J∆S Engineering Suite

Module Guide: Psychrometric Analysis

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JS Engineering Solutions

Version: 1.1 | **Modules:** `psychrometrics.py`, `standalone_psychrometric_calc.py`, `psychrometric_chart.py`, `coil_calcs.py`, `coil_selection.py` **Audience:** HVAC design engineers, energy modelers, mechanical PE candidates **Reference Standards:** ASHRAE Handbook -- Fundamentals 2021, AHRI 410, ASHRAE 90.1-2022, ASHRAE Standard 55-2020

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1. Psychrometric Fundamentals

1.1 What Is Psychrometrics?

Psychrometrics is the branch of thermodynamics that studies the physical and thermal properties of moist air -- the mixture of dry air and water vapor present in every building and HVAC system. The word comes from the Greek "psychro" (cold) and "metron" (measure), reflecting the original wet-bulb thermometer method of measuring moisture content.

Every air-handling unit (AHU), rooftop unit (RTU), fan coil unit (FCU), and duct system in a building moves moist air from one thermodynamic state to another. Psychrometric analysis gives the engineer the tools to quantify those state changes and size the coils, fans, piping, and controls that make them happen.

1.2 Why It Matters for HVAC Design

Psychrometrics is not an academic exercise -- it is the foundation of every HVAC calculation that involves air:

- **Load calculations** depend on the enthalpy difference between outdoor air and room air, not just temperature difference. Ignoring latent load in a humid climate can undersize a cooling coil by 30% or more.
- **Cooling coil selection** requires knowing both sensible and latent loads so the coil can be sized for moisture removal. A coil that handles the sensible load but not the latent load will leave the space humid and uncomfortable.
- **Economizer control** compares outdoor-air enthalpy (or dry-bulb) against return-air enthalpy to decide when "free cooling" is available.
- **Indoor air quality** mandates a minimum outdoor-air fraction per ASHRAE 62.1; the mixed-air state determines coil entering conditions.
- **Energy modeling** (8760-hour simulations) evaluates every hour of the year at a different outdoor psychrometric state. The J∆S Engineering Suite `energy_simulation.py` module calls psychrometric functions 8,760 times per zone per year.
- **Dehumidification design** in humid climates (Miami, Houston, Singapore) requires understanding the dew point and the relationship between coil surface temperature and moisture condensation.
- **Humidification design** in dry/cold climates (Denver, Boise, Anchorage) requires understanding the drop in relative humidity when cold outdoor air is heated, and the energy required to add moisture.

1.3 The Seven Key Properties of Moist Air

Any point in the psychrometric state space is fully defined by exactly two independent properties plus the barometric pressure. From those two known values, all other properties can be calculated. The seven properties are:

1. **Dry-Bulb Temperature (DB)** -- The temperature measured by a standard thermometer shielded from radiation and moisture.
2. **Wet-Bulb Temperature (WB)** -- The temperature measured by a thermometer with a wet wick exposed to moving air. Evaporative cooling depresses the reading below the dry-bulb.
3. **Dew-Point Temperature (DP)** -- The temperature at which the air becomes saturated if cooled at constant pressure and constant humidity ratio.
4. **Relative Humidity (RH)** -- The ratio of the actual water-vapor partial pressure to the saturation pressure at the same dry-bulb temperature.
5. **Humidity Ratio (W)** -- The mass of water vapor per unit mass of dry air, expressed in lb water / lb dry air (or equivalently in grains/lb, where 7,000 grains = 1 lb).

6. Enthalpy (h) -- The total heat content of moist air per pound of dry air, measured in BTU/lb dry air.

7. Specific Volume (v) -- The volume occupied by one pound of dry air plus its associated water vapor, measured in ft3/lb dry air.

Each of these is described in full detail below.

1.4 Dry-Bulb Temperature (DB)

Dry-bulb temperature is the most common temperature measurement. It is the horizontal axis on the psychrometric chart and is what weather stations report.

- **Units:** Degrees Fahrenheit (F) in IP system; Degrees Celsius (C) in SI
- **Typical HVAC range:** -10 F (heating design) to 115 F (cooling design)
- **Indoor design:** Typically 72-76 F for cooling, 68-72 F for heating
- **Chart location:** Horizontal axis (x-axis)

1.5 Wet-Bulb Temperature (WB)

Wet-bulb temperature is measured by wrapping a wet cotton wick around the thermometer bulb and aspirating air over it at a minimum velocity of 900 FPM. Evaporative cooling depresses the reading below the dry-bulb. The greater the humidity, the smaller the depression, because the air cannot evaporate as much water.

- **Units:** Degrees Fahrenheit (F)
- **Relationship to DB:** WB is always less than or equal to DB. They are equal only at 100% RH (saturation).
- **Chart location:** Diagonal lines slanting downward from left to right. These lines are nearly parallel to constant-enthalpy lines.
- **Practical use:** Weather stations report both DB and WB. ASHRAE design conditions are typically specified as DB/MCWB (mean coincident wet-bulb).

1.6 Dew-Point Temperature (DP)

The dew point is the temperature at which moisture begins to condense out of the air if the air is cooled at constant pressure and constant humidity ratio. It is the temperature where the saturation curve intersects the horizontal line drawn from the air's current humidity ratio.

- **Units:** Degrees Fahrenheit (F)
- **Relationship to DB:** DP is always less than or equal to DB. They are equal only at 100% RH.
- **Relationship to W:** Dew point is uniquely determined by humidity ratio (at a given pressure). Two states with the same W have the same DP, regardless of their dry-bulb temperatures.

- **Practical use:** If the cooling coil surface temperature is below the

entering air dew point, condensation will form and the coil removes moisture (latent cooling). If the surface is above the dew point, only sensible cooling occurs.

- **Building envelope use:** If the interior surface temperature of a wall

or window drops below the indoor dew point, condensation forms.

1.7 Relative Humidity (RH)

Relative humidity is the ratio of the actual water-vapor partial pressure (Pv) to the saturation pressure (Pws) at the same dry-bulb temperature:

```
RH = Pv / Pws
```

- **Units:** Fraction (0 to 1) or percentage (0% to 100%)
- **Comfort range:** 30% to 60% RH per ASHRAE Standard 55
- **Chart location:** Curved lines bowing upward from left to right. The

saturation curve (100% RH) forms the upper-left boundary of the chart.

- **Key behavior:** Relative humidity is temperature-dependent. When air is

heated at constant humidity ratio, RH drops (the air can "hold more" moisture at the higher temperature). This is why heated buildings in winter feel dry.

1.8 Humidity Ratio (W)

Humidity ratio, also called mixing ratio or moisture content, is the mass of water vapor per unit mass of dry air:

```
W = 0.621945 * Pv / (P_atm - Pv) [lb water / lb dry air]
```

The constant 0.621945 is the ratio of the molecular weight of water (18.015) to the molecular weight of dry air (28.966).

- **Units:** lb water / lb dry air. Also expressible as grains per lb:

7,000 grains = 1 lb, so W(grains) = W(lb/lb) x 7,000.

- **Typical indoor value:** About 0.0093 lb/lb (65.1 grains/lb) at 75 F DB,

50% RH, sea level.

- **Chart location:** Vertical axis (y-axis) on the right side of the chart.

Horizontal lines across the chart represent constant humidity ratio.

- **Key behavior:** Humidity ratio is conserved during sensible-only processes

(heating coil, fan heat, duct heat gain). It changes only when water is added (humidification) or removed (dehumidification via a coil below the dew point).

1.9 Enthalpy (h)

Enthalpy represents the total heat content of moist air per pound of dry air:

```
h = 0.240 * T + W * (1061 + 0.444 * T) [BTU/lb dry air]
```

Where:

- 0.240 = specific heat of dry air (BTU/lb-F)
- 1061 = latent heat of vaporization of water at approximately 70 F (BTU/lb)
- 0.444 = specific heat of water vapor (BTU/lb-F)
- T = dry-bulb temperature (F)
- W = humidity ratio (lb/lb)

Breaking this down:

- The term `0.240 * T` is the sensible heat of the dry air.
- The term `W * 1061` is the latent heat of the water vapor.
- The term `W` *`0.444`* `T` is the sensible heat of the water vapor

(superheat above 0 F).

- **Units:** BTU per lb of dry air
- **Chart location:** Diagonal lines that run nearly parallel to constant

wet-bulb lines. They extend from the upper-left region to the lower-right.

- **Typical values:** Indoor air at 75 F / 50% RH has h of about 28.1 BTU/lb.

Hot humid outdoor air at 95 F / 75 F WB has h of about 38.5 BTU/lb.

1.10 Specific Volume (v)

Specific volume is the volume occupied by one pound of dry air plus its associated water vapor:

```
v = 0.370486 * T_R * (1 + 1.607858 * W) / P_atm [ft3/lb dry air]
```

Where:

- T_R = T + 459.67 (absolute temperature in Rankine)
- P_atm = barometric pressure in psia
- 0.370486 = R_a / 144, where R_a = 53.350 ft-lbf/(lb-R) is the gas

constant for dry air

The moist-air density (not the dry-air density) is:

```
rho = (1 + W) / v [lb moist air / ft3]
```

- **Units:** ft3 per lb of dry air
- **Chart location:** Diagonal lines running from lower-left to upper-right,

steeper than enthalpy lines.

- **Typical values:** Standard air at 70 F, sea level: v = 13.33 ft3/lb.

At 75 F, 50% RH: v = 13.68 ft3/lb.

1.11 Moist Air Density

The density of moist air is derived from specific volume:

```
rho_dry = 1 / v [lb dry air / ft3]
rho_moist = (1 + W) / v [lb moist air / ft3]
```

Standard air density at sea level, 70 F:

- rho_dry = 0.075 lb/ft3 (the value used in the 1.08 and 4.5 constants)
- rho_moist = approximately 0.075 lb/ft3 (negligible difference at normal W)

At altitude, density decreases because pressure decreases. At Denver (5,280 ft), rho is approximately 17.5% lower than at sea level.

2. ASHRAE Equations -- Complete Reference

The J∆S Engineering Suite implements every psychrometric equation from ASHRAE Handbook -- Fundamentals 2021, Chapter 1. This section documents each equation, including the critical saturation pressure equations that use DIFFERENT coefficient sets for ice and liquid water.

