PDHonline Course M231 (4 PDH)

Principles of Evaporative Cooling System

Instructor: A. Bhatia, B.E.

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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A. Bhatia, B.E.

Course Contents

Evaporative coolers, often called "swamp coolers", are cooling systems that use only water and a blower to circulate air. When warm, dry (unsaturated) air is pulled through a water-soaked pad, water is evaporated and is absorbed as water vapor into the air. The air is cooled in the process and the humidity is increased.

The evaporator cooling technology is an energy-efficient alternative to compressor-based cooling. In dry and arid regions, evaporative cooling can meet most or all building cooling loads using one-fourth the energy of conventional equipment. It can also be applied cost-effectively when integrated with conventional chiller systems, which can greatly improve a facility's load profile. Unfortunately, evaporative cooling requires an abundant water source and is only effective when the relative humidity is low, restricting its efficient use to dry climates (most of the south-western USA and other dry-climate areas worldwide).

This course reviews the above criteria in detail.

SECTION – 1 PRINCIPLES OF EVAPORATIVE COOLING

The rudimentary basis for understanding any air conditioning, dehumidification and evaporative cooling is psychrometrics. Psychrometry consists of the interactions between heat, moisture and air. It is basically the study of air-water mixtures and is an essential foundation for understanding, how to change air from one condition to another. As air temperature rises, its capacity to hold moisture rises also; and warmer air becomes less dense. This makes moisture a very influential factor for heat gain, both for comfort and in calculations. The knowledge of systems consisting of dry air and water vapor is essential for the design and analysis of air conditioning devices, cooling towers, and industrial processes requiring close control of the vapor content in air. Air moisture and heat interactions are rather complex; fortunately, these interactions can be combined in a single chart (see figure below). However before explaining the details of how to use the chart, some terms, definitions, and principles used in the study of systems consisting of dry air and water must be introduced.

1) ***Dry Bulb Temperature (DBT):*** The Dry Bulb Temperature refers to the ambient air temperature measured using a normal thermometer freely exposed to the air but shielded from radiation and moisture. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air.

   The dry bulb temperature is an indicator of heat content of the air. As the DB temperature increases, the capacity of moisture the airspace will hold also increases. The dry bulb temperature is usually given in degrees Celsius (ºC) or degrees Fahrenheit (°F). The SI unit is Kelvin (K). Zero Kelvin equals to -273°C.

2) **Wet Bulb Temperature:** The Wet Bulb temperature is the temperature measured by using a thermometer whose glass bulb is covered by a wet wick/cloth.

   The wet bulb temperature is indicator of moisture content of air. Wet bulb temperature is very useful in evaporating cooling processes as the difference between the dry bulb and wet bulb temperature is a measure of the cooling efficiency. At 100% relative humidity, the wet bulb temperature equals dry bulb temperature.

3) ***Humidity:*** The term humidity describes the quantity of water vapor in air. If the air holds 50% of its capacity, the humidity would be 50%. If the humidity is low, then the capacity to hold more water is higher, and a greater amount of evaporation takes place. It can be expressed as an absolute, specific or a relative value.

4) ***Absolute humidity:*** Absolute humidity is the actual mass of water vapor in the air water vapor mixture. Absolute humidity may be expressed in pounds of water vapor (lbs).

5) ***Specific humidity or (humidity ratio)*** is the ratio between the actual mass of water vapor present in moist air - to the mass of the dry air. The humidity ratio is very useful in evaporative cooling because it provides the measure of the amount of moisture absorbed by the air stream and is useful in determining the spray water requirements. Specific Humidity is normally expressed in grains of water vapor /lb of dry air and may also be expressed in the units of pounds of water vapor/lb of dry air or grams of water vapor /kg of dry air.

6) ***Relative humidity:*** Relative Humidity or RH is the actual amount of moisture in the air compared to the total or maximum moisture the air can hold at a given temperature. When air has 50 percent relative humidity (RH), we say it is 50 percent saturated (the terms are numerically so close that we use them interchangeably). Obviously, as air approaches 100 percent saturation, it can take on less and less water until at 100 percent RH, the air cannot hold more water.

Relative humidity is determined by comparing the "wet-bulb" and "dry-bulb" temperature readings. Dry bulb and wet bulb temperatures are taken simultaneously and then plotted on a psychrometric chart. Relative humidity is determined by the value at the intersection of two temperature lines.

7) ***Dewpoint:*** The Dew Point is the temperature at which water vapor starts to condense out of the air and becomes completely saturated. Above this temperature the moisture will stay in the air. The dew point temperature is an indicator of the actual amount of moisture in air.

   The dew-point temperature is expressed in degrees and like humidity ratio; it represents an absolute measure of the moisture in the air at a constant pressure. *If the dew-point temperature is close to the air temperature, the relative humidity is high, and if the dew point is well below the air temperature, the relative humidity is low.*

8) ***Grains of moisture:*** Term used to express the weight of moisture per pound of air (14 cubic feet). 7000 grains is the most that can be held in one pound of air. Since water weighs 8.34 pounds per US gallon and since there are 8 pints in one gallon, 7000 grains is equal to about 1 pint of water.

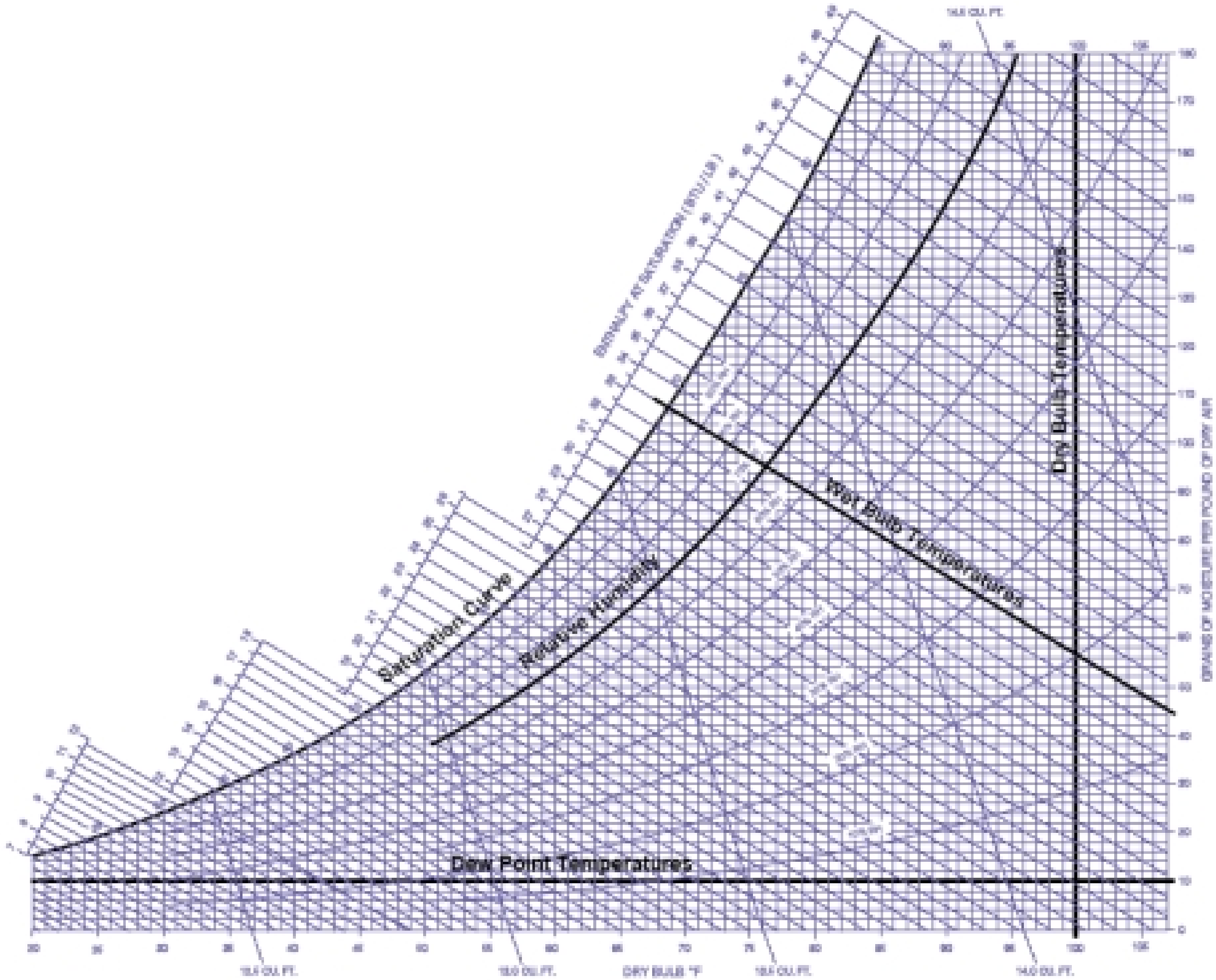
   Grains of moisture per pound of air are most often referred to as "humidity ratio". 50 grains of moisture at 100ºF equals 12% relative humidity and 70ºF wet bulb at sea level.

9) ***Sensible Heat:*** The heat used to change the temperature of the air. Sensible heat will always cause a change in the temperature of the substance.

10) ***Latent heat:*** Latent heat is the heat energy involved in the phase change of water. The heat will only change the structure or phase of the material without change to temperature.

Psychrometric Chart

The psychrometric chart is a graphical representation that describes the relationships between the air temperature and relative humidity. Although complicated in appearance, this chart can be used to establish state points and is used to calculate specific humidity, dew point and vapor pressure.

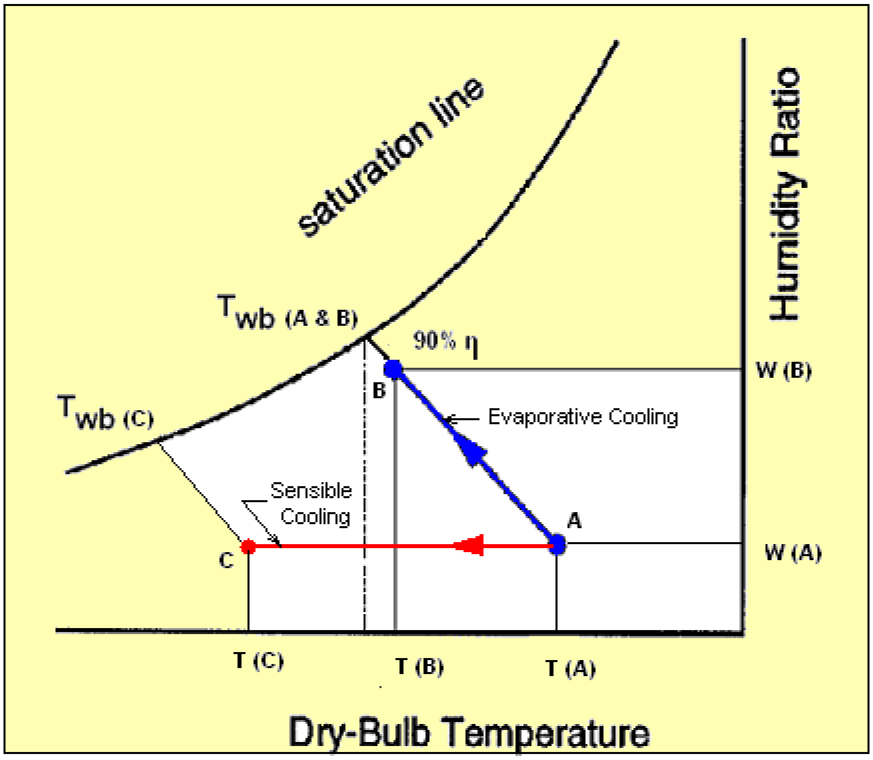


- On the Psychrometric chart, the dry-bulb temperature is the horizontal axis of the chart.
- Lines of constant wet bulb temperatures run diagonally from the upper left to the lower right in the Psychrometric chart.
- The vertical axis represents humidity ratio, the moisture content of the air mixture. In this chart, humidity ratio is expressed as grains of moisture per pound of dry air. Some charts show humidity ratio as pounds of moisture per pound of dry air. Note that 7000 grains of moisture is equivalent to 1 pound of water.
- The curved lines represent relative humidity expressed as %ages. The 100% relative humidity line is the left most upward line shown as “Saturation Curve”. This represents the maximum amount of water vapor that air can hold at a specific temperature.

The air holds increasingly more water vapor at increasing temperatures. As a rule of thumb, the maximum amount of water that the air can hold doubles for every 11°C (20°F) increase in temperature.

The Cooling Processes on Psychrometric Chart

The cooling processes in Psychrometric Chart are illustrated below:



Sensible Cooling – In sensible cooling process, the temperature of air changes from a point 'A' to point 'C', maintaining constant humidity ratio. The temperature is reduced by [$T_{(A)}$ – $T_{(C)}$] and the wet bulb temperature is also reduced. The humidity ratio remains same since there is no addition or loss of moisture.

Evaporative Cooling – In evaporative cooling process, both temperature and humidity of air changes *along the lines of constant wet bulb temperature* (shown as line AB). There is no change in heat content and the energy is merely converted from sensible energy to latent energy.

In evaporative cooling process, changes occur in dry bulb temperature, specific volume, relative humidity, humidity ratio, dewpoint temperature, and vapor pressure of the moist air. No change occurs in wet bulb temperature and enthalpy. The evaporative cooling is constant enthalpy process (technically termed as adiabatic process).

