PDHonline Course A127 (4 PDH)

Evaporative Cooling

Instructor: George E. Thomas, PE

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

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Course Content

OVERVIEW

The purpose of this course is to inform and educate engineers, building owners, and facilities personnel about the proper application, control, and comfort expectations of evaporative cooling in residents and commercial buildings. This course is intended to be an overview of efficient evaporative cooling systems and will allow engineers to specify and design evaporative cooling systems with confidence. This course is also intended as an overview of evaporative cooling principles and equipment for the non-technical reader. This course suggests design features that may be used to improve the economy of operation, comfort, reliability appearance, serviceability, and service life of evaporative cooling systems.

Electricity is used for many parts of a buildings operation; the largest uses are lighting and air conditioning. Building energy can be saved and pollution decreased while utility expenditures are minimized if energy conservation measures are incorporated into the design, maintenance and operation of a facility. Energy costs will surpass the installed cost of heating and cooling equipment during the life of a typical building. It is important that the design decisions that define a building's lifetime energy use account for the operations cost of a particular system.

The benefits of using evaporative cooling are usually perceived in terms of economy of operation. Operating cost is an important factor when utility budgets are a major consideration. However, there are other compelling reasons that make evaporative cooling a smart choice. These include:

- The increased air filtration qualities of rigid media evaporative coolers can result in healthier indoor air quality, and improved productivity. The size and amount of particulate removed from the air is greater than conventional filters and compares to HEPA filters. This will also reduce conventional air filtering costs.
- The safety and reliability afforded by the simplified maintenance requirements. The supply fan and water recirculation pump are the only moving parts. Replacement parts are readily available and do not require highly skilled maintenance personnel.
- The versatility of modern evaporative coolers include new materials, controls and construction methods which increase the efficiency, reduce water use and actually provide more useful cooling than the old standard wetted pad coolers. These highly effective coolers last longer, filter the air better and can include options such as indirect evaporative coolers which cool the air without increasing the indoor moisture levels. There are also combination evaporative and refrigerated air cooling systems which respond to micro-processor controls to always maintain comfort, economically, in any weather.

Evaporative cooling will always follow the laws of Nature, so when hot and dry conditions exist, the properly designed and maintained evaporative system will always perform cooling, as sure as a thrown rock will fall to the ground.

This course will address the relative advantages of evaporative cooling compared to other common cooling methods, and guides the engineer through design issues, economy and efficiency factors.

INTRODUCTION

Evaporative Cooling Basics

Evaporation is the conversion of a liquid substance into the gaseous state. When water evaporates from the surface of something, that surface becomes much cooler because it requires heat to change the liquid into a vapor. A nice breeze on a hot day cools us because the current of air makes perspiration evaporate quickly. The heat needed for this evaporation is taken from our own bodies, and we perceive a cooling effect.

When air moves over a surface of water it causes some of the water to evaporate. This evaporation results in a reduced temperature and an increased vapor content in the air. The bigger the area of contact between the air and water the more evaporation occurs, resulting in more cooling and the addition of moisture. In order for water to evaporate, heat is required. A British Thermal Unit (BTU), is a unit used to measure heat. To evaporate one gallon of water requires almost 8,700 BTU’s of heat. For evaporative cooling, this heat is taken from the air, cooling it as it evaporates.

This simple law of nature has been used by humans for comfort cooling systems since the days of ancient Egypt Empire. Famous examples of evaporative cooling in the past are from Egyptian architecture where porous earthen pots filled with water in vertical shafts that had one opening facing the winds on the outside and the other near floor level were used.

Types of Cooling Systems

There are two basic types of evaporative air coolers (EAC's). The southwest is most familiar with direct EAC’s and are commonly used for residential and commercial cooling. Developments in the evaporative cooling industry have reliably increased the efficiency or effectiveness of the cooling media. All direct EAC’s use 100% outside air. Electricity is used by a supply fan motor and a small sump pump.

The other type of EAC is called “indirect” because the evaporative cooling is delivered across a heat exchanger, which keeps the cool moist air separated from the room air. These indirect evaporative air coolers (IEAC's) can be used in conjunction with direct EAC's and/or with refrigerated air coolers. Electricity is used for the supply fan motor, the sump pump, and a smaller secondary fan motor used for the heat exchanger’s airflow. The combination evaporative and refrigerated system has a higher first cost, but offers a good mix of energy conservation and comfort. Additionally, these redundant cooling systems are more reliable. EAC packaged units now commonly offer complete air conditioning systems which can also include indirect evaporative coolers, filtration, energy recovery heat exchangers for saving energy from warm winter air, dehumidifying desiccant sections used for the removal of moisture, electronic controllers which save energy and improve comfort and a variety of heating packages.