2.1 Saturation Pressure -- ASHRAE Equations 4 and 5

The saturation pressure is the most critical psychrometric calculation. It determines the maximum amount of water vapor the air can hold at a given temperature. ASHRAE provides two separate equations with different coefficient sets, one for temperatures below freezing (over ice) and one for above freezing (over liquid water).

CRITICAL: These equations use DIFFERENT coefficients. Using the wrong set for the temperature range produces incorrect results.

Equation for Ice (T < 32 F) -- ASHRAE Eq. 4

Valid for temperatures from -148 F to 32 F (over ice surface):

```
ln(Pws) = C1/T_R + C2 + C3*T_R + C4*T_R^2 + C5*T_R^3 + C6*T_R^4 + C7*ln(T_R)
```

Constant	Value	Scientific Notation
C1	-10214.165	-1.0214165 x 10^4
C2	-4.8932428	-4.8932428 x 10^0
C3	-0.0053765794	-5.3765794 x 10^-3
C4	0.00000019202377	1.9202377 x 10^-7
C5	0.00000000035575832	3.5575832 x 10^-10
C6	-0.000000000000090344688	-9.0344688 x 10^-14
C7	4.1635019	4.1635019 x 10^0

Note this equation has 7 constants and includes a T_R^4 term.

Equation for Liquid Water (T >= 32 F) -- ASHRAE Eq. 5

Valid for temperatures from 32 F to 392 F (over liquid water surface):

```
ln(Pws) = C8/T_R + C9 + C10*T_R + C11*T_R^2 + C12*T_R^3 + C13*ln(T_R)
```

Constant	Value	Scientific Notation
C8	-10440.397	-1.0440397 x 10^4
C9	-11.294650	-1.1294650 x 10^1
C10	-0.027022355	-2.7022355 x 10^-2
C11	0.000012890360	1.2890360 x 10^-5
C12	-0.0000000024780681	-2.4780681 x 10^-9
C13	6.5459673	6.5459673 x 10^0

Note this equation has 6 constants (no T_R^4 term) and the coefficients are completely different from the ice equation.

In both cases:

- T_R = T(F) + 459.67 (temperature in Rankine)
- The result Pws is in psia (lb/in2 absolute)

Note on equation numbering across ASHRAE editions: *The* `coil_selection.py` *module references the liquid equation as "Equation 5" and the ice equation as "Equation 6." The* `psychrometrics.py` *unified module references them as "Equation 4" (ice) and "Equation 5" (liquid). Both reference the same ASHRAE Fundamentals coefficient sets; the numbering difference reflects edition-to-edition chapter reorganization. The coefficients are identical.*

Code Implementation

From `psychrometrics.py`:

```
def saturation_pressure(t_f: float) -> float:
t_f = max(-148, min(392, t_f))
t_r = t_f + 459.67 # Convert to Rankine

if t_f < 32:
# Ice equation (Equation 4)
C1 = -1.0214165e4
C2 = -4.8932428e0
C3 = -5.3765794e-3
C4 = 1.9202377e-7
C5 = 3.5575832e-10
C6 = -9.0344688e-14
C7 = 4.1635019e0
ln_pws = (C1/t_r + C2 + C3*t_r + C4*t_r**2 +
C5*t_r**3 + C6*t_r**4 + C7*math.log(t_r))
else:
# Water equation (Equation 5)
C8 = -1.0440397e4
C9 = -1.1294650e1
C10 = -2.7022355e-2
C11 = 1.2890360e-5
```

```
C12 = -2.4780681e-9
C13 = 6.5459673e0
ln_pws = (C8/t_r + C9 + C10*t_r + C11*t_r**2 +
C12*t_r**3 + C13*math.log(t_r))

return math.exp(ln_pws)
```

Verification Points

Temperature (F)	Expected Pws (psia)	Phase
0	0.01852	Ice
32	0.08865	Transition
55	0.2141	Liquid
75	0.4298	Liquid
100	0.9503	Liquid
212	14.696	Liquid (boiling at sea level)

2.2 Humidity Ratio from Relative Humidity

Given dry-bulb temperature, relative humidity, and barometric pressure:

```
Step 1: Pws = saturation_pressure(T_db)
Step 2: Pv = RH * Pws
Step 3: W = 0.621945 * Pv / (P_atm - Pv)
```

2.3 Humidity Ratio from Wet-Bulb Temperature

The humidity ratio can be calculated from the dry-bulb and wet-bulb temperatures using ASHRAE Fundamentals equations 33 and 34:

Above freezing (WB >= 32 F) -- Equation 33:

```
W = ((1093 - 0.556 * WB) * Ws_wb - 0.240 * (DB - WB)) / (1093 + 0.444 * DB - WB)
```

Below freezing (WB < 32 F) -- Equation 34:

```
W = ((1220 - 0.04 * WB) * Ws_wb - 0.240 * (DB - WB)) / (1220 + 0.444 * DB - 0.48 * WB)
```

Where:

- Ws_wb = saturation humidity ratio at the wet-bulb temperature
- Ws_wb = 0.621945 * Pws(WB) / (P_atm - Pws(WB))

2.4 Dew Point from Humidity Ratio

To find the dew point, first calculate the vapor pressure from the humidity ratio, then apply ASHRAE equations 37 and 38:

```
Step 1: Pv = P_atm * W / (0.621945 + W)
Step 2: alpha = ln(Pv)
```

Above freezing (Pv >= 0.08865 psia) -- Equation 37:

```
DP = 100.45 + 33.193*alpha + 2.319*alpha^2 + 0.17074*alpha^3 + 1.2063*Pv^0.1984
```

Below freezing (Pv < 0.08865 psia) -- Equation 38:

```
DP = 90.12 + 26.142*alpha + 0.8927*alpha^2
```

2.5 Wet-Bulb from Dry-Bulb and Humidity Ratio

There is no direct equation for wet-bulb from DB and W. The J∆S Engineering Suite uses a bisection method with enthalpy comparison:

1. Set search bounds: T_low = dew point, T_high = dry-bulb.
2. For each trial wet-bulb T_mid:

a. Calculate Ws_mid = saturation humidity ratio at T_mid. b. Calculate h_mid = enthalpy(T_mid, Ws_mid). c. Calculate h_target = enthalpy(DB, W). d. If h_mid > h_target, move upper bound down. Else move lower bound up.

3. Repeat for 40 iterations (yields accuracy better than 0.0001 F).

This works because lines of constant wet-bulb temperature are very nearly lines of constant enthalpy. The bisection finds the temperature on the saturation curve that has the same enthalpy as the given state point.

2.6 Enthalpy Formula

```
h = 0.240 * T + W * (1061 + 0.444 * T) [BTU/lb dry air]
```

The inverse -- finding W from DB and h:

```
W = (h - 0.240 * T) / (1061 + 0.444 * T)
```

2.7 Specific Volume Formula

```
v = 0.370486 * T_R * (1 + 1.607858 * W) / P_atm [ft3/lb dry air]
```

Where:

- T_R = T(F) + 459.67 (Rankine)
- P_atm = barometric pressure in psia
- 0.370486 = R_a / 144, from the ideal gas law applied to moist air
- 1.607858 = M_a / M_w = 28.966 / 18.015 (ratio of molecular weights)

2.8 Barometric Pressure at Altitude

The standard atmosphere model gives pressure at altitude:

```
P_atm = 14.696 * (1 - 0.0000068756 * Z)^5.2559 [psia]
```

Where Z is elevation in feet above sea level.

The inverse (altitude from pressure):

```
Z = (1 - (P_atm / 14.696)^(1/5.2559)) / 0.0000068756 [ft]
```

3. The Psychrometric Chart

3.1 Chart Structure

The psychrometric chart is a graphical representation of all moist-air properties on a single diagram. Understanding how to read and plot on this chart is fundamental to HVAC design.

Axes:

- Horizontal axis (x): Dry-bulb temperature (F)
- Right vertical axis (y): Humidity ratio (lb/lb or grains/lb)

Lines and Curves:

Feature	Appearance	What It Represents
Saturation curve (100% RH)	Bold curved line, upper boundary	Maximum moisture air can hold at each DB
Constant RH curves	Curved lines below saturation	Percentage of maximum moisture (10%, 20%...90%)
Constant WB lines	Diagonal lines sloping down-right	Points with the same wet-bulb temperature
Constant enthalpy lines	Near-parallel to WB lines	Points with the same total heat content
Constant W (horizontal)	Horizontal lines	Points with the same moisture content
Constant DB (vertical)	Vertical lines	Points at the same dry-bulb temperature
Constant specific volume	Diagonal lines (steeper than enthalpy)	Points at the same air volume per pound
Constant dew point	Horizontal lines from saturation curve	Points with the same dew-point temperature

3.2 How to Read the Chart -- Finding a State Point

To find any state point on the psychrometric chart, you need two independent properties. The most common pairs are DB + WB and DB + RH.

Method 1: DB + WB (e.g., 89 F DB / 69 F WB)

1. Find 89 F on the horizontal dry-bulb axis at the bottom.

2. Draw a vertical line upward from 89 F.

3. Find the 69 F wet-bulb line among the diagonal lines slanting from the

saturation curve downward to the right.

4. The intersection of the vertical line and the WB line is the state point.

5. Read across horizontally to the right axis for W (about 0.0104 lb/lb).

6. Note which RH curve is nearest to the point (about 34% RH).

7. Follow the nearest enthalpy diagonal to read h (about 33.2 BTU/lb).

Method 2: DB + RH (e.g., 75 F DB / 50% RH)

1. Find 75 F on the horizontal axis.
2. Find the 50% RH curve (roughly halfway between saturation and the bottom).
3. The intersection is the state point.
4. Read the humidity ratio from the right axis (about 0.0093 lb/lb or 65.1 grains/lb).

Method 3: DB + DP (e.g., 80 F DB / 55 F DP)

1. Find the 55 F dew-point line. This is a horizontal line extending from the saturation curve at 55 F to the right.
2. Find 80 F on the horizontal axis.
3. The intersection of the 80 F vertical and the 55 F DP horizontal line is the state point.

3.3 How to Plot HVAC Processes on the Chart

HVAC air processes appear as lines or paths on the psychrometric chart. The direction and slope of the line tell you what type of process is occurring.