Key Evaporative Cooling Terms

1) **Wet Bulb Depression (WBD):** The difference between the dry bulb and wet bulb temperatures.

   Example: If dry bulb is 100ºF and the wet bulb is 70ºF; the web bulb depression is [100 - 70 = 30ºF].

   At 100% cooling efficiency, the temperature drop across the evaporative cooler would be equal to the Wet Bulb Depression.

2) **Range or Temperature Drop:** The difference between the entering dry bulb temperature and the exit dry bulb temperature.

   Example: If the entering dry bulb temperature across an evaporator cooler is 100°F and the leaving dry bulb temperature is 73°F, the range is 100 – 72 = 27°F.

3) **Saturation or Cooling Efficiency (SE or CE):** The difference between the entering and exit dry-bulb temperatures (i.e. range) over the wet-bulb depression.

   Example: If the Wet Bulb Depression is 30ºF and the actual temperature drop measured across the cooling media is 27ºF (as in the above example), the cooling efficiency is 90%. (27/30 = .90).

4) **Evaporative Cooling Performance Factors:** The evaporative cooler performance is directly related to its ability to evaporate water (cool) at a given relative humidity. The dryer the air, the greater shall be the performance. In morning hours, the humidity may be high, but as the day passes and the temperature increases, the relative humidity will naturally decrease. The hotter the day, the dryer the air becomes, and the more cooling that can take place through the evaporation of water.

   The temperature of the water does not have a great effect upon the cooling produced through evaporation. For example, a gallon of water at 50°F would produce 9,000 BTU's of cooling while a gallon of 90° F water would produce 8,700 BTU's of cooling, only 3% differentials.

5) **Evaporation Rate:** Evaporation rate is measure of the capacity of air to absorb moisture. The amount of absorption depends largely on four factors;

   - Humidity of the air: Dry air has greater ability to hold moisture. If the air already has high moisture content, it will have lower capacity to absorb further moisture.

- Temperature of the air: The hotter the air, the more water it can evaporate.
- Flow rate of the air: The molecules in motion promote evaporation. Stronger the flow of air, the greater the evaporating power of air.
- The saturation efficiency of the cooling media: The cooling pads should have high thickness (12 inches) to ensure large contact area or low bypass.

For practical purposes, this rate is measured in gallons of water per hour (or minute)

5) **Air Changes per hour (ACH):** Air change is the number of times the air within a space is replaced during a specified period such as hour or minute. It is usually expressed in changes per hour or per minute. A good rule of thumb is to have 1 air change every 3 minutes in northern states, 1 air change every 2 minutes in the mid section and 1 air change every 1-2 minutes in the southern states.

6) **British Thermal Units (BTU):** A British thermal unit, or BTU, is a unit used to measure heat. The heat of vaporization (evaporation) of water is 1043 BTU/lb and evaporation of 1 gallon of water requires almost 8700 BTU's of heat (the 8700 conversion factor is based on 8.34 lb. water/gallon and 1043 BTU/lb).

7) **(Standard) Cubic Feet per Minute (S) CFM:** It is a measure of air flow rate per minute. Usually referred to as simply CFM. This is a necessary ingredient in any formula involving evaporative cooling. The air volume can be calculated either by sensible heat load equation or air change method. Both sensible heat and air change method are discussed in subsequent sections

8) **Face Velocity (FV):** Expressed in feet per minute (FPM), it is the ratio of air flow (in CFM) divided by face area of the cooling media.

Evaporative Cooling Example

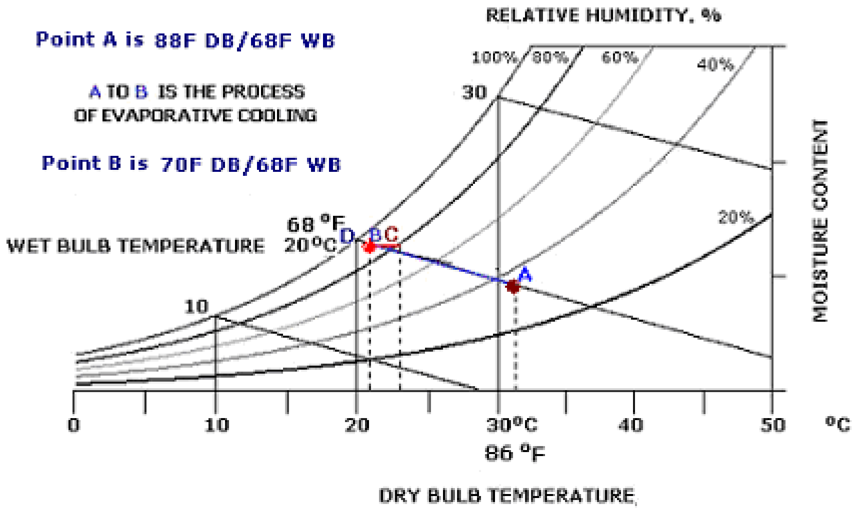
Let's take a set of conditions and apply the process of evaporative cooling on a Psychrometric chart.

Conditions of Air entering evaporative cooler (Point A on the chart)

1) Dry Bulb temperature – 88°F

2) Wet Bulb temperature – 68°F

3) Relative Humidity – 36%



With evaporative cooling system, the maximum reduction that is possible is the differential between the dry bulb and wet bulb temperature (i.e. wet bulb depression). Since no equipment is perfect, there will be certain losses in the evaporative cooler; these losses will be on account of the efficiency of cooling media. If we say that the evaporative cooler is 90% efficient then the process will take place over 90% of the distance from point "A" up towards the saturation line (100% relative humidity) along a constant line of wet bulb temperature. Numerically:

Temperature drop achievable = (dry bulb - wet bulb) x (efficiency of the media)
Example: (88° - 68°) x .9 = 18° F

Achievable temperature = dry bulb - temp drop achievable
Example: 88° – 18° = 70° F

Point B represents the conditions of the air leaving the evaporative cooler.

Conditions of Air leaving evaporative cooler (Point B on the chart)

Dry Bulb temperature – 70° F

Wet Bulb temperature – 68° F

Relative Humidity – 92%

The conditions achieved after evaporative cooling can be stated as "low sensible heat energy" and "high latent heat energy".

Final Conditions of Air in Area being cooled

The final conditions of the air in the room being cooled by the evaporative cooler will depend on the heat loading in the area. If the area is not affected by any other heat conditions then the condition of the air in the room will be very close to the conditions of the air leaving the evaporative cooler. If there are any additional heat loadings in the room (e.g. large number of people or machinery) then the temperature of the air leaving the evaporative cooler will tend to rise by a few degrees. This would be represented by a horizontal movement to the right from the condition B to condition C on the psychrometric chart.

Conclusive Notes:

1) Evaporative cooling is represented on the "Psychrometric Chart" by constant wet bulb temperature lines. With direct evaporative cooling, the dry bulb temperature is reduced while the web bulb temperature remains constant.

2) Higher the differential between the dry bulb and wet bulb temperature, the more effective shall be the evaporative cooling. Where the wet bulb temperature approaches dry bulb temperature, the evaporative cooling effectiveness will drop.

3) Wet bulb temperature is the lowest air temperature that can be achieved at 100% cooling efficiency. This corresponds to point D on the psychrometric chart. At this point the air is fully saturated – it has reached the dewpoint – and can not hold any additional moisture. At this point DBT = WBT.

SECTION – 2 WHY CHOOSE EVAPORATIVE COOLING

Economy:

1) Evaporative coolers do not use compressors, condenser, chiller coils, cooling towers or heavily insulated piping. Thus the cost of acquisition and operation is a fraction of conventional air conditioning and mechanical refrigeration systems.

2) Initial cost is less than 1/2 the cost of refrigerated air conditioning and the operating costs is less than 1/3 rd the cost of refrigerated air conditioning to run. Maintenance costs are minimal requiring simpler procedures and lower skilled maintenance people.

   Example:

   A 1500 square foot home is located in Texas where the dry bulb temperature is 107ºF, the wet bulb temperature is 71ºF, and the wet bulb depression is 36ºF.

   - *Air Conditioner-* Assuming air conditioning supplies 500 square feet of cooling per ton, 3 tons of air conditioning would be required to cool a 1500 square foot home. Since an air conditioner would probably run most of the time in this climate, its electric usage would be approximately 3.6 kW per hour.

- *Evaporative Cooler*- The only power consuming components of an evaporative cooler are fans and small water pumps. Using an evaporative cooler with a minimum of 5000 CFM and ¾ horsepower motor, total power consumption (motor and pump combined) would be approximately 0.991kW per hour.

Results- If the air conditioner and the evaporative cooler ran for a comparable period of time, the ratio of energy for the evaporative cooler to the air conditioner would be 0.991kW per hour to 3.6kW per hour. This means the evaporative cooler would use 72 ½% less power than an air conditioner to cool the same area in the same environment.

Energy Cost Savings

Assuming energy costs of .14¢ per kWh, this comparison would result in a possible net savings of ($362.88 - $99.89) = $262.99 each month!

Effective:

Evaporative air-cooling creates cooler temperatures a number of ways:

1) It lowers effective temperature - the temperature you feel - by at least an additional 4º to 6º. In some cases, the temperature will be lowered more, depending on relative humidity. The rapid motion of cool air increases skin surface evaporation resulting in body heat loss. ASHRAE Handbook, 1995, chapter 47, Evaporative Air Cooling notes "...*dry bulb temperature reduction due to the evaporation of water always results in a lower effective temperature, regardless of the relative humidity level" and that ". . . Evaporative cooling can provide relief cooling of factories almost regardless of geographical location."*

2) It reduces radiated heat- The constant flow of cool air absorbs heat from all exposed surfaces and results in a reduction of the heat radiated to the human body.

Increased Comfort:

In a large number of industries, it is normal in hot weather to experience increased heat-related illness, lower productivity and increased absenteeism among workers. Many of these industries cannot afford the tremendous costs of conventional mechanical refrigeration or air conditioning, while they can afford evaporative cooling. Quoting again from ASHRAE Handbook, 1995, Chapter 47, Evaporative Air Cooling *"evaporative cooling can alleviate this heat problem and contribute to worker efficiency with improved morale*.

Health & Environment Benefits:

Evaporative cooling is healthy and comfortable because it:

1) Brings 100% fresh outside air that is cooled & washed through filter pads
2) Comfort is improved with air movement- not stuffy & stale
3) Constant air movement of the evaporative cooler pushes hot air out removing dust, pollen, smoke, odor, and pollution and replaces it with cool fresh air.
4) Helps maintain natural humidity levels, which benefits both people and furniture and cuts static electricity.
5) Unlike air conditioning, evaporative cooling does not require an airtight structure to operate at maximum efficiency. In fact, the building occupants can open doors and windows.
6) Evaporative cooling is also an environmentally-friendly alternative to air conditioning since it has no CFC's or HCFC's.

Summarizing, the evaporative coolers have a low first cost, use a lot less electricity than conventional air conditioners, and do not use refrigerants, such as chlorofluorocarbons (CFCs) and hydro-chlorofluorocarbons (HCFCs) that can harm the ozone layer. It is economical, effective and it provides much needed alternative to conventional mechanical refrigeration.

Limitations & Disadvantages:

The evaporative coolers have some limitations and disadvantages:

1) Evaporative coolers are not effective in the humid regions.
2) High humidity conditions decreases the cooling capability of the evaporative cooler.
3) The air supplied by the evaporative cooler is nearly 100% humid. Very humid air prevents the evaporative cooling of sweaty or wet skin. High humidity in air accelerates corrosion. This can considerably shorten the life of electronic equipment. High humidity in air may cause condensation (which can be extremely hazardous, if it happens inside electrical equipment).
4) Cooled air may bring dust and pollen into the space causing discomfort for allergy sufferers. Growth of microorganisms such as molds on the cooler pads may cause allergy problems in sensitive individuals.
5) Evaporative coolers use on-site water.

6) Coolers are aesthetically unattractive and if not maintained the overflow of concentrated salts can damage building envelope.

7) Compared to vapor compression systems, evaporative coolers require increased air flow rates to compensate for higher supply air temperatures. Air velocity when operating on high speed may cause annoying noise.

8) The vents that allow air to exit the building may pose a security risk.

Section -3 TYPES OF EVAPORATIVE COOLING SYSTEMS

Two principle methods of evaporative cooling are

1) ***Direct cooling:*** In direct cooling water evaporates directly into the airstream, thus reducing the air’s dry-bulb temperature while humidifying the air.

2) ***Indirect cooling:*** In indirect cooling, one stream of air called primary air is cooled sensibly (without addition of moisture) with a heat exchanger, while the secondary air carries away the heat energy from the primary air.

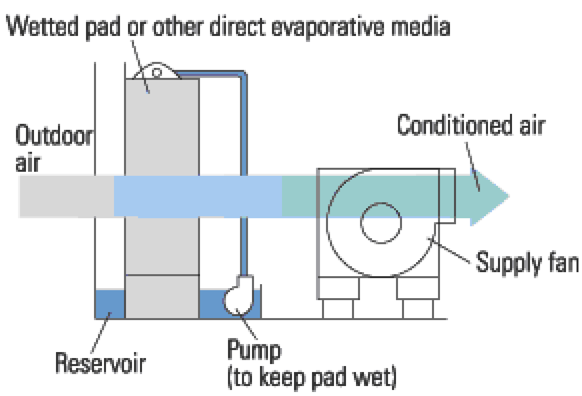
Direct and indirect processes can also be combined (indirect/direct). The effectiveness of either of these methods is directly dependent on the low wet bulb temperature in the supply airstream.