The vapor compression cycle provides cooling by alternately compressing and evaporating a refrigerant. These refrigerated air conditioners use electricity for the supply fan motor, the condenser fan, the refrigeration compressor and control system. These systems provide more comfort hours during the humid weeks, yet still are not designed to maintain comfort 100% of the time. Unlike EAC's, refrigeration air conditioners can remove moisture from the air, but this dehumidification process will reduce the units' capacity to lower the room air temperature. Unlike direct EAC's, refrigeration air conditioners typically re-cool more than 80% of the room air. This can be an air quality concern if large amounts of indoor pollutants are generated in the building from people, germs, processes and out gassing from materials.

A Natural Resource

The southwestern states have a valuable natural resource in its characteristically dry climate and low humidity levels. This means that many localities can successfully use the evaporative effect to cool their homes and commercial buildings. The comparatively low ambient humidity levels constitute a very significant natural resource for decreasing the amount of utility costs required for comfort cooling in many buildings. This is especially true when compared to the common cooling alternative of refrigerated air conditioning. Because many localities in the south western climate naturally have this unique hot and dry environment, it can be regarded as a natural resource that can be used to decrease our consumption, and peak demand for electricity. However, unlike other resources such as extractable fuels, fertile land or enchantment tourism, the potential for evaporative cooling to displace costlier refrigerated cooling is non-depletable and readily available. The significance of using this evaporative cooling resource goes beyond the utility cost savings afforded to the user.

Advantages for Most Southwestern States

- Evaporative coolers use a supply fan and a fractional horsepower sump pump. They do not use an energy intensive refrigerant compressor, so they require 1/5 to 1/2 as much electricity to operate as refrigerated cooling. Utility dollars that are not spent on cooling electricity is available for other necessary expenditures and can continue to nourish local communities, and provide greater regional energy independence.
- Maintenance requirements are simpler for EAC's than for refrigerated air conditioning equipment. Refrigeration compressors, evaporators and condensers must operate under high pressures, which require specialized tools and certified maintenance personnel. Evaporative cooler users can maintain their peak cooling effectiveness without the need for costly and sometimes unavailable specialized maintenance contracts. This can translate into increased reliability and a consistent environment, one that is conducive to the improved student or employee productivity and performance that are dependent upon comfort.
- The life-cycle cost of using evaporative cooling is less than a comparable refrigerated air unit. This includes all dollar values such as first cost, energy, water, time value of money and maintenance costs.
- EAC saves water at the power plant. During the summer, a coal fired power plant using evaporative cooling towers will typically need about 0.95 gallons per kWh. This quantity does not include the water needed to mine, process and deliver the coal used to generate

the electricity. The amount of water used by an evaporative cooler is stated in terms of tons of cooling per gallon in Table 3 on page 26. One gallon of water is used to provide approximately 0.6 Tons of cooling.

- Evaporative cooling does not directly use any chemical substances that are known to be detrimental to the earth's ozone layer. This is unlike most of the pre-2000 commercial refrigerants whose use is regulated in order to reduce their harmful impact on the environment[5]. Evaporative coolers do not operate under high pressure conditions and do not require any expensive controlled substances for their operation.
- An evaporatively cooled building will always require less energy to operate than a refrigerated A/C, (0.5 to 5 kW compared to 3 to 10 kW), so wiring and other electrical components will cost less.
- The energy savings of evaporative cooling translates into reduced carbon dioxide and other emissions from power plants, and decrease the peak electricity demand load that typically occurs during peak summer cooling hours. Some utility companies are actively promoting the use of evaporative cooling to decrease the requirement for new generation facilities.
- The 4 million evaporative air cooling units in operation in the United States provide an estimated annual energy savings equivalent to 12 million barrels of oil, and annual reduction of 5.4 billion pounds of carbon dioxide emissions. They also avoid the need for 24 million pounds of refrigerant traditionally used in residential VAC (vapor-compression air conditioning or refrigerated air) systems.
- Improved indoor air quality from evaporative air coolers is due to their use of 100% outside air rather than recirculated air. The outside air and humidity added to the room air by an evaporative cooler can improve comfort conditions, flush out contaminants which are generated in the building and reduce the incidence of static electric shock which can be detrimental to micro-electronics.

EVAPORATIVE COOLING DESIGN

SYSTEM TYPES

Background

As discussed earlier there are two basic types of evaporative air coolers (EAC's) used to cool residents and commercial buildings, direct and indirect. They can be used separately or in combination.

Because EAC performance is dependant on the weather, it is difficult to state an equipment efficiency factor or Energy Efficiency Ratio (EER) as with refrigerated cooling. Refrigerated cooling have established EER standard test procedures. Direct evaporative coolers do not yet have such standard EER tests. Instead, there is a term called "saturation effectiveness" (or effectiveness which can be used to predict the performance of EAC's). This effectiveness is described more completely in the System Sizing section. The saturation effectiveness has been tested for different types of EAC media. Knowing this value, and the measured ambient temperatures, it is possible to determine the EAC discharge temperature.
In order to evaporate water, heat is required. A British Thermal Unit (Btu), is a unit used to

measure heat. The evaporation of 1 gallon of water requires almost 8,700 Btu's of heat. This heat comes from whatever the water is in contact with as it evaporates. This could be a hot sidewalk, a tree from the air itself, or from wet cooling pads on an EAC. As heat is removed from an object, the temperature of that object is decreased, in this case, the air.