Direction on Chart	Process Type
Horizontal right (constant W)	Sensible heating
Horizontal left (constant W)	Sensible cooling (above dew point)
Down and to the left, toward saturation	Cooling and dehumidification
Up (constant DB)	Adiabatic humidification (evaporative)
Up and to the right	Heating and humidification (steam)
Straight line between two points	Mixing of two airstreams
Angled up and to the right	Room process line (sensible + latent gain)

3.4 The Saturation Curve

The saturation curve (100% RH line) is the most important line on the chart. It represents the maximum amount of water vapor the air can hold at each temperature. Key properties of the saturation curve:

- It forms the upper-left boundary of the chart.
- All state points lie below and to the right of this curve.
- Cooling coil processes move toward this curve (air approaches saturation as it contacts the cold coil surface).
- The curve rises steeply at higher temperatures -- warm air can hold dramatically more moisture than cold air.

3.5 The J∆S Engineering Suite Chart Features

The desktop psychrometric chart (`standalone_psychrometric_calc.py` and `psychrometric_chart.py`) and the web chart (`psychrometric-chart.html`) display the following overlays:

- Saturation curve (100% RH) in cyan
- Constant RH curves (10% through 90%) in light blue with rotated labels
- Constant wet-bulb lines in orange
- Constant enthalpy lines in green (dashed)
- Constant dew-point lines in purple (dash-dot, horizontal from saturation)
- Constant specific-volume lines in tan (dashed, diagonal)
- ASHRAE Standard 55 comfort zones (optional, summer and winter)
- Vapor pressure scale on the far-right axis
- Grains/lb scale as an alternative to lb/lb
- Interactive crosshair with real-time property readout at cursor position

4. Air Processes

4.1 Sensible Heating

Sensible heating adds heat to the air without adding or removing moisture. This is what happens when air passes over a hot-water coil, electric heater, or gas furnace heat exchanger.

On the chart: Horizontal line moving to the right (constant W).

Equations:

```
Q_sensible = 1.08 * CFM * (T_leaving - T_entering) [BTU/hr]
```

What changes: DB increases, WB increases, RH decreases. **What stays constant:** W (humidity ratio), DP (dew point).

Example: Air at 45 F / 0.0040 lb/lb is heated to 72 F:

- W remains 0.0040 lb/lb
- DP remains the same (about 28 F)
- RH drops from about 55% to about 22%
- The air feels dry even though it has the same moisture content

This is why heated buildings in winter often need humidification.

4.2 Sensible Cooling (Above Dew Point)

If the cooling surface temperature is above the air's dew point, only sensible cooling occurs. No moisture is removed.

On the chart: Horizontal line moving to the left (constant W).

Example: Air at 85 F / 50% RH (DP = 63.5 F) passing over a surface at 70 F. Since 70 > 63.5, no condensation occurs. The air simply cools sensibly.

4.3 Cooling and Dehumidification

When the cooling surface temperature (coil, chilled beam, etc.) is below the air's dew point, both sensible and latent cooling occur. Moisture condenses on the surface and drains away.

On the chart: Line moving down and to the left, toward the saturation curve. The slope depends on the Sensible Heat Ratio (SHR).

Equations:

```
Q_total = 4.5 * CFM * (h_entering - h_leaving) [BTU/hr]
Q_sensible = 1.08 * CFM * (T_entering - T_leaving) [BTU/hr]
Q_latent = Q_total - Q_sensible [BTU/hr]
Q_latent = 4840 * CFM * (W_entering - W_leaving) [BTU/hr] (alternative)
SHR = Q_sensible / Q_total
```

What changes: DB decreases, WB decreases, W decreases, h decreases, RH increases (approaches 90-98% at coil leaving).

This is the most common cooling process in HVAC. Nearly every cooling coil in a humid climate operates below the dew point of the entering air.

4.4 Humidification (Adiabatic / Evaporative)

In adiabatic humidification (spray-type humidifier, wetted media), water evaporates into the airstream. The evaporation absorbs heat from the air itself, so the dry-bulb drops while the wet-bulb stays nearly constant.

On the chart: Line moving up and to the left, approximately along a constant wet-bulb line.

What changes: W increases, RH increases, DB decreases, DP increases. **What stays approximately constant:** WB, h (enthalpy).

This is the principle behind evaporative coolers (swamp coolers) used in dry climates. It works well in dry climates (Phoenix, Denver) but poorly in humid climates (Miami, Houston) because the air is already near saturation.

4.5 Steam Humidification

Steam humidification injects dry steam (at approximately 212 F) into the airstream. Unlike adiabatic humidification, steam adds both moisture and heat.

On the chart: Line moving up and slightly to the right (nearly vertical, because the temperature rise from the steam heat is small relative to the moisture addition).

What changes: W increases, RH increases, DB increases slightly.

4.6 Chemical Dehumidification

Desiccant systems (silica gel, lithium chloride) remove moisture by adsorption. The heat of adsorption raises the air temperature.

On the chart: Line moving down and to the right. Moisture decreases while temperature increases.

4.7 Mixing of Two Airstreams

When two airstreams at different conditions combine (outdoor air + return air in a mixing box), the resulting mixed-air state lies on the straight line connecting the two states on the psychrometric chart. The position along that line depends on the mass ratio of the two streams.

On the chart: Straight line between the two states. The mixed point divides the line in inverse proportion to the mass flow rates.

This is covered in detail in Section 6.

4.8 Fan Heat

The supply fan motor converts electrical energy into kinetic energy (airflow) and thermal energy (friction, motor heat). This thermal energy heats the airstream by approximately 1-3 F, depending on fan size and efficiency.

On the chart: Horizontal line moving to the right (identical to sensible heating). Humidity ratio is unchanged.

Typical values:

- Small AHU (5,000 CFM): 1-2 F fan heat
- Medium AHU (25,000 CFM): 2-3 F fan heat
- Large AHU (50,000+ CFM): 2-4 F fan heat

4.9 Room Process (Sensible + Latent Gain)

As supply air enters a room, it absorbs both sensible heat (from people, lights, equipment, envelope) and latent heat (from people, infiltration). The air state moves from the supply-air point upward and to the right toward the return-air point.

On the chart: Angled line from supply to return. The slope is determined by the room Sensible Heat Ratio:

```
Room SHR = Q_sensible_room / Q_total_room
```

The SHR line slope on the psychrometric chart is:

```
dW/dT = (0.240 * (1 - SHR)) / (1061 * SHR) [lb/lb per F]
```

Higher SHR (sensible-dominated) = flatter line (more horizontal). Lower SHR (latent-heavy, like a kitchen) = steeper line (more vertical).

5. Coil Processes

5.1 Cooling Coil -- Total, Sensible, and Latent Loads

The cooling coil is the central component in an air conditioning system. It simultaneously removes sensible heat (lowers temperature) and latent heat (removes moisture) from the airstream.

Total coil load (enthalpy-based):

```
Q_total = 4.5 * CFM * (h_entering - h_leaving) [BTU/hr]
```

The constant 4.5 = 60 min/hr x 0.075 lb/ft3 (standard air density).

Sensible coil load (temperature-based):

```
Q_sensible = 1.08 * CFM * (T_entering - T_leaving) [BTU/hr]
```

The constant 1.08 = 60 x 0.075 x 0.24 (min x density x Cp_air).

Latent coil load (humidity ratio-based):

```
Q_latent = 4840 * CFM * (W_entering - W_leaving) [BTU/hr]
```

The constant 4840 = 60 x 0.075 x 1076 (min x density x h_fg at ~75 F).

Or simply: Q_latent = Q_total - Q_sensible.

> ***IMPORTANT:*** *The constants 1.08, 4.5, and 4840 all assume standard sea-level air density of 0.075 lb/ft3. At altitude, these must be corrected. See Section 7.*

5.2 Coil Sensible Heat Ratio (SHR)

```
Coil SHR = Q_sensible / Q_total
```

The coil SHR determines the slope of the coil process line on the chart:

Coil SHR	Interpretation	Typical Application
0.95-1.00	Almost all sensible	Dry climate, low OA fraction
0.80-0.95	Moderate latent	Typical comfort cooling
0.70-0.80	Significant latent	Humid climate, high OA fraction
0.50-0.70	Heavy latent	Dedicated outdoor air system (DOAS)
< 0.50	Mostly latent	Process dehumidification

5.3 Bypass Factor (BF)

The bypass factor represents the fraction of air that passes through the coil without contacting the surface. Not all air molecules touch the coil fins; some "bypass" through the gaps.

```
BF = (T_leaving - ADP) / (T_entering - ADP)
```

Or equivalently:

```
T_leaving = BF * T_entering + (1 - BF) * ADP
```

The same relationship applies to humidity ratio:

```
W_leaving = BF * W_entering + (1 - BF) * W_adp
```

Typical bypass factors:

Coil Rows	Fins/Inch	Face Velocity	Bypass Factor
3	8	500 FPM	0.12 - 0.18
4	10	500 FPM	0.08 - 0.12
6	12	500 FPM	0.04 - 0.08
8	14	400 FPM	0.02 - 0.04

Factors that decrease BF (more effective coil):

- More rows (more surface contact)
- More fins per inch (finer spacing)
- Lower face velocity (more contact time)
- Wet coil (condensate improves heat transfer)

The J∆S Engineering Suite calculates BF dynamically using the `calculate_bypass_factor()` function, which correlates rows, FPI, face velocity, and coil type.

5.4 Apparatus Dew Point (ADP)

The apparatus dew point is the effective surface temperature of the cooling coil. If all the air made perfect contact with the coil surface (BF = 0), it would leave at the ADP at 100% saturation.

```
ADP = (T_leaving - BF * T_entering) / (1 - BF)
```

The ADP is a useful concept because it tells you:

- The minimum achievable leaving-air temperature (at BF = 0)
- The chilled water temperature needed (ADP is slightly above EWT)
- Whether the coil can achieve the required dehumidification

Relationship to chilled water: For a typical chilled-water coil with 44 F entering water and 56 F leaving water, the ADP is typically 49-52 F, depending on coil geometry.

5.5 Heating Coil

A heating coil (hot water, steam, electric) is a sensible-only process. No moisture is added or removed.

```
Q_heating = 1.08 * CFM * (T_leaving - T_entering) [BTU/hr]
```

Hot water flow:

```
HW GPM = Q_heating / (500 * Delta_T_hw)
```

Where 500 = 60 x 8.33 x 1.0 (min x lb/gal x Cp_water), and Delta_T_hw is typically 20 F (180/160 F system) or 30 F (140/110 F low-temp system).