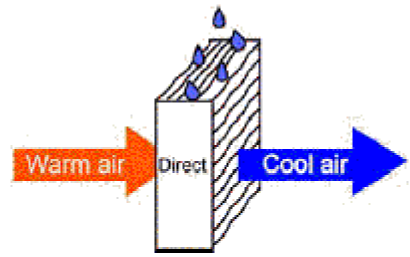
Direct Evaporative Cooling (open circuit)

Direct evaporative cooling introduces water directly into the supply airstream (usually with a spray or some sort of wetted media). As the water absorbs heat from the air, it evaporates and cools the air.

In direct evaporative cooling the dry bulb temperature is lowered but the wet bulb temperature remains unchanged.

In operation, a blower pulls air through a permeable, water-soaked pad. As the air passes through the pad, it is filtered, cooled, and humidified. A recirculation pump keeps the media (pad of woven fibers or corrugated paper) wet, while air flows through the pad. To ensure that the entire media is wet, more water is usually pumped than can be evaporated and excess water drains from the bottom into a sump. An automatic refill system replaces the evaporated water.





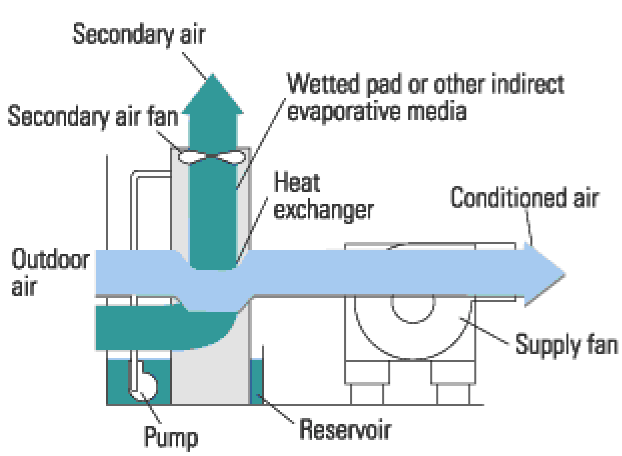
The efficiency of direct cooling depends on the pad media. A good quality rigid cellulose pad can provide up to 90% efficiency while the loose aspen wood fiber pad shall result in 50 to 60% contact efficiencies.

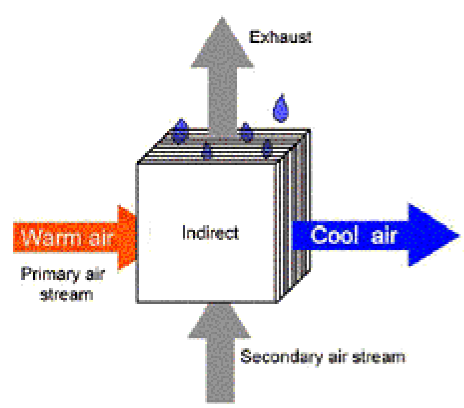
Indirect Evaporative Cooling (closed circuit)

Indirect evaporative cooling lowers the temperature of air via some type of heat exchanger arrangement, in which a secondary airstream is cooled by water and which in turn cools the primary airstream. The cooled air never comes in direct contact with water or environment.

In indirect evaporative cooling system both the dry bulb and wet bulb temperatures are reduced.

Indirect evaporative coolers do not add humidity to the air, but cost more than direct coolers and operate at a lower efficiency.



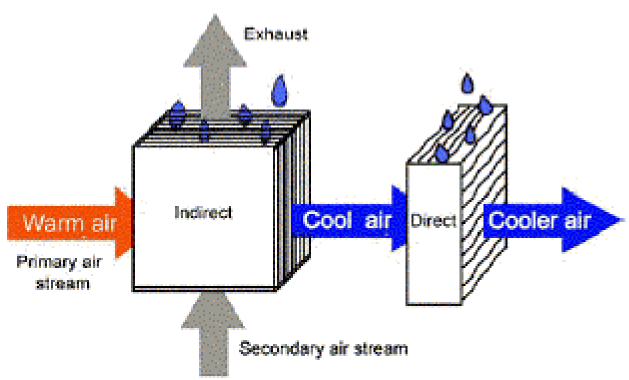


The efficiency of indirect cooling is in the range of 60-70%.

Two-stage Indirect/direct Evaporative Cooling

Two stage evaporative coolers combine indirect with direct evaporative cooling. This is accomplished by passing air inside a heat exchanger that is cooled by evaporation on the outside. In the second stage, the pre-cooled air passes through a water-soaked pad and picks up humidity as it cools. Because the air supply to the second stage evaporator is pre-cooled, less humidity is added to the air, whose affinity for moisture is directly related to temperature. The two-stage evaporative cooling provides air that is cooler than either a direct or indirect single-stage system can provide individually. In many cases, these two-stage systems provide better comfort than a compressor-based system, because they maintain a more favorable indoor humidity range.

An advanced two-stage evaporative cooler uses 100 percent outdoor air and a variable speed blower to circulate cool air. Two-stage evaporative coolers can reduce energy consumption by 60 to 75 percent over conventional air conditioning systems, according to the American Society of Heating and Engineers (ASHRAE). Yet this relative improvement depends on location and application.



Comparison of Direct, Indirect and Two - Stage Cooling

In the following examples, we will see the temperature reduction achievable through three different approaches. These examples consider using a starting dry bulb (DB) temperature of 86^o and wet bulb (WB) temperature of 66^o. Assume cooling efficiency is 90% for direct cooling and 70% for indirect cooling.

1) Temperature reduction achievable using Direct Evaporative Cooling

A. Temp drop achievable = (dry bulb - wet bulb) x (efficiency of the media)
Example: (86° - 66°) x .9 = 18°

B. Achievable temp = dry bulb - temp drop achievable
Example: 86° - 18° = 68° DB

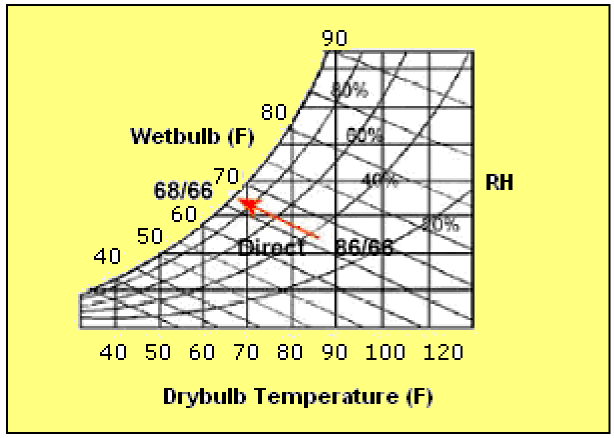
C. Results*

Starting DB: 86°
Ending DB: 68°

Starting WB: 66°

Ending WB: 66°

**Because cooling is achieved by adding moisture to the supply air stream, the new dry bulb/web bulb temperatures are found on the web bulb gradient.*



Note that with direct evaporative cooling, the dry bulb temperature is reduced while the web bulb temperature remains the same.

2) **Temperature reduction achievable using Indirect Evaporative Cooling**

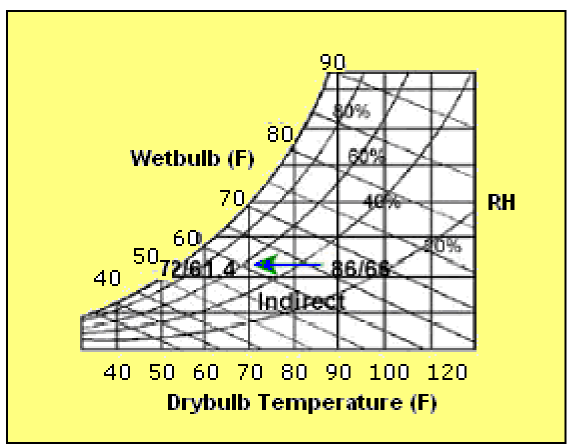
A. Temp drop achievable = (dry bulb – wet bulb) x (efficiency of indirect module)
Example: (86° - 66°) x .7 = 14°

B. Achievable temp = dry bulb – temp drop achievable
Example: 86° – 14° = 72° DB/61.4° WB

C. Results*

Starting DB: 86°
Ending DB: 72°

Starting WB: 66°

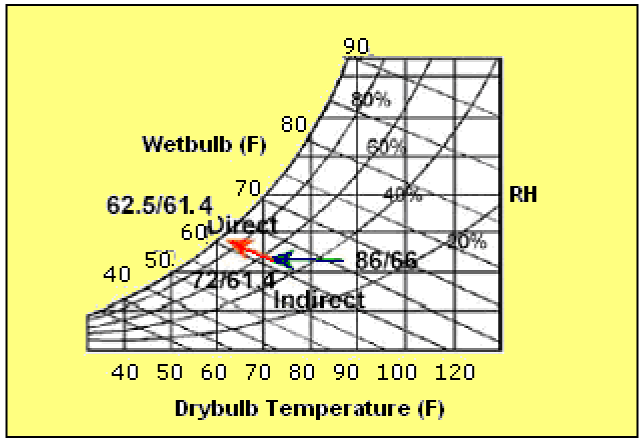


Note that with indirect evaporative cooling, both the dry bulb and web bulb temperatures are reduced.

Ending WB: 61.4°

**Because no moisture is added to the supply air stream, the new dry bulb/wet bulb temperatures are found on the dry bulb gradient.*

3) **Temperature reduction achievable using Two-stage Indirect / Direct Evaporative Cooling**



Note that with two stage evaporative cooling, both the dry bulb and web bulb temperatures are reduced.

First calculate the dry bulb and wet bulb temperatures achievable with indirect evaporative cooling:

A. Temp drop achievable = (dry bulb - wet bulb) x (efficiency of indirect module)

Example: $(86^o - 66^o) \times .7 = 14^o$

B. Achievable temp = dry bulb - temp drop achievable
Example: $86^o - 14^o = 72^o$ DB

Results after stage -1, indirect cooling

Starting DB /WB: 86^o / 66^o
Ending DB / WB: 72^o / 61.4^o

Then use the dry bulb/wet bulb values from step 3 to calculate the dry bulb/wet bulb temperatures achievable with direct evaporative cooling:

C. Temp drop achievable: (dry bulb - wet bulb) x (efficiency of the direct module media)
Example: $(72^o - 61.4^o) \times .9 = 9.5^o$

D. Achievable temp = dry bulb - temp drop achievable

Example: 72^o - 9.5^o = 62.5^o DB

Results after stage -2, direct cooling

Starting DB /WB: 72^o / 61.4^o

Ending DB / WB: 62.5^o / 61.4^o

Net results after stage-1 & 2 cooling

Starting DB /WB: 86^o / 66^o

Ending DB / WB: 62.5^o / 61.4^o

SECTION -4 SIZING THE EVAPORATIVE COOLING EQUIPMENT

Two principle method of sizing evaporative coolers are:

1) Air change sizing method
2) Sensible heat load removal method

Air Change Sizing Method

The "Air Change" method is a practical approach to assist in the determination of the size of evaporative cooling equipment. The principle behind this method is to determine two factors:

1) Leaving air temperature from the evaporator cooler
2) Difference between the inside temperature of the space, when evaporative cooling is not in use and the outside ambient temperature during its highest condition

Once the above two factors have been determined, refer to table below to determine the proper number of air changes.

Leaving Air Temperature	Temperature over ambient NOTE1	Air Changes/Hr NOTE 2
Above 78(F)	20 degrees (F)	30 to 60
76 (F) to 78 (F)	15 to 20 (F)	20 to 40

Leaving Air Temperature	**Temperature over ambient**[NOTE1]	**Air Changes/Hr** [NOTE 2]
74 (F) to 76 (F)	10 to 15 (F)	15 to 30
72 (F) to 74 (F)	5 to 10 (F)	12 to 20
under 72 degrees (F)	less than 10 (F)	10 to 15

Note1 - Average indoor temperature over the outdoor temperature when evaporative cooling is not in use. For example, say in an industrial building due to occupancy, lighting and machinery heat load the indoor temperature may rise to 20°F over ambient temperature without any ventilation/evaporative cooling in place.

Note 2 - The air change column indicates a range of frequency and is used in determining air volume requirements.

Procedure

Step 1: Determine the Cubic Capacity of the structure or that portion of the structure to be evaporative cooled

Formula = Width X Length X Effective Cooling Height* = Capacity in Cubic Feet

*The actual height to be cooled i.e. in a 25' tall building, it is the usual practice to cool only to about 16' to 20' based on the highest point the cooling is required. A heat stratification layer will form at the roof level which will not adversely affect the cooling process provided that space is not used. Remember cold air drops and hot air rises.

Step 2: Calculate the leaving dry bulb temperature

Using the formula: LDB = ODB – [SE x (ODB - OWB)], determine the predicted discharge temperature.

Where

- LDB is the leaving dry bulb temperature
- ODB is the outdoor dry bulb temperature
- OWB is the outdoor wet bulb temperature
- (ODB – OWB) is the wet bulb depression

- SE is the saturation efficiency of the cooling media

It is first necessary to know the climate design conditions of Dry Bulb (ODB) and Wet Bulb (ODB) for your location. This information is available from ASHRAE publications.

