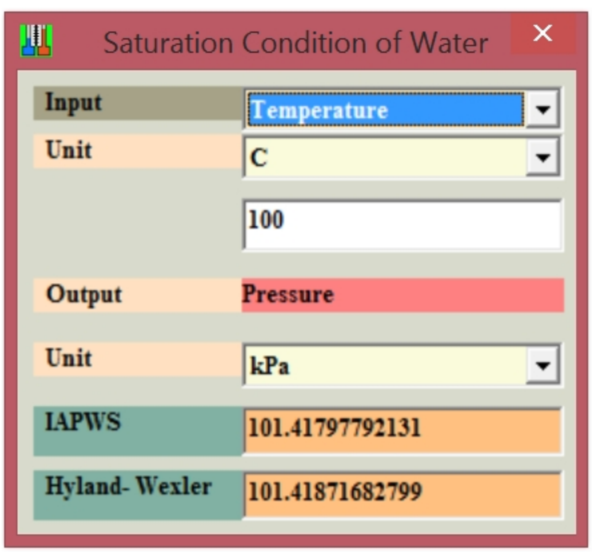

Fig. (5): Selecting method of calculation for saturation condition

- **Unit Convertor**

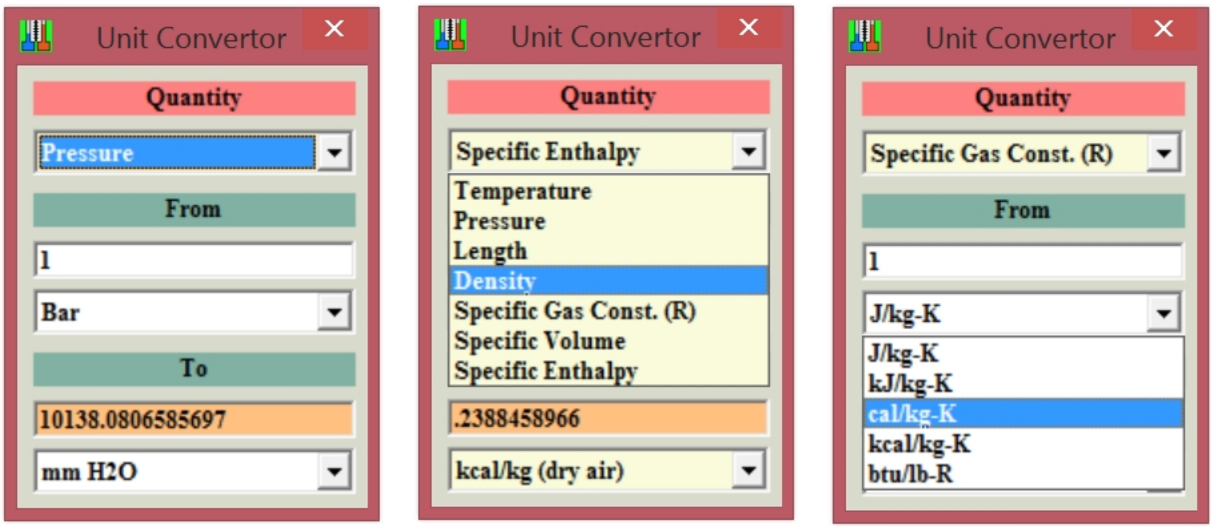

Fig. (6): Unit Convertor

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[3] ASHRAE. 2005. 2005 ASHRAE Handbook - Fundamentals. ASHRAE.

[4] Hyland, R.W. and A. Wexler. 1983a. Formulations for the thermodynamic properties of dry air from 173.15 K to 473.15 K, and of saturated moist air from 173.15 K to 372.15 K, at pressures to 5 MPa. ASHRAE Transactions 89(2A):520-535.

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