5.6 Chilled Water Flow

```
CHW GPM = Q_total / (500 * Delta_T_chw)
```

For a standard 44/56 F chilled-water system (Delta_T = 12 F):

```
CHW GPM = Q_total / 6,000
```

5.7 Coil Tonnage

```
Tons = Q_total / 12,000
```

One ton of refrigeration = 12,000 BTU/hr = the rate of heat absorption when melting one ton (2,000 lb) of ice in 24 hours.

6. Mixed Air Calculations

6.1 Mixing Box Fundamentals

Every AHU with an outdoor-air intake has a mixing box where outdoor air (OA) and return air (RA) blend before entering the coil. The mixed-air (MA) state determines the coil entering conditions and therefore the coil load.

6.2 Simple Volumetric Mixing (Approximation)

For a quick approximation when OA and RA temperatures are within 30 F of each other, use volumetric mixing:

```
T_mix = OA_fraction * T_OA + (1 - OA_fraction) * T_RA
W_mix = OA_fraction * W_OA + (1 - OA_fraction) * W_RA
h_mix = OA_fraction * h_OA + (1 - OA_fraction) * h_RA
```

Where OA_fraction = OA_CFM / Total_CFM.

6.3 Mass-Weighted Mixing (Accurate)

For accurate results, especially when OA and RA temperatures differ significantly, the J∆S Engineering Suite uses mass-weighted averaging:

```
Step 1: m_OA = CFM_OA / v_OA (mass flow of outdoor air, lb/min)
Step 2: m_RA = CFM_RA / v_RA (mass flow of return air, lb/min)
Step 3: m_total = m_OA + m_RA
Step 4: f_OA = m_OA / m_total (mass fraction of outdoor air)
Step 5: f_RA = m_RA / m_total (mass fraction of return air)
Step 6: T_mix = f_OA * T_OA + f_RA * T_RA
Step 7: W_mix = f_OA * W_OA + f_RA * W_RA
```

Then calculate the complete mixed-air state from T_mix and W_mix.

The difference between volumetric and mass-weighted mixing is typically small (0.1-0.3 F) for normal conditions, but can be 1-2 F when outdoor temperature exceeds 100 F or is below 0 F.

6.4 Dynamic OA Fraction Calculation

In the J∆S Engineering Suite, the OA fraction can come from:

1. **ASHRAE 62.1 ventilation calculation** -- Based on zone population,

area, and system ventilation efficiency.

2. User-specified percentage -- Direct entry of OA%.

3. Actual CFM values -- User enters OA CFM and Total CFM separately.

4. Economizer calculation -- Dynamic OA fraction based on outdoor

conditions (see Section 15).

6.5 Multi-Stream Mixing

The desktop tool supports mixing more than two airstreams. The `_build_air_collection_group()` in `standalone_psychrometric_calc.py` provides a multi-stream mixing calculator where the user can specify multiple airstreams with different conditions and flow rates:

```
For N streams with states S_i and flows CFM_i:
m_i = CFM_i / v_i (mass flow of each stream)
m_total = sum(m_i)
T_mix = sum(m_i * T_i) / m_total
W_mix = sum(m_i * W_i) / m_total
```

6.6 Graphical Mixing on the Psychrometric Chart

On the psychrometric chart, the mixed-air point lies on the straight line connecting the OA and RA points. The position is determined by the lever rule:

- If OA fraction is 20%, the mixed point is 20% of the distance from RA

toward OA.

- If OA fraction is 100%, the mixed point coincides with OA.
- If OA fraction is 0%, the mixed point coincides with RA.

7. Altitude Effects

7.1 Why Altitude Matters

At elevations above sea level, the reduced atmospheric pressure changes air density, which affects virtually every psychrometric and HVAC calculation. This is one of the most commonly overlooked factors in HVAC design.

7.2 Barometric Pressure at Altitude

```
P_atm = 14.696 * (1 - 0.0000068756 * Z)^5.2559 [psia]
```

Location	Elevation (ft)	P_atm (psia)	Pressure Ratio
Sea Level	0	14.696	1.000
San Diego, CA	16	14.694	1.000
Phoenix, AZ	1,086	14.148	0.963
Salt Lake City, UT	4,226	12.626	0.859

Location	Elevation (ft)	P_atm (psia)	Pressure Ratio
Denver, CO	5,280	12.130	0.825
Albuquerque, NM	5,312	12.112	0.824
Flagstaff, AZ	6,910	11.445	0.779
Mexico City	7,350	11.257	0.766
La Paz, Bolivia	11,975	9.478	0.645

7.3 The Pressure Ratio and Corrected Constants

The pressure ratio (also called density ratio) is:

```
pressure_ratio = P_alt / P_sea_level = P_alt / 14.696
```

All standard HVAC airflow constants must be multiplied by this ratio:

Constant	Sea Level	Formula	Denver (5,280 ft)
Sensible: 1.08	1.08	1.08 * pressure_ratio	0.893
Total: 4.5	4.5	4.5 * pressure_ratio	3.71
Latent: 4840	4840	4840 * pressure_ratio	3,993

Why the correction is needed: These constants all contain the standard air density of 0.075 lb/ft3. At altitude, the density is lower because the pressure is lower. The same CFM of airflow carries fewer pounds of air per minute, so it carries less heat.

7.4 Effect on Psychrometric Properties

At altitude, for the same DB and RH:

1. Humidity ratio INCREASES. The saturation pressure Pws depends only

on temperature, but W = 0.621945 * Pv / (P_atm - Pv). With lower P_atm, the denominator is smaller, so W is larger. At Denver, W is about 21% higher than at sea level for the same DB/RH.

2. Specific volume INCREASES. With lower pressure in the denominator of

the specific volume formula, v increases. This means the air is less dense.

3. Enthalpy INCREASES. Because W is higher, and enthalpy includes the

term W *(1061 + 0.444* T), the total enthalpy is higher.

4. Dew point INCREASES. Because W is higher, the dew point is higher for

the same DB/RH combination.

5. Wet-bulb depression CHANGES. The wet-bulb depression (DB - WB) changes

at altitude due to the pressure-dependent psychrometric equations.

7.5 Practical Implications for HVAC Design at Altitude

1. Larger ducts and fans. The same mass flow requires more CFM because the air is less dense. Ducts must be larger to maintain acceptable velocities without excessive static pressure.

2. Sensible load per CFM is lower. Each cubic foot of air carries less heat. You need more CFM to handle the same load.

3. Fan motor sizing. Fan laws show that at lower density, the same fan speed produces less pressure rise and less power draw. But the required CFM is higher, so the net effect depends on the system.

4. Cooling towers and evaporative coolers. Lower pressure means lower boiling point and easier evaporation. Evaporative cooling is more effective at altitude.

5. Combustion equipment. Gas furnaces and boilers must be derated at altitude because the air contains less oxygen per unit volume.

7.6 Implementation in the J∆S Engineering Suite

The `PsychrometricCalculator` class accepts an `altitude_ft` parameter:

```
calc = PsychrometricCalculator(altitude_ft=5280) # Denver
state = calc.state_from_db_rh(75, 0.50)
print(f"P_atm: {calc.p_atm:.3f} psia") # 12.130
print(f"W: {state.humidity_ratio:.5f} lb/lb") # Higher than sea level
print(f"v: {state.specific_volume:.2f} ft3/lb") # Higher than sea level
```

The `CoilCalculationEngine` in `coil_calcs.py` also applies altitude correction:

```
engine = CoilCalculationEngine(altitude_ft=5280)
# engine.sensible_factor is now 0.893 instead of 1.08
```

8. Desktop Psychrometric Tool -- Step-by-Step

8.1 Launching the Tool

The psychrometric calculator is launched from the J∆S Engineering Suite dashboard:

1. Open the application: `python launcher.py`

2. Log in with your credentials.

3. In the sidebar, find "Psychrometrics" under the Engineering Tools category.

4. Click to launch the standalone psychrometric calculator.

The tool opens as a full-featured PyQt6 application with:

- Interactive psychrometric chart on the left (70% of screen width)

- Controls panel on the right (30% of screen width)
- Header bar with export buttons (Copy, PDF, CSV)
- Status bar at the bottom
- Hint bar below the chart: "Click on chart to add points | Scroll to zoom | Right-drag to pan"

8.2 Setting the Altitude

Before performing any calculations, set the correct altitude:

1. In the "Altitude" group at the top of the right panel, enter the project elevation in feet.

2. The barometric pressure updates automatically and is displayed in psia.

3. The psychrometric chart redraws with the corrected saturation curve.

Example: For a project in Denver, enter 5280. The pressure label shows 12.130 psia.

8.3 Selecting Input Properties

The tool supports six input property pairs:

Input Mode	Fields
Dry Bulb + Relative Humidity	DB (F) and RH (%)
Dry Bulb + Wet Bulb	DB (F) and WB (F)
Dry Bulb + Dew Point	DB (F) and DP (F)
Dry Bulb + Humidity Ratio	DB (F) and W (grains/lb)
Dry Bulb + Enthalpy	DB (F) and h (BTU/lb)
Wet Bulb + Relative Humidity	WB (F) and RH (%)

Select the input mode from the dropdown, enter values, and click "Calculate & Plot."

8.4 Reading the Results

After calculation, the "Calculated Properties" panel shows all properties in a compact two-column layout:

- DB (dry-bulb, F)
- WB (wet-bulb, F)
- DP (dew point, F)
- RH (relative humidity, %)
- W (humidity ratio, lb/lb and grains/lb)
- h (enthalpy, BTU/lb)
- v (specific volume, ft3/lb)

- rho (density, lb/ft3)
- Pv (vapor pressure, psia)

All values are selectable for copy-paste.

8.5 Adding State Points to the Chart

Method 1: Calculate and Plot Enter properties and click "Calculate & Plot." The point is plotted on the chart with an auto-assigned color and index number.

Method 2: Click on Chart Left-click directly on the chart. The point is added at the clicked DB and W coordinates.

State points are listed in the "State Points" table showing: index, label, color, DB, WB, RH, DP, W, and h. Double-click the label column to rename a point (e.g., "OA", "RA", "MA", "SA").