Step 3: Determine the number of air changes per hour required to maintain desired indoor temperatures

The air changes can be determined from the column-3 of above table. This is an extremely important determination. Too many air changes will result in unnecessary cost while too few air changes will not achieve the indoor conditions desired. Experience has shown that significant benefit can be achieved with 10-15 AC/Hr for 12 feet height. For a 24-foot-high building, this would mean 5-6 AC/Hr for the entire volume. This will vary by application.

Sensible Heat Removal Sizing Method

Use the sensible heat load equation to determine the air flow rate:

$$SCFM = \frac{\text{Indoor Sensible Heat Gain (BTUH)}}{1.08 \times (\text{IDB-LDB}) \times \text{Density Ratio}}$$

Where

IDB = Desired indoor (Design) Dry Bulb

LDB = Leaving Dry Bulb from Cooler

Example:

A manufacturing facility located at 4000 feet elevation has a heat load of 144,000 BTUH. The outside design conditions are 94 Dry Bulb and 64 Wet Bulb and the desired indoor temperature is 80^0 F. Determine the capacity of an evaporative cooler. An Evaporative Cooler with 12" cooling media @ 500 FPM velocity is to be used to remove this heat gain.

Solution:

The discharge temperature (Db) must first be determined. Using the formula of ODB - (SE x (ODB - OWB)), the following result is reached. 94 - (.89 x (94 - 64) = 67.3^0 F LDB.

At 4000 feet elevation the Density Ratio is .87. [The Density Ratio* is determined from the tables; refer annexure -1 at the end of this course].

To determine SCFM to offset this indoor heat gain we can now utilize the formula:

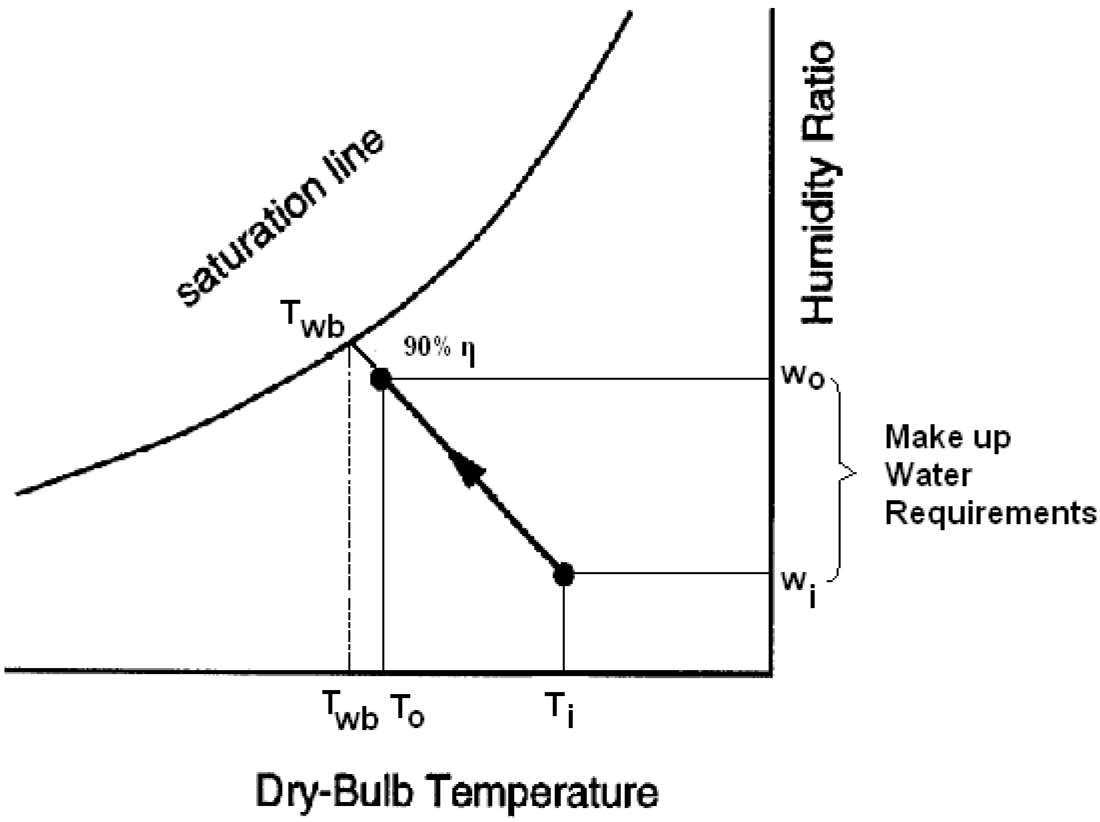
144000/ [1.08 x (80 - 67.3) x .87] = 12067 SCFM

This result indicates we need at least 12,067 Cubic Feet per Minute of air flow @ 67.3ºF to offset the indoor heat gain of 144,000 BTUH.

(*Note that the air change method does not take into consideration the density ratio which would have to be considered in higher elevations).

Saturation Efficiency & Make up Water Requirements

Saturation efficiency is defined as the difference between the entering and exit dry-bulb temperatures over the wet-bulb depression. On the Psychrometric chart, the process is indicated below:



$$\text{Saturation Efficiency } (\eta) = \frac{T_i - T_o}{T_i - T_{wb}}$$

Where

T_i = Dry bulb temperature of air at the inlet of evaporative cooler

T_o = Dry bulb temperature of air at the outlet of evaporative cooler

T_{wb} = Wet bulb temperature of air at inlet of evaporative cooler

On the psychrometric chart, the moisture absorbed by air or the evaporation rate can be calculated by: [$w_o - w_i$] and is given by lbs per pound of air. Empirically, the evaporation rate is given by equation:

Air flow rate in CFM x ($T_i - T_{wb}$) x Saturation Efficiency / 8700

Note without bleed off, the evaporation rate is equal to the make up water requirements.

RELEVANT FORMULAS:

(See abbreviations below)

1) **Leaving Dry Bulb** = ODB – [SE x (ODB - OWB)]
2) **Leaving Wet Bulb** = normally considered same as entering WB (for direct evaporative coolers)
3) **Wet Bulb Depression** = ODB – OWB
4) **Evaporation Rate (GPH)** = CFM x WBD x SE/ 8700*NOTE1
5) **Bleed - Off Rate** = Evaporation Rate x .20 (….approximately 20% of evaporation rate)
6) **(Recirculation) Water flow Rate** = 3 times the evaporation rate (approx)
7) **Standard CFM** = Area Sensible Heat Gain / {1.08 * [IDB - LDB] x Density Ratio}
8) **CFM** = Standard CFM/Density Ratio
9) **BTU** = CFM X Delta T x 1.08
10) **Density Ratio** = 1.325 x Barometric Pressure/ [Temp. (F) + 459]/.07494
11) **Water weight (US gallon)** = 8.33 pounds per gallon (based on distilled water)
12) **Water volume (US gallon)** = 7.481 gallons per cubic foot
13) **Water weight (US gallon cubic foot)** = 7.481 x 8.33 = weight of cubic foot of water (62.288#)
14) **Face Area** = Width x Height of open face area through which air will flow (expressed in square feet.)
15) **Face Velocity** = CFM / Face Area (Sq Ft) (expressed in Feet per minute (FPM).

16) **Heat of vaporization** = 1043 BTU/lb

17) **Weight of water** = 8.34 lb./Gallon

18) **Sensible BTU** = CFM *1.08 * [IDB - LDB]

Note # 1: 8700 conversion factor is based on 8.34 lb water/gallon and 1043 BTU/lb. water

Note # 2: Saturation efficiency from media supplier data (refer table 4 below)

Abbreviations and Definitions

- AC...........Air Changes
- BTUH ....British Thermal Units per Hour
- (S)CFM...... (Standard) Cubic Feet per Minute
- GPH ....Gallons per Hour
- IDB ....Indoor (design) Dry Bulb temperature
- LDB ....Leaving Dry Bulb temperature
- LWB ....Leaving Wet Bulb temperature
- ODB ....Outdoor (design) Dry Bulb temperature
- OWB ....Outdoor (design) Wet Bulb temperature
- SE ....Saturation Efficiency of the evaporative media
- T_{room} ......Temperature in space being controlled
- WBD ....Wet Bulb Depression

OTHER DESIGN INFORMATION

Refer to the following design information tables presented in Annexure# 1 at the end.

Table#1	Psychrometric Chart
Table #2	Evaporation Rate (gallons per hour evaporated per 1000 CFM)
Table #3	Dry Bulb Temperature drop across media (@ 500 FPM face velocity)
Table #4	Saturation Efficiency
Table #5	Air Density Ratio (Density Ratio for Various Elevations and Temperatures)

Table #6 Suggested air changes per hour and

Table # 7 Climatic conditions in USA in Annexure-1 at the end of this course.

EVAPORATIVE COOLER SELECTION EXAMPLES

Example #1: Sensible Heat Removal Method

A car manufacturing plant decides to install direct evaporative cooling for production areas. The following information is available:

1) Location ....Detroit
2) Elevation ....619 ft
3) Air Density Ratio...0.95
4) Summer Outdoor Design Conditions.....................91°F DB/73°F WB (Refer to Table 7, annexure #1)
5) Summer Indoor Design Conditions ....80°F DB
6) Summer Sensible Heat Gain...............................600,000 BTUH (total sensible heat generated from the equipment, lighting, personal etc.)
7) 12" Evaporative Media Saturation Efficiency ....88% (Refer to Table 4, annexure#1)
8) Evaporative Media Face Velocity ....600 FPM

Determine: Leaving dry-bulb temperature; Cooling SCFM, Evaporation Rate and the Makeup water requirements

Step #1: Equipment leaving dry and wet bulb temperatures

The leaving dry bulb temperature can be determined from the following equation:

Leaving Dry Bulb = ODB - (SE x (ODB - OWB))

= 91°F - 88% x [91°F - 73°F]

= 91°F - 15.8°F = 75.2°F DB

Leaving Wet Bulb remains unaffected at 73°F

Step #2: Evaporative Cooling Module CFM

SCFM = Area Sensible Heat Gain / {1.08 * [IDB - LDB] x Density Ratio}

= 600,000 / {1.08 * [80°F - 75.2°F] x .95}

= 121,832 or say 122000 SCFM

Step #3: Evaporation Rate

Wet Bulb depression = (91°F – 73°F) = 18°F

From Table 2 (refer to annexure -1) and interpolating the 88% efficiency column and 18F wet bulb depression, the evaporation rate is approximately 2.0 gallons per hour per 1000 CFM. Or alternatively you may use formula: Evaporation rate = CFM x Wet Bulb Depression x Saturation Efficiency/ 8700

Step #4: Makeup Water Requirements

Evaporation Rate – 2 GPH per hour per 1000 CFM

Total airflow - 122000 CFM

Evaporation water requirements – 2 * 122000/ 1000 = 244 GPH

Bleed off rate – 0.2 * 244 = 48.8 GPH

Total Makeup water requirements – Evaporative water + Bleed off rate = 244 + 48.8 = 292.8 GPH

Example # 2: Air Change Method

A heat treatment workshop building 500 ft wide x 100 ft long x 20 ft high is to be evaporative cooled. Determine**:**

1) Effective air volume to be cooled
2) Leaving Dry-Bulb Temperature
3) Number Air Changes Required
4) Evaporative Cooling CFM

The following design information is available.

Outdoor Design Conditions.......................................95°F DB/74°F WB

12” Evaporative Media Saturation Efficiency 88%

Evaporative Media Face Velocity ....600 FPM

Step #1: Building Air Volume to be cooled

For buildings with high ceilings, normally only the air space occupied by people up to a height of about 12' above floor level needs to be considered as building volume. In addition, where a large percentage of the air volume will always be displaced by stored goods or equipment, the volume of the goods can be omitted from consideration of the air volume. This assumes that normal stratification will occur between the warm upper part of the building and the cooler discharge air from the evaporative cooling equipment.

Building Volume = Width x Length x Height Up To 12'

= 500' x 100' x 12'

= 600,000 Cubic Feet

Step #2: Equipment Leaving Dry and Wet Bulb Temperatures

Leaving Dry Bulb = ODB - (SE x (ODB - OWB))

= 95°F - 88% x [95°F - 74°F]

= 95°F - 18.4°F = 76.6°F DB

Leaving Wet Bulb = 74°F

Step #3: Building Air Change Determination

Using the leaving dry-bulb temperature calculated in Step #2 and using air change sizing table, select 25 building air changes. (Note: This method normally does not use a correction for elevation.)

Step #4: Evaporative Cooling SCFM

Using the building volume established in STEP #1 and the number of building air changes determined in STEP

#3, the evaporative cooling module SCFM is calculated to be:

SCFM = 600,000 cu-ft /AC x 25 AC/Hr / 60 Minutes/Hour

= 250,000 SCFM

Next, we need to answer the question of how many individual coolers and the location of the equipment.

Do we want to put ten (10), 25000CFM coolers across the roof of the structure (on mounted on the side or ground) or do we want to install three (3) 82000CFM coolers or perhaps five (5) 50000CFM units? The answer to this question lies mostly in the consideration of costs. Cost of acquiring the five (5) units in this example would cost less than either of the other options.

It is suggested that you compare the air volume required to provide comfort cooling by the sensible heat removal method (see example #1) and the building air change method to minimize equipment requirements.

Section – 5 WHERE TO USE EVAPORATIVE COOLING

Before you invest in an evaporative cooling system, you must determine whether your operation would benefit from evaporative cooling. The most important factor you should consider is the temperature and humidity conditions in your location. You need to know how hot the temperature gets and for how long it stays hot, as well as the humidity at your location. If you live in a high temperature, low humidity region then evaporative cooling will be more effective for you as the air has less water content to begin with and therefore can hold more evaporating water. Some of the questions that should be answered are:

1) *What is to be cooled? People, Equipment or other?* If people, what are they doing. Office, production, warehousing, etc. If Equipment, what type and operation? Does the Equipment generate high heat loads, etc?
2) *What kind of work is going to be performed?* Certain kinds of operations can be better served than others. An example is printing processes. Color printing cannot dry too quickly or too slowly. Paper cannot be allowed to absorb too much moisture or it becomes too limp so humidity control is very important.
3) *What are the cost parameters?* Can mechanical refrigeration be afforded even if it is desired?
4) *What is the structure capable of supporting? Are there other structural considerations?* Is it necessary to locate the equipment on the ground or roof or some other mounting method?
5) *What are the climate conditions?* Is the climate hot and dry or mild conditions?

Qualifying the Application:

Answering the above questions will go a long way in the determination of *whether or not* evaporative cooling will be the best type cooling system or not. Some of the following considerations will help to provide some answers to these questions:

1) People in production or warehousing type jobs are prime users of evaporative cooling.

Evaporative cooling not only cools by dropping the dry bulb temperature but it also *cools by the chill factor* of air passing over the body. For people in office type work, it is usually the practice to use mechanical refrigeration due to the need to maintain very low humidity levels. In addition to human comfort it is also important to maintain humidity control and cool equipment (like computers). Most mechanical equipment is best cooled by evaporative cooling due to the need for large volumes of air passing over the equipment and exhausting the air to the outside. Also production and/or warehousing type jobs are usually best served by evaporative cooling. It is far easier to exhaust heat than it is to recirculate it and treat it. Perishable goods usually require mechanical refrigeration.

2) The type of work being performed influences the selection of cooling equipment. For example, the textile spinning plant has high sensible heat gain from machinery and requires high humidity for production. Evaporative cooling is the best option.

   Other types of work to be considered are those that require large volumes of air flow. Some types of work are just the opposite. High volumes of air flow may adversely affect the work (such as in some plastic film manufacturing).

3) Acquisition cost of mechanical refrigeration is usually about 3 times that of evaporative cooling for a similar structure. Costs vary widely due to type of structure, climate and other factors. Upkeep and maintenance costs are somewhat lower with evaporative cooling partially due to the technical expertise required. Operating costs are usually much higher for mechanical refrigeration. Sometimes 3 to 5 times higher in energy use alone.

4) Equipment selection must consider the ability of the structure to support it. It is not too unusual to have to locate equipment on the ground or some other mounting method because the roof will not support its weight. Structural integrity is a serious consideration in selection and location of equipment.

5) The climate is a major consideration in the selection of cooling equipment. Evaporative cooling is especially effective in hot dry climates. Temperature drops of 30 to 40 degrees are rather easy to achieve. It is not too unusual to achieve lower temperatures with evaporative cooling than with mechanical refrigeration during very low humidity periods due the lowered performance of mechanical refrigeration equipment in these conditions.

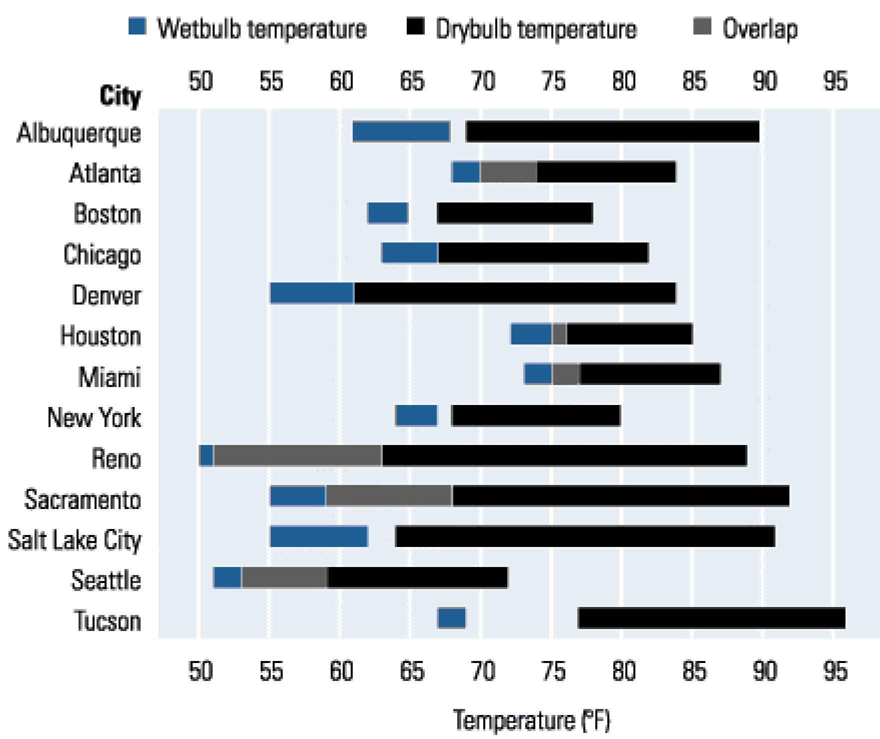
   In hotter areas or where cooling loads are high, such as in office buildings, one of the most useful applications for indirect evaporative cooling is supplementing a chiller or DX system. Evaporative cooling can be used during the hot dry periods and mechanical refrigeration during high humidity periods. By cooling the air stream before it reaches the cooling coil, an indirect evaporative unit extends chiller life, cuts energy costs, and provides the boost the chiller needs to function effectively on hot days. You can add an indirect evaporative cooling unit to an existing system or design a new cooling system that incorporates the indirect unit with the chiller or a standard roof-top DX system.

How to assess the potential for evaporative cooling in your climate?

Evaporative cooling performance is dynamic due to changes in external temperature and humidity level. Under typical operating conditions, an evaporative cooler will nearly always deliver to within 6°F – 8°F of the wet bulb temperature. Some rough examples clarify this relationship.

- At 90°F and 15% relative humidity, air may be cooled to nearly 60°F
- At 90°F and 50% relative humidity, air may be cooled to about 75°F
- At 105°F and 15% relative humidity, air may be cooled to nearly 70°F

Figure below shows average July daily wet bulb and dry bulb temperature ranges for 13 U.S. cities.



Daily average wet bulb and dry bulb temperatures in July for selected cities

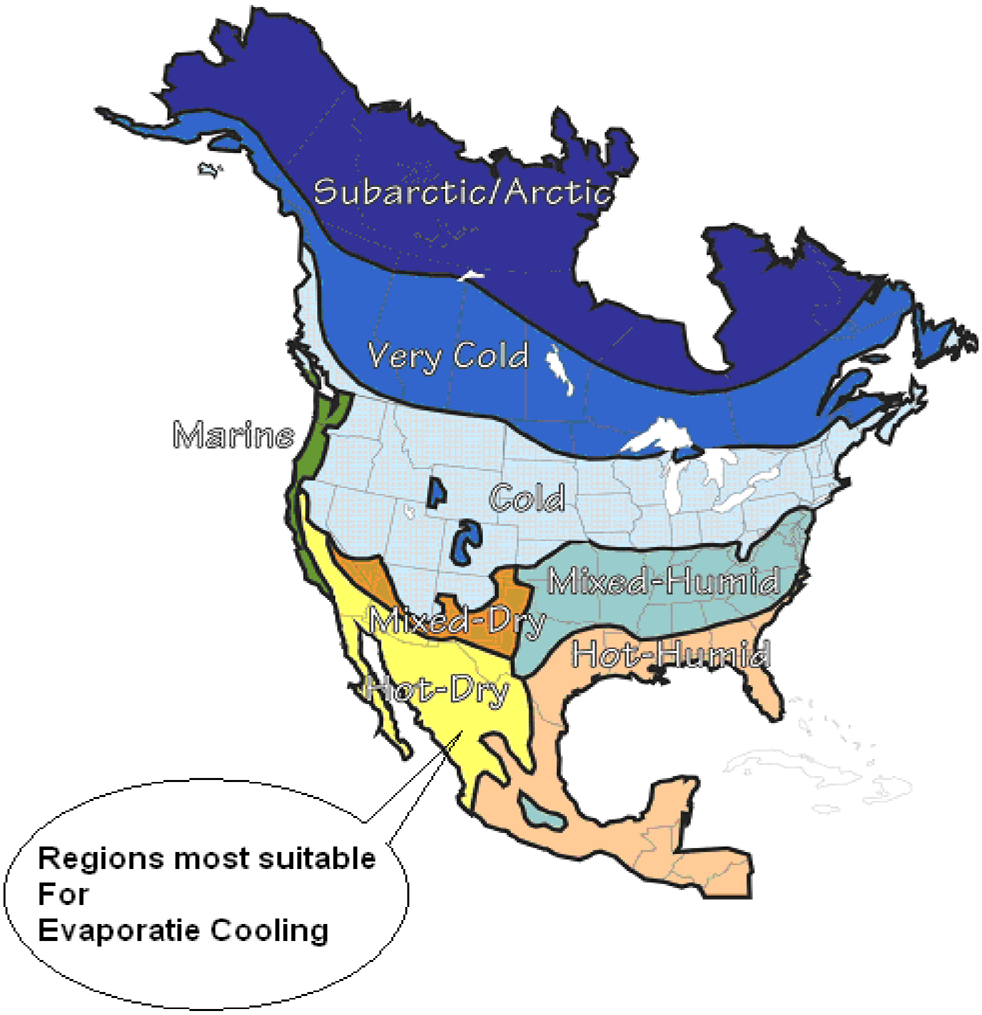
1) In five of the cities shown (Albuquerque, Boston, New York, Salt Lake City, and Tucson), the average wet bulb range is fully below the dry bulb range, and in all these locations, the wet bulb range is below 70° F.

    - The arid climates of Albuquerque, Salt Lake City, and Tucson make them excellent locations for evaporative cooling.
    - In more humid locations like Boston and New York, evaporative cooling may be used in dry weather, but will need to be supplemented by compressor-based cooling in hot, humid weather.

2) Locations with average July wet bulb temperature ranges extending above 70°F (Atlanta, Houston, and Miami) are not good candidates for evaporative cooling in July.

3) Prospects for completely eliminating compressor-based cooling are best in high-altitude climates that have dry air and lower summer daytime temperatures, as represented by Denver in figure above.

Evaporative cooling work best in very dry climates like southwestern USA and northern Mexico and are not effective for much of the east coast, Midwest and coastal US.



Cities where the wet bulb range is fully below the dry bulb range are excellent candidates for evaporative cooling. The five cities with wet bulb ranges extending to or below 55°F are all in the West. (However, Seattle's low dry bulb temperature range means cooling loads can usually be satisfied with outdoor air).

Section - 6 DESIGN SPECS & FREQUENT ASKED QUESTIONS

1) What are the main differences between *Air Conditioning* and *Evaporative Cooling*?

When most people say a*ir-conditioning* they are referring to refrigerated air conditioning systems/equipment. There are three main differences between air-conditioning solutions and using evaporative cooling; these are,

- **Cost:** typically a modern evaporative cooling solution will cost less than one third of the installed cost of a refrigerated AC system, and the monthly running costs will usually be far less than one tenth.

- **Operation:** Refrigerated air-conditioning relies on recirculation the air inside a building through chilled coils (a heat-exchanger) in order to cool the workplace - in many ways it can be said to be *fighting* the heat - this is why an air-conditioning engineer will talk about how many *tons* of air-conditioning you need to cool a given environment. Evaporative Cooling on the other hand is a single-pass approach. It constantly replaces the atmosphere in the workplace with fresh cool air – and that's why an evaporative cooling engineer will talk about the number of a*ir-changes per hour* you require for your application
- **Precise Control:** Refrigerated air-conditioning, if properly designed, can provide precise control of both temperature and humidity. Evaporative cooling is a cost-effective alternative in hot-dry regions and is associated with drop in temperature while increasing humidity.
- **Design Limitations:** There are certain limitations with evaporative cooling systems. Evaporative cooling design will need to accommodate higher airflow because these are designed for higher supply air temperatures compared to air-conditioning systems. Larger ducts are required, which may be a consideration in the architectural and structural design. Therefore, careful attention is necessary in locating and sizing supply outlets. Direct evaporative cooling may also be not appropriate for spaces with materials such as wood floors that might be damaged by high humidity.

2) Should you use evaporative cooling or mechanical cooling?

A common question asked by customers is should I install an Evaporative cooler or Mechanical cooling. If you live in a coastal or tropical region, you probably never hear this, because "evaporative' cooling is not very efficient when your ambient air is full of humidity.

If your wet bulb temperature is around 60 % and higher, then mechanical cooling is the correct answer. In lower wet bulb regions a properly sized evaporative cooler can be a very cost- effective and comfortable choice.

3) Should you use both evaporative cooling and mechanical cooling together?