8.6 Auto-Connect and Process Lines

When "Connect Points" is checked (default), the chart automatically draws dashed lines with arrowheads between consecutive state points. The lines are color-coded:

- Blue: Cooling and dehumidification (DB drops, W drops)
- Red: Heating (DB rises)
- Green: Humidification (W rises)
- Gray: Other processes

8.7 Process Analysis

In the "Process Analysis" panel:

1. Enter the airflow in CFM.

2. The tool automatically calculates for each consecutive pair of points:

- Temperature changes: delta-DB, delta-WB, delta-DP
- Humidity changes: delta-W (grains/lb), delta-RH (%)
- Enthalpy change: delta-h (BTU/lb)
- Sensible load (BTU/hr and tons)
- Latent load (BTU/hr and tons)
- Total load (BTU/hr and tons)
- Sensible Heat Ratio (SHR)

8.8 Quick Calculations

The "Quick Calculations" panel provides four common operations:

1. Mix Two Points: Select two state points and their CFM values.

Calculates the mixed-air state and plots it.

2. Sensible Heat Only: Select a starting point and enter a delta-T. Calculates the new state after sensible heating/cooling.

3. Target Supply Temp: Select a starting point and enter a target DB and RH. Calculates the coil leaving conditions.

4. Required CFM: Given two points and a load (total, sensible, or latent), calculates the airflow needed.

8.9 Advanced Mode

Click "Advanced Mode" in the header to reveal additional tools:

- **HVAC Process Modeling:** Model multi-step processes (OA, mix, cool, heat, supply).
- **Coil LAT Calculator:** Calculate leaving-air temperature for a coil given entering conditions and bypass factor.
- **Air Collection:** Multi-stream mixing calculator for complex systems.
- **SHR Line Tool:** Plot a sensible-heat-ratio line from any state point.
- **Weather Data Lookup:** Look up ASHRAE design conditions for US cities.
- **Chart Settings:** Toggle display of RH lines, WB lines, enthalpy lines, dew-point lines, specific-volume lines, comfort zones, grids, and the vapor-pressure scale.
- **Unit Toggle:** Switch between IP and SI units.

8.10 Zooming and Panning

- **Scroll wheel:** Zoom in/out centered on cursor position.
- **Right-click drag:** Pan the chart.
- The chart range automatically adjusts (DB: -40 to 200 F; W: 0.005 to 0.050 lb/lb).
- Click "Reset Zoom" to restore defaults (20-120 F DB, 0-0.030 W).

8.11 Exporting

Copy to Clipboard: Copies all state point data as formatted text.

Export PDF: Renders the psychrometric chart to a PDF file. The chart is drawn at high resolution with all state points, process lines, and labels.

Export CSV: Saves all state points to a CSV file with columns for every property (DB, WB, DP, RH, W, h, v, rho, Pv, Pws, P_atm).

8.12 Managing State Points

- **Remove:** Select a point in the table and click "Remove."
- **Clear All:** Remove all state points.
- **Move Up:** Change point order (affects auto-connect lines).
- **Rename:** Double-click the label column to edit the point name.

9. Web Psychrometric Calculator -- Step-by-Step

9.1 Accessing the Web Calculator

The web-based psychrometric calculator is available on the JΔS Engineering Suite website at the free-tools page. It provides quick calculations without installing the desktop application.

9.2 Input Fields

The web calculator accepts three inputs:

1. **Dry Bulb Temperature (F):** Default 75 F.
2. **Relative Humidity (%):** Default 50%.
3. **Altitude (ft):** Default 0 (sea level).

9.3 Calculation Process

When you click "Calculate," the JavaScript implementation:

1. Converts altitude to barometric pressure using the standard atmosphere formula.
2. Calculates saturation pressure using the same ASHRAE equations as the desktop app (Eq. 4 for ice, Eq. 5 for liquid, with identical coefficients).
3. Calculates vapor pressure: Pv = RH * Pws.
4. Calculates humidity ratio: W = 0.621945 * Pv / (P_atm - Pv).
5. Calculates enthalpy: h = 0.240 *DB* + *W* (1061 + 0.444 * DB).
6. Calculates specific volume: v = 0.370486 *T_R* (1 + 1.607858 * W) / P_atm.
7. Calculates density: rho = (1 + W) / v.
8. Calculates dew point using ASHRAE Eq. 37/38.
9. Calculates wet bulb using 40-iteration bisection method matching desktop.

9.4 Output

The web calculator displays:

- Humidity Ratio (lb/lb and grains/lb)
- Enthalpy (BTU/lb)
- Dew Point (F)
- Wet Bulb (F)
- Specific Volume (ft3/lb)
- Density (lb/ft3)
- Saturation Pressure (psia)
- Vapor Pressure (psia)
- Barometric Pressure (in Hg and psia)

All results match the desktop application to within rounding precision.

10. Web Psychrometric Chart -- Interactive Tool

10.1 Overview

The website also hosts a full interactive psychrometric chart at `psychrometric-chart.html`. This HTML5 Canvas-based tool provides:

- Full ASHRAE psychrometric chart with saturation curve, RH lines, WB lines,

and enthalpy lines

- Multiple input methods (DB+RH, DB+WB, DB+DP)
- Click-to-add state points on the chart canvas
- Altitude correction
- State point table with all calculated properties
- Process line visualization between points

10.2 Adding Points

1. Enter properties in the input panel on the right side.
2. Click "Add Point" to calculate and plot.
3. Or click directly on the chart canvas to add a point at that location.

10.3 Chart Navigation

- Hover over the chart to see real-time property values at the cursor

position.

- State points appear as colored dots with labels.

- Process lines connect consecutive points with directional arrows.

11. Real-World Worked Examples

11.1 Example 1: San Diego Cooling Design -- Complete AHU Analysis

System Parameters:

Parameter	Value
Unit	AHU-1 serving office floors
Supply airflow	26,125 CFM
Outdoor airflow	7,470 CFM (per ASHRAE 62.1)
OA fraction	28.6% (7,470 / 26,125)
Return airflow	18,655 CFM
Location	San Diego, CA
ASHRAE Climate Zone	3C (Marine)
Cooling design DB/MCWB	89 F / 69 F (0.4% annual)
Chilled water	44 F EWT / 56 F LWT
Altitude	16 ft (sea level)

State Point 1 -- Outdoor Air (OA):

Start with DB = 89 F, WB = 69 F.

```
Step 1: Pws at 69 F WB:
T_R = 69 + 459.67 = 528.67 R
ln(Pws) = -10440.397/528.67 + (-11.29465) + (-0.027022355)*528.67
+ 1.289036e-5 * 528.67^2 + (-2.4780681e-9) * 528.67^3
+ 6.5459673 * ln(528.67)
Pws(69) = 0.3392 psia

Step 2: Ws at 69 F WB:
Ws = 0.621945 * 0.3392 / (14.696 - 0.3392) = 0.01470 lb/lb

Step 3: W from ASHRAE Eq. 33:
W = ((1093 - 0.556*69) * 0.01470 - 0.240*(89-69)) / (1093 + 0.444*89 - 69)
W = (1054.64 * 0.01470 - 4.80) / 1063.5
W = (15.503 - 4.80) / 1063.5
W = 0.01006 lb/lb (about 70.4 grains/lb)

Step 4: All other properties from DB=89, W=0.01006:
Pv = 14.696 * 0.01006 / (0.621945 + 0.01006) = 0.2340 psia
Pws(89) = 0.6343 psia
RH = 0.2340 / 0.6343 = 36.9%
h = 0.240*89 + 0.01006*(1061 + 0.444*89) = 21.36 + 11.06 = 32.42 BTU/lb
v = 0.370486 * 548.67 * (1 + 1.607858*0.01006) / 14.696 = 14.05 ft3/lb
```

Property	Value
DB	89.0 F
WB	69.0 F
DP	~61 F
RH	~37%
W	0.0101 lb/lb (70.4 gr/lb)
h	~32.4 BTU/lb
v	~14.05 ft3/lb

State Point 2 -- Return Air (RA):

DB = 75 F, RH = 50%.

```
Pws(75) = 0.4298 psia
Pv = 0.50 * 0.4298 = 0.2149 psia
W = 0.621945 * 0.2149 / (14.696 - 0.2149) = 0.00923 lb/lb (64.6 gr/lb)
h = 0.240*75 + 0.00923*(1061 + 0.444*75) = 18.00 + 10.07 = 28.07 BTU/lb
v = 0.370486 * 534.67 * (1 + 1.607858*0.00923) / 14.696 = 13.68 ft3/lb
DP = ~55.1 F (from Eq. 37)
WB = ~62.5 F (from bisection)
```

Property	Value
DB	75.0 F
WB	~62.5 F
DP	~55.1 F
RH	50%
W	0.00923 lb/lb (64.6 gr/lb)
h	~28.1 BTU/lb
v	~13.68 ft3/lb

State Point 3 -- Mixed Air (MA):

Using mass-weighted mixing:

```
m_OA = 7,470 / 14.05 = 531.7 lb/min
m_RA = 18,655 / 13.68 = 1,363.7 lb/min
m_total = 1,895.4 lb/min
f_OA = 531.7 / 1,895.4 = 0.2805
f_RA = 1,363.7 / 1,895.4 = 0.7195

T_mix = 0.2805 * 89.0 + 0.7195 * 75.0 = 24.96 + 53.96 = 78.9 F
W_mix = 0.2805 * 0.0101 + 0.7195 * 0.00923 = 0.00283 + 0.00664 = 0.00947 lb/lb
h_mix = 0.240*78.9 + 0.00947*(1061 + 0.444*78.9) = 18.94 + 10.38 = 29.32 BTU/lb
```

Property	Value
DB	78.9 F

Property	Value
W	0.00947 lb/lb (66.3 gr/lb)
h	~29.3 BTU/lb
RH	~44%

State Point 4 -- Leaving Coil (LC):

Target: 53 F DB, approximately 92% RH (typical coil leaving condition).

```
Pws(53) = 0.1917 psia
Pv = 0.92 * 0.1917 = 0.1764 psia
W = 0.621945 * 0.1764 / (14.696 - 0.1764) = 0.00755 lb/lb (52.9 gr/lb)
h = 0.240*53 + 0.00755*(1061 + 0.444*53) = 12.72 + 8.18 = 20.90 BTU/lb
```

State Point 5 -- Supply Air (SA):

After the coil, the supply fan adds approximately 2 F of sensible heat.

```
DB = 53 + 2 = 55 F
W = 0.00755 lb/lb (unchanged -- sensible-only process)
h = 0.240*55 + 0.00755*(1061 + 0.444*55) = 13.20 + 8.19 = 21.39 BTU/lb
RH ~ 86% (drops because DB increased while W stayed constant)
```

Coil Load Calculations:

```
Q_total = 4.5 * 26,125 * (29.3 - 20.9) = 4.5 * 26,125 * 8.4 = 987,525 BTU/hr
Q_sensible = 1.08 * 26,125 * (78.9 - 53.0) = 1.08 * 26,125 * 25.9 = 730,827 BTU/hr
Q_latent = 987,525 - 730,827 = 256,698 BTU/hr
Coil SHR = 730,827 / 987,525 = 0.74
Coil Tons = 987,525 / 12,000 = 82.3 tons
CHW GPM = 987,525 / (500 * 12) = 164.6 GPM
```

Complete State Point Table:

Property	SP1: OA	SP2: RA	SP3: MA	SP4: LC	SP5: SA
DB (F)	89.0	75.0	78.9	53.0	55.0
WB (F)	69.0	62.5	64.0	52.0	52.5
DP (F)	61.0	55.1	56.5	51.5	51.5
RH (%)	37	50	44	92	86
W (lb/lb)	0.0101	0.0092	0.0095	0.0076	0.0076
W (gr/lb)	70.4	64.6	66.3	52.9	52.9
h (BTU/lb)	32.4	28.1	29.3	20.9	21.4
v (ft3/lb)	14.05	13.68	13.78	13.14	13.19

11.2 Example 2: Denver Altitude Correction

The same AHU-1 system at Denver (5,280 ft) instead of San Diego.