Evaporative coolers can be used as a sole cooling system in a home, as an alternative cooling system to a conventional refrigerant air conditioner, or in combination with a refrigeration system. However, conventional air conditioners should not be operated simultaneously with direct evaporative coolers, because air conditioners dehumidify while evaporative coolers humidify, and the two systems will work in opposition.

4) What are the benefits and disadvantages of combined evaporative cooling and mechanical cooling?

One advantage to having both systems is that you get the best of two worlds - evaporative cooling during the dry months in spring and fall, and refrigeration in the hot –humid months.

Despite the convenience of the combined system, there are drawbacks. For example, considerable air movement is required for comfort with evaporative cooling. Refrigeration ducts are often too small for this and result in insufficient air flow and more noise. For systems using shared ductwork, dampers must be installed to separate the two units. Without dampers, refrigerated air will escape to the outside through the evaporative cooler and, conversely, moist air from the evaporative cooler will enter and corrode the refrigeration unit.

Also from the utility standpoint, the use of both systems results in an enhancement of the peaking problem for both water and power suppliers and, therefore, contribute to the need for additional capacity of these systems which are poorly utilized in off-peak demand periods.

5) How does an evaporative cooler work?

The cooling process works on the principle of evaporation of moisture. The fan of the cooler draws outside air through pads soaked with water. The evaporation of the water lowers the temperature of the air passing through the wet pads of the cooler and is blown through an opening into the building.

6) What are the major components of evaporative cooler?

Evaporative coolers typically consist of the following components:

- A sheet metal or fiberglass housing
- A centrifugal or propeller fan with drive motor and accessories (pulley and belts)
- Wetted media through which the air passes
- A means of keeping the media wet (often a pump, sometimes just a city water connection)
- A water reservoir

- A spray header and nozzles which disperse the water directly over the media
- Float valve and other controls
- Drift eliminators to prevent water droplets from blowing off especially for high face velocity applications.

7) Specify the construction details for an evaporative cooler

- The housing and sump shall be constructed from 304 stainless steel or galvanized sheet. The top and sides shall be 16gauge with intermediate support channels and welded construction. The sump shall be 14gauge with fully welded seams and joints.
- The media support shall be the full width and depth of the media, with 1 1/2" diameter perforations to allow unrestricted water flow into the sump.
- Provide a vapor proof incandescent light, installed in the evaporative cooler section to aid maintenance efforts. The switch should be mounted on the exterior of the cabinet near the access door. A removable panel shall be provided for maintenance access.
- A stainless steel baffle plate shall extend into the sump to prevent air bypass around the media.
- Lifting lugs shall be provided to simplify rigging.

8) What are the advantages and disadvantages of Evaporative Coolers?

Advantages

- Power consumption is limited to the fan and water pump vs. compressors, pumps and blowers in mechanical refrigeration. Coolers are economical to operate, using one-third the energy of refrigerated air-conditioning.
- Installing a new evaporative cooling system adequate for 1,500-square-foot home costs about $700. For the same home, installing a new air-conditioning system, using existing duct work, costs about $2,500.
- Most cooler maintenance and repairs can be accomplished by the homeowner.
- Most cooler replacement parts (pads, belts, etc.) are nominal in cost when compared to air-conditioning system replacement parts.
- Evaporative coolers can improve the indoor air quality inside a home by drawing a large supply of fresh outdoor air through the home.

Disadvantages

- Evaporative coolers will not work well in humid climates--they will not cool air significantly and cause discomfort by excessive humidity.
- The air supplied by the evaporative cooler is nearly 100% humid. Very humid air prevents the evaporative cooling of sweaty or wet skin.
- Coolers use on-site water; the consumption varies between 3.5 and 10.5 gallons of water per hour of operation depending on the size and geographical location.
- Coolers are aesthetically unattractive, if not maintained and overflow of concentrated salts from the cooler can damage building envelope.
- Air velocity when operating on high speed may cause annoying noise.
- High humidity in air accelerates corrosion. This can considerably shorten the life of electronic equipment.
- High humidity in air may cause condensation (which can be extremely hazardous, if it happens inside electrical equipment).
- The vents that allow air to exit the building may pose a security risk.
- Cooled air may bring dust and pollen into the space causing discomfort for allergy sufferers. Growth of microorganisms such as molds on the cooler pads may cause allergy problems in sensitive individuals.

9) **Does the evaporative cooler add humidity?**

Yes evaporative cooling adds humidity but by maintaining a constant flow of outside air and maintaining right exhaust rate, high humidity levels can be avoided.

10) What kind of temperature reductions can you expect with evaporative cooling?

How much temperature drop you experience depends largely on how much moisture is already present in the air. The greater the difference between the wet bulb and dry bulb temperatures, the greater shall be the achievable temperature reduction. In general an 8 to 28 degree drop, depending on the existing dry bulb temperature and humidity is achievable.

11) How much water does an evaporative cooler use?

Data for evaporative cooler water use are scarce since little research on this topic has been undertaken and many factors, from household composition to the geographical location, influence cooler water use. The amount of water consumed by an evaporative cooler is generally dependent on their size, air movement, temperature, humidity, and make-up water quality. It is estimated that a 4500 CFM (cubic foot per minute) cooler, under certain weather conditions, uses 200 gallons of water per day. The water use is split between evaporation and water being bled off or drained to reduce build-up of solids and minerals in the sump. Bled off requirements is usually 20% of the recirculation rate.

12) **Does the cooler spray or mist water?**

No, moisture is added to the air in a vapor state. Therefore, no puddles or wet spots are created from the cooler.

13) **How long do the cooling media pads last?**

3 to 5 years depending on the care given to them. If you have hard water, use the water softening conditioning tablets that will help prolong the pads life.

14) **How effective is the cooler in humid areas?**

The air temperature and relative humidity will determine the effective temperature drop. Even in humid climates, you can expect around an 8 degree temperature drop, which can still create a chill factor that equals effective cooling.

15) How much does it cost to operate an evaporative cooler?

Studies indicate that the average annual cooling energy usage for a 1,600 square foot home is approximately 6,000 kilowatt hours for refrigeration and 1,500 kilowatt hours for evaporative cooling.

If electricity costs were 10 cents per kilowatt hour (a sample cost), the average annual cost would be $600.00 for a refrigeration system versus $150.00 for evaporative cooling. However, the cost of water must be added to the electricity cost for evaporative cooling. Based on the cost of $2.00 for 1 hundred cubic feet or 740 gallons, the use of about 19,000 gallons of water by an evaporative cooler with a bleed-off system the additional average annual cost for water would be $54.00 for an evaporative cooler compared to $0 for a refrigeration system.

16) How much does a new cooler cost?

A new, completely installed 4500 CFM cooler costs about $700. Coolers are available for less money and for more money. This is an “average” figure.

17) Where coolers are typically placed on a building?

Evaporative coolers can be classified according to the position of the cooler in relation to the building. Generally, there are three types: (a) down-draft (roof mounted), (b) sidedraft (typically eave or window mounted), and (c) up-draft (ground mounted). Roof mounted, down-draft coolers (a) are sometimes preferred since they can usually be more readily connected to duct systems. However, eave mounted or ground mounted units can be more easily and safely serviced since the person doing the maintenance does not have to use a ladder to inspect or repair the system. Access for maintenance should also be considered when installing.

18) How do you size your evaporative cooler?

A good rule of thumb is to have 1 air change every 3 minutes in northern states, 1 air change every 2 minutes in the mid section and 1 air change every 1-2 minutes in the southern states. The formula for sizing your cooler is very simple; just multiply the length by the width by the height of the area to be cooled and divide by your air change factor.

For example a home in mid section that is 30' wide, 40' long 7' high has a total of 8400 cubic feet of area to be cooled. 30x40x7 = 8400
Using the factor two (for an air change every two minutes), divide 8400 by two to give you the CFM required, in this case 4200 CFM.

CFM is usually clearly marked on the front of the cooler. Too large coolers are wasteful of both water and energy and or too small coolers will not provide the comfort.

19) What is meant be bleed off of water?

Water (hard or soft) contains relatively large amounts of dissolved minerals. Since only pure water evaporates, leaving behind the minerals, the concentration of those minerals increases over time in the evaporative system. Eventually, the mineral concentration will exceed the ability of the water to hold them in solution, and scaling will occur. Some scaling is acceptable, even desirable, because it makes the media more rigid. Excess scale, however, will restrict airflow and degrade performance. To reduce the formation of excess scale, it is necessary to maintain the mineral levels below that point at which scaling occurs.

20) Do the minerals in hard water affect the operation of evaporative coolers?

Mineral deposits and scale build-up caused by hard water can cause rust and corrosion in metal coolers. Some estimates are that this rust and corrosion can shorten a cooler’s life by 50 percent. Further, scale build-up on cooler pads can cause uneven distribution of water, leading to “hot spots” on the pads and reduced cooling because of reduced air flow. Some manufacturers recommend installing a “bleed-off” valve to the recirculation water line and this result in draining part of the recirculation water thus reducing buildup of hard water minerals. Bleed-off valves are controversial because it is estimated that they increase cooler water usage from 10 to 50 percent.

21) If I decide not to install a bleed-off valve because it increases water usage, what can I do to prolong the life of the cooler?

Thorough cleaning of the cooler is suggested to remove mineral deposits and scale build-up at least once during the cooling season. Additives to the water supply also are available to help reduce scale build-up. Chemicals will not reduce scale build-up but they can increase the solubility of calcium and other minerals, thus allowing a lower bleed-off rate, or they can combine with the calcium and produce a softer scale that is easier to remove. Some cooler manufacturers do not recommend their use because they may damage the protective coating on the cooler. Caution should also be exercised about what chemicals are used because these can be blown into the home during the normal operation of the cooler. However, you may have to replace the cooler sooner than you would if you used a bleed-off valve.

22) Can coolers be used to circulate air only, without water?

With cool air in the evening and nighttime hours, the cooler fan can be run with dry pads. This brings cool air into the home and circulates it without using water.

If cooler pads have been allowed to dry out, either through non-use or by circulating air only, it is advisable to run the pump and saturate the pads thoroughly before running the cooler fan. This ensures that cooler air begins to circulate sooner and reduces the introduction of dust and pollen into the home.

If you switch to air conditioning during the “monsoon” season and then switch back to the evaporative cooler as the relative humidity decreases at the end of the rainy season, remember that standing water in the cooler pan is a stagnant pool. This water can become a good place for the growth of bacteria, even the bacteria that causes Legionnaire’s Disease. For safety it is best to drain the cooler if it will not be used for several days. Alternatively, the water in the cooler pan can be treated with chlorine for at least 30 minutes before turning the cooler.

23) Why do you need to maintain a slight negative pressure in the space?

The direct evaporative cooling system cools 100% outside air and does not recirculate any air. Therefore, it is imperative that the building's exhaust system must be compatible with the supply airflow rate. If this is not done, the building will become pressurized leading to insufficient airflow; difficulty in opening/closing doors; air whistling through stairwells and elevator shafts. A good design is to exhaust slightly more air then your cooler is supplying.

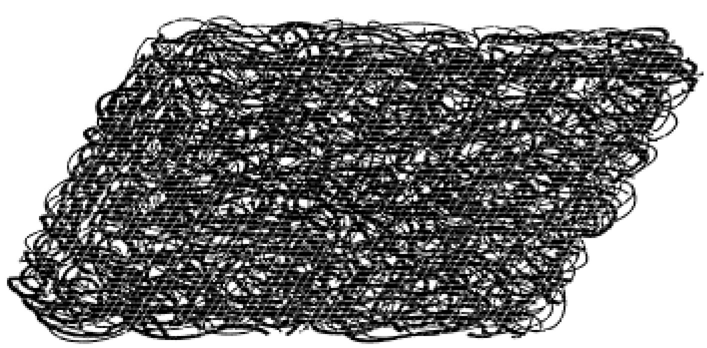
24) What are ceiling vents?

Ceiling vents or open windows are required to permit the exhaustion of the air blown into the home by the blower. Unlike refrigeration systems which recycle air within the home, coolers blow large volumes of cooled outside air into the living areas, and this air needs to be vented from the home. Ceiling vents make it possible to keep windows and doors closed while the cooler is running. This is helpful for security.

25) What types of cooling media are available?

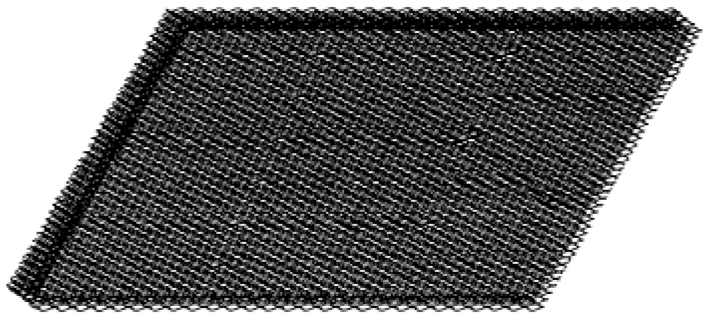
Cooler pads (sometimes called media) come in several alternatives.

The aspen wood fiber pads encased in chemically treated cheesecloth is widely used option. Literally wood fibers are packed together loosely, which offer the least amount of resistance to air flow through the cooler. This type of media was packed into 2" thick slabs within a cloth mesh. This pad was held on a wire hanger frame to support it within a metal frame. Water was introduced across the top of this pad and air was pulled through it by a blower. The cooling efficiency was only about 50% which was relatively poor. They may also produce debris in the water reservoir, increasing cooler maintenance.



Aspenwood fiber pad

Some cooler manufacturers recommend a cellulose fiber media or a slab of expanded paper to form a 2" thick media. This media is said to be uniform throughout, to provide consistent cooling performance and to last for several seasons. They are superior to spun aluminum and plastic pads available at hardware or do-it-yourself stores or supermarkets. These are less expensive initially than aspen wood but may need to be changed several times in one cooling season. The newer single pad coolers require a much thicker pad. This type of pad is more expensive than the traditional aspen wood fiber pad but is designed to last for several years if the cooler is operated in compliance with the owner's manual.



Paper cellulose pad

The newest and most efficient media is Rigid Cooling Media. This media is usually used in 12" thickness which performs at 90% efficiency. It is available in any thickness up to 24" which performs at (up to) 99% cooling efficiency. The construction of this media is unique in that it has alternating, transverse flutes of 45 degrees and 15 degrees. The 45 degree flutes carry the water (introduced over the top of the media) to the front of the media where the oncoming air forces it back into the media assisting in the thorough wetting of the media. The air flows through the 15 degree flutes. This media is made from a cellulose material with wetting agents and rigidifying saturants. The useful life of this media is usually 2 to 6 or even more years. Refer to section on "Rigid Media" from our home page for further information about this media.

26) Specify the design considerations for the selection of media pads

- The thickness of the padding media plays a large part in cooling efficiency, allowing longer air contact. The media shall be 12" thick for optimum saturation efficiency.
- The most commonly selected evaporative media design face velocity is 500-600 FPM; however face velocities up to 750 FPM can be used. All selections with face velocities over 600 fpm should be provided with PVC drift (air-borne moisture) eliminator to prevent excessive carryover of moisture. Uniformly distributed air flow across the media is essential for optimum equipment performance.

27) Specify the design considerations for air distribution

- An evaporative cooling system requires higher airflow rates. Therefore, special attention to duct design and sizing is required to avoid high fan energy costs.

- Proper air distribution and building relief is essential to maximize system performance and operation. In addition, the total supply air volume should exceed exhaust volume enough to slightly pressurize the building. [Ten percent (10%) excess air minimum.]
- A propeller or centrifugal fan (blower) provides the air flow across the wetted media. The appropriate fan selection depends on the required static pressure, which is the function of the resistance imposed to the airflow by the ductwork, wetted media, filters and other fittings. For large scale distribution, requiring static pressure above 0.5 inch-WG, centrifugal fans is an appropriate selection.

28) Specify the design considerations for plumbing and recirculation pump

- Recirculating Pump shall be a submersible pump(s) with a polypropylene body and impeller, polypropylene base, polycarbonate cover, lifetime oil supply, non-clogging impeller, and built-in overload protection. The pump shall be conservatively sized typically three times the design evaporation rate.
- Under upset conditions, the water level in the sump may fall below the level necessary for safe (non-damaging) pump operation. The pump must shut off, if the water level drops below a safe level. To accomplish this, install a water level switch which monitors the sump water level and prevents pump operation until the sump has filled to a safe operating level. An anti-siphon float valve shall be provided for introducing makeup water to the sump.
- All plumbing connections shall be stainless steel, welded to the housing or sump and of the size scheduled on the drawings. Internal piping shall be copper for pressure lines, PVC for *recirculation* pump discharge and header and overflow.
- The distribution header should be of a cleanable design, with spray orifices designed for complete and efficient water dispersal over the me*dia.*
- Consider provision for “bleeds off” valve to drain a fixed amount of water so that the mineral concentration is kept under control.

29) Specify the electrical and control options for evaporative coolers

Following controls need to be considered:

- Low water level control consists of a float switch set to turn off the pump, if the sump water level drops to less than 6”.
- High water level control consists of a float switch to turn off the make up water inlet

and prevent unnecessary drainage of water through overflow.

- Freeze protection control includes an outdoor air thermostat supply line fill and drain solenoid valves and a sump drain ball valve.
- Conductivity controls to automatically control the bleed-off rate when the total dissolved solids (TDS) exceed permissible limits.
- A Thermostat to shut-off the pump and/or fan, if the indoor temperature drops below the setpoint.
- A Humidistat to shut-off the pump and/or fan, if the humidity exceeds the humidistat setpoint (normally about 90%).
- All controls shall be 120 VAC or lower, routed through a single junction box. The wiring diagram for the evaporative cooling module shall be fully integrated with the air handler controls.

30) Is there any advantage of using a thermostat with evaporative cooler?

A thermostat can be set to start the cooler when a certain temperature, for example 80 degrees, is reached in the home. When the cooler is not operating, it is using neither water nor energy. Thermostats cost from $30.00 - $45.00. Timers can also be used to start the cooler and begin the cooling of the home prior to the arrival of the family. The use of 2 function thermostats starts the wetting of the cooler pads prior to air movement and thus prevents the blowing of dry air into the residence.

31) Things to consider before deciding

The first is cost. Get at least three estimates from reliable cooling suppliers or contractors, and don't forget to include the hidden costs, like installation, maintenance, and operational costs of utilities (electricity and water).

Perhaps the greatest advantage of evaporative cooling is the low cost: about one-third as much as refrigeration. The costs for operating a system will depend on the size and number of units, and how homeowners choose to run the evaporative cooler or refrigeration unit and the overall thermal properties of the home (insulation, thermal mass, amount of window area, orientation of the structure).

The next consideration is comfort. Evaporative cooling cannot keep every home comfortable all the time. A typical desert home will not be able to achieve temperatures in what is usually considered the comfort range on days when the humidity is high. Performance can be maximized, however, if all the windows are shaded from direct sunlight, the walls are properly insulated, and protected from direct sunlight, especially on the east and west sides or passive solar concepts were used in the construction of the home. Keep in mind that air movement, not just air temperature, contributes to comfort: 82 feels like 75 in a moderate breeze.

32) What maintenance options needed for evaporative coolers?

A cooler should be inspected monthly and serviced as needed during operation. The owner's manual should be read to determine if more frequent servicing is required. Before starting any maintenance operations, read all operating and maintenance instructions and observe all cautions and warnings.

- Since cooling efficiency is determined by how much water is evaporated, it is important to see that the pads receive a uniform wetting and be thoroughly wet at all times to provide the most cooling. Dry spots will greatly decrease cooling efficiency.
- The more frequent pads are changed the better - don't try to get 2-3 years out of pads. Twice a season is good (although seldom done, even at my house).
- Water treatment - many types of cooler treatment tablets are available. These tablets usually not only control corrosion but also freshen the air.
- Oil the motor and bearings - Most evaporative cooler motors do have oil ports. Use SAE #20 non-detergent oil.
- Check for proper belt tension, and amp draw.
- Water level in the reservoir should be checked periodically.

33) My cooler doesn't cool well and increases the humidity levels. Is there any trouble shooting advice?

Follow the general trouble shooting advice for inadequate cooling:

PROBABLE CAUSE	**SUGGESTED REMEDIES**
Cooler undersized	Replace with larger cooler
Clogged or dirty filters	Replace with pads
Dry pads or lack of water while cooler is operating	Check water distributing system for possible obstruction in tubing. Check pump.
Insufficient air discharge	Make sure there is adequate provision for

openings or inadequate exhaust from area being cooled, causing humidity building up and discomfort.	exhausting air from area being cooled.
Excessive humidity. (See also item above re: inadequate exhaust)	In some areas, there may be a few days during the summer when the relative humidity is high, resulting in complaints about poor cooling. The limitations of an evaporative cooler under conditions of high wet bulb temperature should be explained to the customer.
Blower turning backwards	Reconnect motor for correct direction
Blower installed backward	Remove and reinstall blower wheel to turn in correct direction
Blower running too slow	Check motor amps. If below name plate amperage, readjust variable pitch motor pulley to increase blower speed.

34) What is the startup and commissioning requirements?

- Check for correct airflow.
- Check for correct water flow rate over the evaporative media.
- Check the bleed-off rate of water from the evaporative system to ensure that it is adequate to prevent mineral buildup but not too large to cause excessive water consumption.
- Verify all modes of operation.

35) Is there any specific code requirements?

System design and specifications must be reviewed and verified to assure that they comply with all applicable local, state and federal codes. In general check the following:

- In areas which require fireproof media, a UL-900-listed media can be used.
- Some codes may place limits on the water volume allowed into the sanitary sewer system. Consult your local municipality.
- Most local codes permit the placement of PVC plumbing in an airstream entering the facility. If the PVC piping is not acceptable, select the copper or stainless piping option.

Annexture-1

USEFUL DESIGN DATA

Table 1: Psychrometric Chart

Lbs of H_2O per Lb of Dry Air	Temperature (Dry Bulb in °F)															
	40		50		60		70		80		90		100		110	
	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%
.001	27	20	34	12	41	10	46	8	51	5	54	3	57	2	62	2
.002	32	40	36	28	43	19	47	12	53	10	57	7	60	5	63	4
.003	35	58	41	40	45	28	50	19	54	15	58	10	62	7	65	6
.004	36	75	43	51	47	38	52	26	56	19	59	13	63	10	66	8
.005	39	95	45	65	50	47	54	32	57	23	61	17	64	12	67	9
.006	x	x	46	78	51	55	55	39	59	27	63	20	66	15	69	10
.007	x	x	49	91	53	64	57	45	61	31	65	24	67	18	70	12
.008	x	x	x	x	55	73	59	51	63	36	66	28	68	20	71	14
.009	x	x	x	x	56	82	60	57	64	41	67	30	70	22	72	16
.010	x	x	x	x	57	90	62	63	65	46	68	33	72	25	74	18
.011	x	x	x	x	60	99	64	70	66	50	70	36	73	27	76	20
.012	x	x	x	x	x	x	65	76	67	55	71	40	74	29	77	22
.013	x	x	x	x	x	x	66	83	69	59	72	44	75	31	78	24
.014	x	x	x	x	x	x	67	90	70	63	74	47	76	33	78	26

Lbs of H_2O per Lb of Dry Air	Temperature (Dry Bulb in °F)															
	40		50		60		70		80		90		100		110	
	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%	Wb	RH%
.015	x	x	x	x	x	x	69	95	72	68	75	50	77	36	79	27
.016	x	x	x	x	x	x	70	99	73	72	76	53	78	39	81	29
.017	x	x	x	x	x	x	x	x	74	76	77	57	79	42	82	31
.018	x	x	x	x	x	x	x	x	75	80	77	59	80	45	82	33
.019	x	x	x	x	x	x	x	x	76	85	78	62	81	47	83	35
.020	x	x	x	x	x	x	x	x	77	90	80	65	82	49	84	37
.021	x	x	x	x	x	x	x	x	78	95	81	69	83	51	85	39
.022	x	x	x	x	x	x	x	x	79	99	82	72	84	53	86	40
.023	x	x	x	x	x	x	x	x	x	x	83	75	85	55	87	41
.024	x	x	x	x	x	x	x	x	x	x	84	78	86	58	88	42
.025	x	x	x	x	x	x	x	x	x	x	85	81	87	60	89	43
.026	x	x	x	x	x	x	x	x	x	x	86	85	88	62	90	44
.027	x	x	x	x	x	x	x	x	x	x	87	88	89	65	91	46
.028	x	x	x	x	x	x	x	x	x	x	88	91	90	67	92	47
.029	x	x	x	x	x	x	x	x	x	x	89	95	91	69	93	49
.030	x	x	x	x	x	x	x	x	x	x	90	99	92	71	94	51

Acronyms: Db is Dry Bulb temperature, Wb is Wet Bulb temperature, and $\#H_2O$ is Pounds of moisture per pound of dry air which is a measure of absolute humidity. RH is Relative Humidity.

Read the chart by finding the known elements, such as Dry Bulb and Relative Humidity and move horizontal to find the Wet Bulb and pounds of moisture per pound of dry air i.e. the weather forecast is for 100º at 15% Relative Humidity. You will find that the Web Bulb is 66º and the pound of moisture is .006 per pound of dry air. Knowing the wet bulb will allow you to determine the Wet Bulb depression.

The Psychrometric chart will provide you the necessary information to design systems, predict outcomes and many other useful applications of the information! This chart is digitalized to make it simpler to use. It is necessary to interpolate and extrapolate accordingly for those in-between conditions not directly covered in the above chart i.e. if 105 degrees was the temperature to use, then it would be necessary to interpolate the available data to reach the right conclusion. In this instance, the Wet Bulb would be 67.5 degrees. This chart is intended to be reasonably accurate at sea level and should be within ±5%. If greater accuracy is required, it is recommended that you use the proper Psychrometric chart for the elevation desired or make proper adjustments for elevation (barometric pressure).