Step 1: Barometric pressure

```
P_atm = 14.696 * (1 - 0.0000068756 * 5280)^5.2559 = 12.130 psia
pressure_ratio = 12.130 / 14.696 = 0.825
```

Step 2: Corrected constants

```
Sensible factor = 1.08 * 0.825 = 0.893
Total factor = 4.5 * 0.825 = 3.71
Latent factor = 4840 * 0.825 = 3,993
```

Step 3: Room conditions at altitude

At 75 F / 50% RH in Denver:

```
Pws(75) = 0.4298 psia (same -- independent of altitude)
Pv = 0.50 * 0.4298 = 0.2149 psia (same)
W = 0.621945 * 0.2149 / (12.130 - 0.2149) = 0.01122 lb/lb
```

Notice W is 0.01122 at Denver vs. 0.00923 at sea level -- a 21.6% increase for the same DB/RH condition.

```
v = 0.370486 * 534.67 * (1 + 1.607858*0.01122) / 12.130 = 16.54 ft3/lb
```

Specific volume is 16.54 vs. 13.68 at sea level -- a 20.9% increase. The air is much less dense.

Step 4: Coil load at altitude

Using the same airflow (26,125 CFM) and mixed-air conditions, but with altitude-corrected constants:

```
Q_sensible = 0.893 * 26,125 * 25.9 = 604,218 BTU/hr (vs 730,827 at sea level)
```

The sensible load is 17.3% lower per CFM. However, the required CFM is typically higher at altitude (same mass flow requires more volume flow), so the total system load may not change as much.

11.3 Example 3: Houston -- High Latent Load

Houston design conditions: 97 F DB / 79 F MCWB (0.4% cooling).

```
W_OA = humidity_ratio_from_wb(97, 79, 14.696) = 0.01587 lb/lb (111 gr/lb)
h_OA = 0.240*97 + 0.01587*(1061 + 0.444*97) = 23.28 + 17.54 = 40.82 BTU/lb
```

Room conditions: 75 F / 50% RH:

```
W_RA = 0.00923 lb/lb
h_RA = 28.07 BTU/lb
```

Mixed air at 20% OA:

```
T_mix = 0.20*97 + 0.80*75 = 79.4 F
W_mix = 0.20*0.01587 + 0.80*0.00923 = 0.01056 lb/lb
h_mix = 0.20*40.82 + 0.80*28.07 = 30.62 BTU/lb
```

Coil leaving at 53 F / 92% RH:

```
W_LC = 0.00755 lb/lb
h_LC = 20.90 BTU/lb
```

Coil loads at 10,000 CFM:

```
Q_total = 4.5 * 10,000 * (30.62 - 20.90) = 437,400 BTU/hr = 36.5 tons
Q_sensible = 1.08 * 10,000 * (79.4 - 53.0) = 285,120 BTU/hr
Q_latent = 437,400 - 285,120 = 152,280 BTU/hr
SHR = 285,120 / 437,400 = 0.65
```

The SHR of 0.65 is characteristic of Houston's humid climate -- the coil must handle a very large latent load compared to San Diego's SHR of 0.74.

11.4 Example 4: Economizer Analysis at 55 F Outdoor Air

San Diego frequently has mild outdoor conditions perfect for economizer operation. At 55 F OA / 40% RH:

```
OA: DB=55, RH=0.40 -> W=0.00369, h=17.12
RA: DB=75, RH=0.50 -> W=0.00923, h=28.07

Required OA fraction for 55 F supply:
OA_frac = (75 - 55) / (75 - 55) = 1.0 -> 100% OA

But at 100% OA, mixed air = 55 F -> equals supply setpoint!
Mechanical cooling = 0 BTU/hr
Free cooling = 1.08 * 26,125 * (75 - 55) = 564,300 BTU/hr = 47.0 tons saved
```

This is "full free cooling" -- the economizer provides all the cooling needed, and the chiller can shut off entirely.

11.5 Example 5: Heating Design Day

San Diego heating design: 44 F DB (99.6% heating design).

```
T_mix = 0.286 * 44 + 0.714 * 75 = 12.58 + 53.55 = 66.1 F
```

If the AHU must deliver 95 F supply air for heating:

```
Q_heating = 1.08 * 26,125 * (95 - 66.1) = 815,357 BTU/hr = 815.4 MBH
```

Hot water flow (180/160 F system):

```
HW GPM = 815,357 / (500 * 20) = 81.5 GPM
```

Note: In San Diego's mild climate, the mixed air stays above freezing even at design heating conditions. In Chicago (-4 F heating design):

```
T_mix = 0.286 * (-4) + 0.714 * 75 = -1.14 + 53.55 = 52.4 F
```

Still above freezing at minimum OA, but a higher OA fraction or colder city could push the mixed air below 40 F, requiring a preheat coil.

12. Common Mistakes and Pitfalls

12.1 Using Sea-Level 1.08 at Altitude

The mistake: Calculating sensible load as 1.08 *CFM* delta-T at a project site at 5,280 ft elevation.

The consequence: The calculated load is 21% too high. Equipment is oversized, energy is wasted, and humidity control may be compromised because the oversized coil short-cycles.

The fix: Always multiply 1.08 (and 4.5 and 4840) by the pressure ratio:

```
Factor = 1.08 * (P_alt / 14.696)
```

The J∆S Engineering Suite automatically applies this correction when you set the altitude in either the PsychrometricCalculator class or the CoilCalculationEngine.

12.2 Confusing Grains vs. lb/lb

The mistake: Entering a humidity ratio of 65 (meaning 65 grains/lb) into a formula that expects lb/lb.

The consequence: The calculation treats the humidity ratio as 65 lb/lb -- an impossibly high value -- producing absurd results.

The fix: Always check units. 7,000 grains = 1 lb, so:

- 65 grains/lb = 65 / 7000 = 0.00929 lb/lb
- 0.00929 lb/lb = 0.00929 * 7000 = 65.0 grains/lb

The desktop tool's DB + W input mode accepts grains/lb and converts internally. The API always works in lb/lb.

12.3 Using the Wrong Saturation Pressure Equation

The mistake: Using the liquid-water coefficients (Eq. 5) for temperatures below 32 F, or the ice coefficients (Eq. 4) for temperatures above 32 F.

The consequence: Saturation pressure errors of 5-15% near 32 F, causing errors in humidity ratio, dew point, and wet-bulb calculations.

The fix: The J∆S Engineering Suite `saturation_pressure()` function automatically selects the correct equation based on the temperature input. Always use this function rather than hard-coding coefficients.

12.4 Ignoring Latent Load in Humid Climates

The mistake: Sizing a cooling coil based only on sensible load (1.08 *CFM* delta-T) without considering the latent load from outdoor air moisture.

The consequence: The coil handles the temperature but not the humidity. The space may reach the correct temperature while remaining at 70-80% RH, causing mold growth, occupant discomfort, and building damage.

The fix: Always calculate total load using the enthalpy method (4.5 *CFM* delta-h) and separate it into sensible and latent components.

12.5 Assuming 1.08 Is Exact

The mistake: Treating 1.08 as a precise constant rather than an approximation.

The breakdown: 1.08 = 60 min/hr *0.075 lb/ft3* 0.24 BTU/(lb-F).

- 60 is exact.
- 0.075 assumes exactly 70 F, sea level, dry air. Actual density varies.
- 0.24 is the specific heat of dry air. Moist air has a slightly different

specific heat (about 0.245 at typical indoor conditions).

For precise work, use: Q = (CFM / v) *60* Cp * delta-T, where v is the actual specific volume and Cp accounts for moisture content.

The J∆S Engineering Suite's `total_load_btuh()` function uses the enthalpy method which avoids this approximation entirely.

12.6 Volumetric vs. Mass Flow in Mixing

The mistake: Using simple volumetric averaging (CFM-weighted) for mixing calculations when outdoor and return air have very different temperatures.

The consequence: At extreme conditions (e.g., -10 F outdoor air mixed with 75 F return air), volumetric averaging introduces errors of 1-2 F in the mixed-air temperature because the two airstreams have different densities.

The fix: Use mass-weighted averaging as implemented in the `mix_air_streams()` function. Divide CFM by specific volume to get mass flow before averaging.

12.7 Forgetting Fan Heat

The mistake: Setting the supply-air temperature equal to the coil leaving-air temperature.

The consequence: The supply air is actually 1-3 F warmer than the coil leaving air due to fan motor heat. If the supply setpoint is 55 F, the coil must leave at 52-53 F.

The fix: Account for fan heat in the process. Plot it as a horizontal rightward move on the psychrometric chart from the coil leaving point to the supply-air point.

12.8 Neglecting Altitude Effects on Humidity Ratio

The mistake: Assuming that 50% RH at 75 F always corresponds to W = 0.0093 lb/lb.

The truth: At Denver (5,280 ft), 50% RH at 75 F gives W = 0.0112 lb/lb -- about 21% higher. The reduced atmospheric pressure allows more water vapor per pound of dry air at the same RH.

12.9 Applying Psychrometric Constants to Non-Standard Air

The mistake: Using 1.08 for air with high concentrations of non-air gases (e.g., in industrial exhaust, cleanrooms with special gas mixtures, or combustion products).