Table 2: Evaporation Rate (Gallons per Hour evaporated per 1000 CFM)

Wet bulb Depression (F)	**Saturation Efficiency**									
	0.80	**0.82**	**0.84**	**0.86**	**0.88**	**0.90**	**.092**	**0.94**	**0.96**	**0.98**
5	0.50	0.51	0.52	0.53	0.55	0.56	0.57	0.58	0.60	0.61
10	0.99	1.02	1.04	1.07	1.09	1.12	1.14	1.17	1.19	1.22
15	1.49	1.53	1.56	1.60	1.64	1.68	1.71	1.75	1.79	1.83
20	1.99	2.04	2.09	2.14	2.19	2.23	2.28	2.33	2.38	2.43
25	2.48	2.55	2.61	2.67	2.73	2.79	2.86	2.92	2.98	3.04
30	2.98	3.05	3.13	3.20	3.28	3.35	3.43	3.50	3.58	3.65
35	3.48	3.56	3.65	3.74	3.82	3.91	4.00	4.08	4.17	4.26
40	3.97	4.07	4.17	4.27	4.37	4.47	4.57	4.67	4.77	4.87

Wet bulb Depression (F)	**Saturation Efficiency**									
	0.80	**0.82**	**0.84**	**0.86**	**0.88**	**0.90**	**.092**	**0.94**	**0.96**	**0.98**
45	4.47	4.58	4.69	4.80	4.92	5.03	5.14	5.25	5.36	5.48

To determine Gallons per Minute divide by 60. Formula to determine evaporation rate is shown in formulas section.

Table 3: Dry Bulb Temperature drop across media (@ 500 FPM face velocity)

Wet bulb Depression (F)	**Media Thickness**					
	4"	6"	8"	12"	18"	24"
10.0	5.3	6.8	7.9	8.9	9.8	9.9
12.5	6.6	8.5	9.8	11.1	12.2	12.3
15.0	7.9	10.2	11.8	13.3	14.6	14.8
17.5	9.2	11.9	13.8	15.6	17.1	17.3
20.0	10.5	13.6	15.8	17.8	19.5	19.7
22.5	11.8	15.3	17.7	20.0	21.9	22.2
25.0	13.2	17.0	19.7	22.2	24.4	24.7
27.5	14.5	18.7	21.7	24.4	26.8	27.2
30.0	15.8	20.4	23.6	26.7	29.3	29.6
32.5	17.1	22.1	25.6	28.9	31.7	32.1
35.0	18.4	23.8	27.6	31.1	34.1	34.6
37.5	19.7	25.5	29.5	33.3	36.6	37.0
40.0	21.1	27.2	31.5	35.6	39.0	39.5

Note: 12" thick media @ 500 FPM face velocity is the preferred design. This is the best trade-off between performance and cost.

Table 4: Saturation Efficiency

The following table defines the saturation efficiency by media thickness and face velocity. Efficiency & Pressure Drop Data is based on the field performance information and is approximate.

Face Velocity	Percent Media Efficiency at Media Depth:						Static Pressure Drop at Media Depth:					
	4"	6"	8"	12"	18"	24"	4"	6"	8"	12"	16"	24"
200 FPM	71%	86%	91%	98%	99%	99%	0.02"	0.03"	0.04"	0.06"	0.08"	0.09"
300 FPM	67%	81%	88%	96%	98%	99%	0.03"	0.05"	0.07"	0.10"	0.13"	0.19"
400 FPM	62%	77%	84%	94%	97%	99%	0.05"	0.09"	0.11"	0.18"	0.25"	0.31"
500 FPM	59%	72%	82%	92%	96%	99%	0.09"	0.12"	0.17"	0.26"	0.36"	0.50"
600 FPM	57%	70%	80%	91%	95%	99%	0.12"	0.18"	0.22"	0.36"		

Note: Face velocities higher than 600 FPM are not recommended as it will lead to excessive moisture carryover problems. Example: At air velocity of 500 FPM and media thickness of 12", the saturation efficiency will be 92%. Recommended design velocity is 500 - 550 feet per minute. This is the best trade-off between performance and cost.

Table 5: Air Density Ratio (Density Ratio for Various Elevations and Temperatures)

Temp (F)	Elevation (ft) / Inches Hg										
	0 / 29.92	1000 / 28.86	2000 / 27.82	3000 / 26.82	4000 / 25.84	5000 / 24.90	6000 / 23.98	7000 / 23.09	8000 / 22.22	9000 / 21.39	10000 / 20.58
68	1.00	0.97	0.93	0.90	0.87	0.84	0.80	0.77	0.75	0.72	0.69
70	1.00	0.96	0.93	0.90	0.86	0.83	0.80	0.77	0.74	0.71	0.69

Temp (F)	**Elevation (ft) / Inches Hg**										
	0 / 29.92	**1000 / 28.86**	**2000 / 27.82**	**3000 / 26.82**	**4000 / 25.84**	**5000 / 24.90**	**6000 / 23.98**	**7000 / 23.09**	**8000 / 22.22**	**9000 / 21.39**	**10000 / 20.58**
72	1.00	0.96	0.93	0.89	0.86	0.83	0.80	0.77	0.74	0.71	0.69
74	0.99	0.96	0.92	0.89	0.86	0.83	0.80	0.77	0.74	0.71	0.68
76	0.99	0.95	0.92	0.89	0.85	0.82	0.79	0.76	0.73	0.71	0.68
78	0.99	0.95	0.92	0.88	0.85	0.82	0.79	0.76	0.73	0.70	0.68
80	0.98	0.95	0.91	0.88	0.85	0.82	0.79	0.76	0.73	0.70	0.68

Table 6: Suggested Air Changes per hour

Leaving Air Temperature	**Temperature over ambient** [NOTE1]	**Air Changes / Hr** [NOTE 2]
Above 78(F)	20 degrees (F)	30 to 60
76 (F) to 78 (F)	15 to 20 (F)	20 to 40
74 (F) to 76 (F)	10 to 15 (F)	15 to 30
72 (F) to 74 (F)	5 to 10 (F)	12 to 20
under 72 degrees (F)	less than 10 (F)	10 to 15

Note1 - Average amount indoor temperature exceeds the outdoor temperature when evaporative cooling is not in use. For example, say in an industrial building due to machinery heat load the indoor temperature may raise to 20°F over ambient temperature without any ventilation/evaporative cooling in place.

Note 2 - The air change column indicates a range of frequency and is used in determining air volume requirements.

Table 7: Climate Design Conditions (USA)

The following table includes climate design conditions for selected cities around the USA. The co-incident Dry Bulb/Wet Bulb temperatures are those not exceeded more than 1% of the time for a four (4) month period, June through September. The Design Wet Bulb (DWb) is representative of Wet Bulb alone not exceeding shown temperature more than 1% of the time during the same 4 months and not co-incident with Dry Bulb temperature.

State & Station	Elev	Design Condition			--	State & Station	Elev	Design Condition		
-	Feet	Db	Wb	DWb	--	-	Feet	Db	Wb	DWb
Alabama:	-	-	-	-	--	**Alaska:**	-	-	-	-
Auburn	730	96	77	79	--	Anchorage	90	71	59	60
Birmingham	610	96	74	78	--	Fairbanks	436	82	62	64
Decatur	580	95	75	78	--	**Arizona:**	-	-	-	-
Dothan	321	94	76	80	--	Douglas	4098	98	63	70
Florence	528	97	74	78	--	Flagstaff	6973	84	55	61
Gadsden	570	96	75	78	--	Kingman	3446	103	65	70
Huntsville	619	95	75	78	--	Nogales	3800	99	64	71
Mobile	211	95	77	80	--	Phoenix	1117	109	71	76
Montgomery	195	96	76	79	--	Prescott	5014	96	61	66
Talladega	565	97	77	79	--	Tucson	2584	104	66	72
Tuscaloosa	170	98	75	79	--	Winslow	4880	97	61	66

State & Station	Elev	Design Condition			--	State & Station	Elev	Design Condition		
-	Feet	Db	Wb	DWb	--	-	Feet	Db	Wb	DWb
Arkansas:	-	-	-	-	--	Yuma	199	111	72	79
Fort Smith	449	101	75	80	--	**California:**	-	-	-	-
Hot Springs	535	101	77	80	--	Bakersfield	495	104	70	73
Little Rock	257	99	76	80	--	Barstow	2142	106	68	73
Texarkana	361	98	76	80	--	Blythe	390	112	71	75
Colorado:	-	-	-	-	--	Burbank	699	95	68	71
Boulder	5385	93	59	64	--	Chico	205	103	69	71
Colorado Springs	6173	91	58	63	--	El Centro	-30	112	74	81
Denver	5283	93	59	64	--	Eureaka	217	68	60	62
Pueblo	4639	97	61	67	--	Fresno	326	102	70	72
Idaho:	-	-	-	-	--	Los Angeles	99	83	68	70
Boise	2842	96	65	68	--	Needles	913	112	71	75
Idaho Falls	4730	89	61	65	--	Oakland A	3	85	64	66
Lewiston	1413	96	65	67	--	Palm Springs	411	112	71	76
Pocatello	4444	94	61	64	--	Pasadena	864	98	69	73

State & Station	Elev	Design Condition			--	State & Station	Elev	Design Condition		
-	Feet	Db	Wb	DWb	--	-	Feet	Db	Wb	DWb
Twin Falls	4148	99	62	64	--	Pomona	871	102	70	74
Illinois:	-	-	-	-	--	Riverside	1511	100	68	72
Champaign	743	95	75	78	--	Sacramento	17	101	70	72
Chicago	594	94	75	79	--	San Bernardino	1125	102	70	74
Danville	558	93	75	78	--	San Diego	19	83	69	71
Joliet	588	93	75	78	--	San Francisco	8	82	64	65
Peoria	652	91	75	78	--	San Jose	70	85	66	68
Rantoul	740	94	75	78	--	Santa Ana	115	89	69	71
Indiana:	-	-	-	-	--	Stockton	28	100	69	71
Anderson	847	95	76	79	--	**Iowa:**	-	-	-	-
Bloomington	820	95	76	79	--	Cedar Rapids	863	91	76	78
Columbus	661	95	76	79	--	Des Moines	948	94	75	78
Fort Wayne	791	92	73	77	--	Sioux City	1095	95	74	78
Indianapolis	793	92	74	78	--	**Kansas:**	-	-	-	-
Kentucky:	-	-	-	-	--	Topeka	877	99	75	79

State & Station	Elev	Design Condition			--	State & Station	Elev	Design Condition		
-	Feet	Db	Wb	DWb	--	-	Feet	Db	Wb	DWb
Lexington	979	93	73	77	--	Witchita	1321	101	72	77
Louisville	474	95	74	79	--	**Michigan:**	-	-	-	-
Missouri:	-	-	-	-	--	Detroit	633	91	73	76
Farmington	928	96	76	78	--	Grand Rapids	681	91	72	75
St Joseph	809	96	77	81	--	Pontiac	974	90	73	76
St Louis	465	98	75	78	--	**Montana:**	-	-	-	-
Nebraska:	-	-	-	-	--	Billings	3567	94	64	67
N. Platte	2779	97	69	74	--	Butte	5526	86	58	60
Omaha	978	94	76	78	--	Great Falls	3664	91	60	64
Nevada:	-	-	-	-	--	Helena	3893	91	60	64
Las Vegas	2162	108	66	71	--	**New Mexico:**	-	-	-	-
Reno	4490	96	61	64	--	Albuquerque	5310	96	61	66
North Dakota:	-	-	-	-	--	Clovis	4279	95	65	69
Bismark	1647	95	68	73	--	Farmington	5495	95	63	67
Fargo	900	92	73	76	--	Gallup	6465	90	59	64

State & Station	Elev	Design Condition			--	State & Station	Elev	Design Condition		
-	Feet	Db	Wb	DWb	--	-	Feet	Db	Wb	DWb
Ohio:	-	-	-	-	--	Los Alamos	7410	89	60	62
Akron	1210	89	72	75	--	Santa Fe	7045	90	61	63
Cincinnati	761	92	73	77	--	**Oklahoma:**	-	-	-	-
Cleveland	777	91	73	76	--	Norman	1109	99	74	77
Oregon:	-	-	-	-	--	Oklahoma City	1280	100	74	78
Corvallis	221	92	67	69	--	Tulsa	650	101	74	79
Klamath Falls	4091	90	61	63	--	**South Dakota:**	-	-	-	-
Portland	57	90	68	69	--	Rapid City	3165	95	66	71
Tennessee:	-	-	-	-	--	Sioux Falls	1420	94	73	76
Knoxville	980	94	74	77	--	**Texas:**	-	-	-	-
Memphis	263	98	77	80	--	Abilene	1759	101	71	75
Nashville	577	97	75	78	--	Amarillo	3607	98	67	71
Utah:	-	-	-	-	--	Austin	597	100	74	78
Ogden	4455	93	63	66	--	Beaumont	18	95	79	81
Provo	4470	98	62	66	--	Brownsville	16	94	77	80

State & Station	**Elev**	**Design Condition**			--	**State & Station**	**Elev**	**Design Condition**		
-	**Feet**	**Db**	**Wb**	**DWb**	--	-	**Feet**	**Db**	**Wb**	**DWb**
Salt Lake City	4220	97	62	66	--	Dallas	481	102	75	78
Washington:	-	-	-	-	--	El Paso	3918	100	64	69
Longview	12	88	68	69	--	Houston	158	97	77	80
Larson AFB	1183	97	66	67	--	San Antonio	792	99	72	77
Spokane	2357	93	64	65	--	**Wyoming:**	-	-	-	-
Yakima	1061	96	65	68	--	Casper	5319	92	58	63

(Based on ASHRAE Handbook 1981 Fundamentals Design Dry Bulb with Co-incident Wet Bulb 1% scale)

Note: Climate conditions above are shown for the convenience of the user and accuracy is not guaranteed for system design.