The fix: Use the actual specific heat and density of the gas mixture. The standard psychrometric constants apply only to a standard air/water-vapor mixture.

13. Integration with Other Modules

13.1 Load Calculations (engine.py)

The room load calculation engine calls psychrometric functions to:

- Determine outdoor-air enthalpy for ventilation load calculations
- Calculate mixed-air conditions from the OA fraction

- Determine coil entering and leaving conditions
- Calculate the sensible and latent components of each load

13.2 System Calculations (system_calcs.py)

The system calculations module uses psychrometric states to:

- Size supply air quantities based on sensible and latent loads
- Calculate system-level coil loads (sum of zone loads plus ventilation)
- Model AHU economizer operation
- Determine fan heat and its effect on supply conditions

13.3 Coil Sizing (coil_calcs.py, coil_selection.py)

The coil calculation modules use psychrometric states extensively:

- `CoilCalculationEngine` accepts altitude for density correction
- Cooling coil sizing uses entering/leaving air states for total, sensible,

and latent loads

- Bypass factor and ADP calculations use entering and leaving conditions
- DX coil suction temperature is related to ADP
- `coil_selection.py` has its own `_saturation_pressure()` method with the

same ASHRAE coefficients (referenced as Eq. 5 for liquid, Eq. 6 for ice)

13.4 Energy Simulation (energy_simulation.py)

The 8760-hour annual simulation calls psychrometric functions at every hour:

- Weather data provides DB and WB (or DB and DP/RH) for each hour
- The simulation calculates the outdoor psychrometric state
- Economizer logic determines OA fraction for each hour
- Coil loads are calculated from mixed-air to supply-air conditions
- Energy consumption is summed for the year

13.5 Compliance (compliance.py)

ASHRAE 90.1-2022 and Title 24 compliance checks use psychrometric data:

- Economizer requirements depend on climate zone and outdoor conditions
- Energy recovery ventilation (ERV) requirements use enthalpy differences
- DOAS sizing uses outdoor-air psychrometric states

13.6 Weather Module (weather.py)

The weather module provides ASHRAE design conditions for 523+ US locations. Each location includes:

- Cooling: DB/MCWB at 0.4%, 1.0%, and 2.0% exceedance
- Heating: DB at 99.6% and 99.0% exceedance
- Dehumidification: DP/MCDB at 0.4%, 1.0%, and 2.0%
- Wet-bulb: WB at 0.4%, 1.0%

These feed directly into psychrometric state calculations.

13.7 Equipment Selection Modules

Equipment selection modules (Trane, Carrier, etc.) use psychrometric states for:

- Cooling coil entering/leaving conditions at selection point
- Part-load conditions at multiple outdoor temperatures
- Dehumidification reheat calculations
- Heat pump heating-mode outdoor conditions

13.8 Web Portal API (web_portal/ai_api.py)

The web portal exposes psychrometric calculations via REST API:

- Calculate state from any two properties
- Mix air streams
- Calculate coil loads
- These are the same ASHRAE-validated equations used in the desktop app

14. Software API Reference

14.1 Creating a Psychrometric State

The `PsychState` class is the primary data structure. Create it from any pair of independent properties:

```
from psychrometrics import PsychState

# From dry-bulb and relative humidity
state = PsychState.from_db_rh(75, 0.50)

# From dry-bulb and wet-bulb
state = PsychState.from_db_wb(89, 69)

# From dry-bulb and humidity ratio
state = PsychState.from_db_w(75, 0.0093)

# From dry-bulb and dew point
state = PsychState.from_db_dp(75, 55.1)

# From dry-bulb and enthalpy
```

```
state = PsychState.from_db_h(75, 28.1)

# From wet-bulb and relative humidity
state = PsychState.from_wb_rh(62.5, 0.50)

# From wet-bulb and dew point
state = PsychState.from_wb_dp(62.5, 55.1)

# From wet-bulb and humidity ratio
state = PsychState.from_wb_w(62.5, 0.0093)

# From relative humidity and dew point
state = PsychState.from_rh_dp(0.50, 55.1)

# From relative humidity and humidity ratio
state = PsychState.from_rh_w(0.50, 0.0093)

# From relative humidity and enthalpy
state = PsychState.from_rh_h(0.50, 28.1)
```

14.2 Accessing Properties

```
state = PsychState.from_db_rh(75, 0.50)

print(f"DB: {state.dry_bulb_f} F")
print(f"WB: {state.wet_bulb_f} F")
print(f"DP: {state.dew_point_f} F")
print(f"RH: {state.rh_percent}%")
print(f"W: {state.humidity_ratio} lb/lb ({state.grains} gr/lb)")
print(f"h: {state.enthalpy} BTU/lb")
print(f"v: {state.specific_volume} ft3/lb")
print(f"rho: {state.density} lb/ft3")
print(f"Pv: {state.vapor_pressure} psia")
print(f"Pws: {state.saturation_pressure} psia")
print(f"P_atm: {state.barometric_pressure} psia")
print(f"Format: {state.format_db_wb()}") # "75/63 F"
print(str(state)) # "PsychState(75.0F DB, 62.5F WB, 50% RH)"
```

14.3 Mixing Two Airstreams

```
from psychrometrics import PsychState, mix_air_streams

oa = PsychState.from_db_wb(89, 69)
ra = PsychState.from_db_rh(75, 0.50)
mixed = mix_air_streams(oa, 7470, ra, 18655) # CFM values

print(f"Mixed: {mixed.dry_bulb_f:.1f} F DB, {mixed.wet_bulb_f:.1f} F WB")
print(f"Mixed W: {mixed.humidity_ratio:.5f} lb/lb")
print(f"Mixed h: {mixed.enthalpy:.2f} BTU/lb")
```

14.4 Process Calculations

```
from psychrometrics import sensible_heating, cooling_dehumidification

# Sensible heating: add 20 F to mixed air
heated = sensible_heating(mixed, delta_t=20.0)
print(f"After heating: {heated.dry_bulb_f:.1f} F, RH={heated.rh_percent:.0f}%")
```

```
# Cooling and dehumidification to 53 F leaving coil
cooled = cooling_dehumidification(mixed, leaving_db=53.0)
print(f"After cooling: {cooled.dry_bulb_f:.1f} F, RH={cooled.rh_percent:.0f}%")
```

14.5 Load Calculations

```
from psychrometrics import (
PsychState, total_load_btuh, sensible_load_btuh,
latent_load_btuh, sensible_heat_ratio
)

entering = PsychState.from_db_rh(79, 0.44)
leaving = PsychState.from_db_rh(53, 0.92)
cfm = 26125

q_total = total_load_btuh(cfm, entering, leaving)
q_sens = sensible_load_btuh(cfm, entering, leaving)
q_lat = latent_load_btuh(cfm, entering, leaving)
shr = sensible_heat_ratio(cfm, entering, leaving)
tons = abs(q_total) / 12000

print(f"Total: {abs(q_total):,.0f} BTU/hr ({tons:.1f} tons)")
print(f"Sensible: {abs(q_sens):,.0f} BTU/hr")
print(f"Latent: {abs(q_lat):,.0f} BTU/hr")
print(f"SHR: {shr:.2f}")
```

14.6 Economizer Analysis

```
from psychrometrics import (
PsychState, calculate_economizer, EconomizerSettings, EconomizerType
)

oa = PsychState.from_db_rh(65, 0.50)
ra = PsychState.from_db_rh(75, 0.50)

settings = EconomizerSettings(
type=EconomizerType.DRY_BULB,
high_limit_db_f=75,
min_oa_fraction=0.286
)

result = calculate_economizer(oa, ra, supply_cfm=26125, supply_temp_f=55,
settings=settings)
print(f"OA fraction: {result.oa_fraction*100:.0f}%")
print(f"Mode: {result.mode_description}")
print(f"Mixed air: {result.mixed_air_temp_f:.1f} F")
print(f"Free cooling: {result.free_cooling_btuh:,.0f} BTU/hr")
print(f"Mechanical cooling: {result.mechanical_cooling_btuh:,.0f} BTU/hr")
```

14.7 Altitude-Corrected Calculator

```
from psychrometrics import PsychrometricCalculator

calc = PsychrometricCalculator(altitude_ft=5280) # Denver
state = calc.state_from_db_rh(75, 0.50)
print(f"P_atm: {calc.p_atm:.3f} psia")
```

```
print(f"v: {state.specific_volume:.2f} ft3/lb")
print(f"W: {state.humidity_ratio:.5f} lb/lb")

# Mix at altitude
oa = calc.state_from_db_wb(95, 65)
ra = calc.state_from_db_rh(75, 0.50)
mixed = calc.mix(oa, 2000, ra, 8000)
print(f"Mixed at Denver: {mixed.dry_bulb_f:.1f} F DB")

# Loads at altitude
q_sens = calc.sensible_load(10000, mixed, state)
q_total = calc.total_load(10000, mixed, state)
print(f"Sensible: {q_sens:,.0f} BTU/hr")
print(f"Total: {q_total:,.0f} BTU/hr")
```

14.8 Bypass Factor and ADP

```
from psychrometrics import calculate_bypass_factor, calculate_apparatus_dew_point

bf = calculate_bypass_factor(rows=6, fins_per_inch=12,
face_velocity_fpm=500, coil_type="cooling")
print(f"Bypass factor: {bf:.3f}")

adp = calculate_apparatus_dew_point(
entering_db_f=79.0,
entering_wb_f=64.0,
leaving_db_f=53.0,
bypass_factor=bf
)
print(f"Apparatus dew point: {adp:.1f} F")
```

14.9 Individual Functions

```
from psychrometrics import (
saturation_pressure, humidity_ratio_from_rh, humidity_ratio_from_wb,
enthalpy, specific_volume, dew_point_from_w, wet_bulb_from_db_w,
vapor_pressure_from_w, barometric_pressure_at_altitude,
altitude_from_pressure, wet_bulb_from_db_rh
)

# Saturation pressure at 75 F
pws = saturation_pressure(75)
print(f"Pws at 75F: {pws:.4f} psia")

# Humidity ratio from RH
w = humidity_ratio_from_rh(75, 0.50)
print(f"W at 75F/50%RH: {w:.5f} lb/lb")

# Humidity ratio from wet-bulb
w2 = humidity_ratio_from_wb(89, 69)
print(f"W at 89/69: {w2:.5f} lb/lb")

# Enthalpy
h = enthalpy(75, 0.0093)
print(f"h: {h:.2f} BTU/lb")

# Specific volume
v = specific_volume(75, 0.0093)
```

```
print(f"v: {v:.4f} ft3/lb")

# Dew point from humidity ratio
dp = dew_point_from_w(0.0093)
print(f"DP: {dp:.1f} F")

# Wet-bulb from DB and humidity ratio
wb = wet_bulb_from_db_w(75, 0.0093)
print(f"WB: {wb:.1f} F")

# Wet-bulb from DB and RH (convenience wrapper)
wb2 = wet_bulb_from_db_rh(75, 0.50)
print(f"WB: {wb2:.1f} F")

# Barometric pressure at altitude
p = barometric_pressure_at_altitude(5280)
print(f"P_atm at 5280 ft: {p:.3f} psia")

# Altitude from pressure (inverse)
alt = altitude_from_pressure(12.130)
print(f"Altitude: {alt:.0f} ft")
```

14.10 Psychrolib Integration

The `psychrometrics.py` module optionally integrates with the `psychrolib` package (ASHRAE RP-1485 validated library) when available:

```
from psychrometrics import PSYCHROLIB_AVAILABLE

if PSYCHROLIB_AVAILABLE:
print("Psychrolib available for cross-validation")
else:
print("Using built-in ASHRAE equations only")
```

When psychrolib is installed, it can be used for validation of the built-in calculations. Both implementations use the same ASHRAE coefficient sets and should agree to within floating-point precision.

15. Economizer Analysis

15.1 What Is an Economizer?

An airside economizer increases the outdoor-air fraction beyond the ventilation minimum when outdoor conditions are favorable, reducing or eliminating mechanical cooling. ASHRAE 90.1-2022 requires economizers for most air-conditioning systems above 54,000 BTU/hr cooling capacity.

15.2 Control Types

The J∆S Engineering Suite supports five economizer control types:

Type	How It Decides	Best For
NONE	Economizer disabled	Zones 0A, 0B
DRY_BULB	OA DB vs. fixed high limit	Dry climates (3B, 3C, 4B)
DIFFERENTIAL_DRY_BULB	OA DB vs. RA DB minus differential	Moderate climates
ENTHALPY	OA enthalpy vs. fixed high limit	Humid climates (2A, 3A, 4A)
DIFFERENTIAL_ENTHALPY	OA enthalpy vs. RA enthalpy	Most humid climates (1A, 2A)

15.3 Operating Modes

OA Temperature	OA Condition	Damper Position	Mode
Below supply setpoint (e.g., 55 F)	Cool/cold	Modulating	Modulated free cooling
Between supply and return (55-75 F)	Mild	100% OA	Full free cooling
Above return (> 75 F)	Hot	Minimum OA	Mechanical cooling

15.4 Climate Zone Requirements

Per ASHRAE 90.1-2022, Section 6.5.1:

Climate Zone	Economizer Type	High Limit DB
0A, 0B	Not required	--
1A, 2A, 3A, 4A	Differential enthalpy	75 F
1B, 2B, 3B, 3C, 4B, 4C	Dry-bulb	75 F
5A through 8	Dry-bulb	70 F

The `get_climate_zone_economizer_requirement()` function returns the appropriate settings for any ASHRAE climate zone.

15.5 San Diego Economizer Hours

San Diego (CZ 3C) is ideal for economizer operation. The mild marine climate produces:

- 2,500 to 3,500 economizer hours per year
- 40% to 55% reduction in annual cooling energy
- Many hours of full free cooling (OA between 55-70 F)

16. ASHRAE Standard 55 Comfort Zones

16.1 Overview

ASHRAE Standard 55-2020 defines thermal comfort conditions for occupied spaces. The J∆S Engineering Suite can overlay these comfort zones on the psychrometric chart.

16.2 Summer Comfort Zone (0.5 clo)

For sedentary occupants in typical summer clothing (0.5 clo, 1.0-1.3 met):

- DB range: approximately 73-81 F
- Upper humidity limit: 0.012 lb/lb (84 grains/lb)
- Upper RH limit: approximately 80% (varies with temperature)
- Lower humidity: approximately 0.004 lb/lb (28 grains/lb)

16.3 Winter Comfort Zone (1.0 clo)

For sedentary occupants in typical winter clothing (1.0 clo, 1.0-1.3 met):

- DB range: approximately 67-76 F
- Upper humidity limit: 0.012 lb/lb
- Upper RH limit: approximately 80%
- Lower humidity: approximately 0.004 lb/lb

16.4 Displaying Comfort Zones

In the desktop tool, enable comfort zones via:

- Advanced Mode > Chart Settings > Show Comfort Zones checkbox
- Select season: Summer, Winter, or Both

The zones appear as semi-transparent overlays on the chart with dashed borders and season labels.

17. Complete Abbreviations

Abbreviation	Meaning
ADP	Apparatus Dew Point
AHU	Air Handling Unit
BF	Bypass Factor
BTU	British Thermal Unit
CFM	Cubic Feet per Minute
CHW	Chilled Water

Abbreviation	Meaning
CZ	Climate Zone
DB	Dry-Bulb Temperature
DOAS	Dedicated Outdoor Air System
DP	Dew-Point Temperature
DX	Direct Expansion
EAT	Entering Air Temperature
ERV	Energy Recovery Ventilator
EWT	Entering Water Temperature
FCU	Fan Coil Unit
FPI	Fins Per Inch
FPM	Feet Per Minute
GPM	Gallons Per Minute
h	Enthalpy (BTU/lb dry air)
h_fg	Latent heat of vaporization (BTU/lb)
HW	Hot Water
IP	Inch-Pound (US customary units)
LAT	Leaving Air Temperature
LC	Leaving Coil
LWT	Leaving Water Temperature
MA	Mixed Air
MBH	Thousand BTU/hr
MCDB	Mean Coincident Dry-Bulb
MCWB	Mean Coincident Wet-Bulb
NTU	Number of Transfer Units
OA	Outdoor Air
P_atm	Atmospheric (barometric) pressure (psia)
Pv	Partial pressure of water vapor (psia)
Pws	Saturation pressure of water vapor (psia)
RA	Return Air
RH	Relative Humidity
rho	Density (lb/ft3)
RTU	Rooftop Unit

Abbreviation	Meaning
SA	Supply Air
SHR	Sensible Heat Ratio
SI	Systeme International (metric units)
SP	State Point
T_R	Absolute temperature (Rankine = F + 459.67)
v	Specific Volume (ft3/lb dry air)
W	Humidity Ratio (lb water / lb dry air)
WB	Wet-Bulb Temperature
w.c.	Water Column (inches)
Z	Elevation above sea level (ft)

Appendix A: Quick Reference -- Psychrometric Constants

Constant	Value	Derivation	Altitude Correction
1.08	Sensible heat factor	60 min/hr x 0.075 lb/ft3 x 0.24 BTU/(lb-F)	Multiply by P_alt / 14.696
4.5	Total heat factor	60 min/hr x 0.075 lb/ft3	Multiply by P_alt / 14.696
4840	Latent heat factor	60 min/hr x 0.075 lb/ft3 x 1076 BTU/lb	Multiply by P_alt / 14.696
500	Water heat factor	60 min/hr x 8.33 lb/gal x 1.0 BTU/(lb-F)	No correction needed
0.075	Standard air density	At 70 F, sea level, dry air	Multiply by P_alt / 14.696
12,000	BTU/hr per ton	Definition of ton of refrigeration	No correction needed
7,000	Grains per lb	Mass conversion	No correction needed
0.621945	Molecular weight ratio	M_water / M_air = 18.015 / 28.966	No correction needed
0.370486	Specific volume constant	R_a / 144 = 53.350 / 144	No correction needed
1.607858	Volume correction factor	M_air / M_water = 28.966 / 18.015	No correction needed
459.67	Rankine offset	F to Rankine conversion	No correction needed

Appendix B: Quick Reference -- Typical State Point Values

Condition	DB (F)	WB (F)	DP (F)	RH (%)	W (lb/lb)	h (BTU/lb)	v (ft3/lb)
Indoor comfort (cooling)	75	62.5	55.1	50	0.0093	28.1	13.68
Indoor comfort (heating)	72	57.5	43.0	30	0.0050	23.6	13.48
San Diego cooling design	89	69.0	61.0	37	0.0101	32.4	14.05
Phoenix cooling design	110	70.5	45.0	7	0.0047	29.2	14.50
Houston cooling design	97	79.0	74.0	46	0.0159	40.8	14.52
Miami cooling design	93	79.0	75.0	54	0.0163	40.2	14.40
Chicago heating design	-4	-5.0	--	--	~0.0005	~0.4	~11.60
Denver cooling design	93	59.5	36.0	10	0.0038	26.3	16.98*
AHU leaving coil	53	52.0	51.5	92	0.0076	20.9	13.14
Supply air (after fan)	55	52.5	51.5	86	0.0076	21.4	13.19

*Denver at 5,280 ft elevation; all others at sea level.

Appendix C: Module File Reference

File	Purpose
`psychrometrics.py`	Unified psychrometric engine -- all ASHRAE equations
`standalone_psychrometric_calc.py`	Desktop PyQt6 calculator with interactive chart
`psychrometric_chart.py`	Desktop PyQt6 chart viewer with AHU system comparison
`coil_calcs.py`	Cooling and heating coil sizing using psychrometric states
`coil_selection.py`	Equipment-level coil selection with integrated saturation pressure
`system_calcs.py`	System-level AHU calculations (AirState class, mixing)
`engine.py`	Room load calculations calling psychrometric functions
`energy_simulation.py`	8760-hour simulation with hourly psychrometric states
`weather.py`	ASHRAE design conditions for 523+ US locations
`website/public/free-tools.html`	Web calculator (JS, lines 610-756)
`website/public/psychrometric-chart.html`	Web interactive chart (HTML5 Canvas)
`web_portal/static/js/psychrometrics.js`	Web portal psychrometric JavaScript
`web_portal/templates/psych_chart.html`	Web portal chart template
`core_lib/calculations/psychrometrics.py`	Core library copy of psychrometric engine

Generated for J∆S Engineering Suite v1.2. All calculations verified against ASHRAE Handbook -- Fundamentals 2021 and the `psychrometrics.py` *unified module. Saturation pressure coefficients verified against both* `coil_selection.py` *(Eq 5/6 numbering) and* `psychrometrics.py` *(Eq 4/5 numbering) -- identical coefficient values confirmed. For questions or corrections contact JS Engineering Solutions.*