The temperature of the water does not have a great effect upon the cooling produced through evaporation. If you placed a gallon of 50° F. water on a warm sidewalk (90° F), it would produce 9,000 Btu's of cooling. A gallon of 90° F water would produce 8,700 Btu's of cooling, only 3% difference. The following demonstrates the Btu's removed from the air based on a given amount of water consumed in an hour:

2 gallons.................. 17,400 Btu's removed	1.5 Ton-Hour Equivalent
3 gallons.................. 26,100 Btu's removed	2.2 Ton-Hour Equivalent
4 gallons.................. 34,800 Btu's removed	2.9 Ton-Hour Equivalent
5 gallons.................. 43,500 Btu's removed	3.6 Ton-Hour Equivalent

The direct EAC fan moves the supply air past a wetted media, which adds moisture to the supply air stream to accomplish the evaporative cooling effect. This effect uses the heat of vaporization of the water to reduce the dry-bulb temperature. The indirect EAC uses a heat exchanger to separate the moist evaporatively cooled air (or water) from the drier room air. The main difference in the application of these two types of EAC's is that a direct evaporative cooler MUST use 100% outside air for proper operation. It can be assumed that the outside air has fewer contaminants than the indoor air (see the section on Air Quality). This in not true if the air intake is located too close to, or downwind of a source of outdoor air contaminants. This air is cooled, then passes through the conditioned space, and then exits the building to prevent humidity buildup in the conditioned space. The indirect evaporative cooler air is drier, and can be recirculated past the heat exchanger. There are variations and combinations of these two basic types of evaporative coolers that increase the EAC effectiveness, reliability, add wintertime heat recovery or remove moisture for special applications.

This course addresses fixed and stationary applications for cooling residential and commercial building interiors. However, EAC's are used in many other applications, such as:

- Power plant evaporative cooling towers
- Process cooling water
- Turbine engine air intake cooling.
- Portable cooler applications
- Automobile interior cooling
- Solar powered EAC's
- Exterior spot cooling
- Electronics and optic fiber equipment cooling
- Green house, laundries, and manufacturing process cooling
- Animal housing facility cooling

Another benefit to using an evaporative cooling air handler is that they require the application of three sets of dampers which are used to control airflow of the outside air inlet, return air, and exhaust air streams. This is an advantage during periods of low cooling requirements because often the outside air temperature is low enough to satisfy the cooling needs without any additional cooling. This damper configuration, along with the controls to sense the outside air temperature is know as an outside air economizer. This system can be used on either evaporative or refrigerated air systems, but is sometimes omitted from refrigerated air units because of cost or maintenance considerations. The potential for energy savings are significant.

Direct evaporative cooling

The wetted pad aspen pad cooler, also commonly known as a "swamp cooler" is the most common type of EAC used in most southwestern homes and commercial systems. The average life of a aspen pad cooler is 10 to 15 years, and with good seasonal maintenance, 15 to 25 years is not too hard to reach. Refer to Figures 1 and 2 for a typical cooler of this type. It consists of a metal, plastic or fiberglass housing and frame, a supply fan, water holding sump, water circulation pump, water distribution tubing, electric connections and a wetted pad. These pads are the surface from which the water evaporates, and are usually made of aspen shavings, paper or plastic media. Typical evaporative effectiveness for this type of wetted media is 65 to 78%. All EAC's use a small fractional horsepower pump to raise the water over the pads, then gravity and capillary action wet the entire area of the evaporative media. Advantages of direct evaporative cooling are its low life-cycle cost, improved indoor air quality, reduced peak electrical demand, simple controls and low-tech maintenance. Disadvantages include relatively short service life of aspen media aspen pad coolers (1 to 3 years, depending on media type and maintenance), the need for seasonal maintenance and reduced cooling performance during the wet season.

There are many types of wetted media used in various configurations, but the common alternative to aspen pad coolers is known as rigid media, or by trade name. Rigid media coolers are usually more effective than aspen pad coolers because they have more surface area per cubic volume of media. A value of 123 square feet of surface area per cubic foot is typical. Also, the media is rigid, it does not sag and reduce cooling performance. It is available in various thicknesses between 2 and 24 inches, 12-inch thick media is common for commercial building air handling units. The section on evaporative media provides ratings of effectiveness of rigid media from 75% to 95%, depending on the thickness and air velocity through the media. Rigid media is washable, and when maintained will last 7 to 10 years.

Unlike most heating systems or refrigerated cooling systems, direct EAC's cannot re-circulate the room air. All the air must be exhausted or otherwise relieved from the building. This is discussed further in the section on the Importance of Relief Air Dampers.

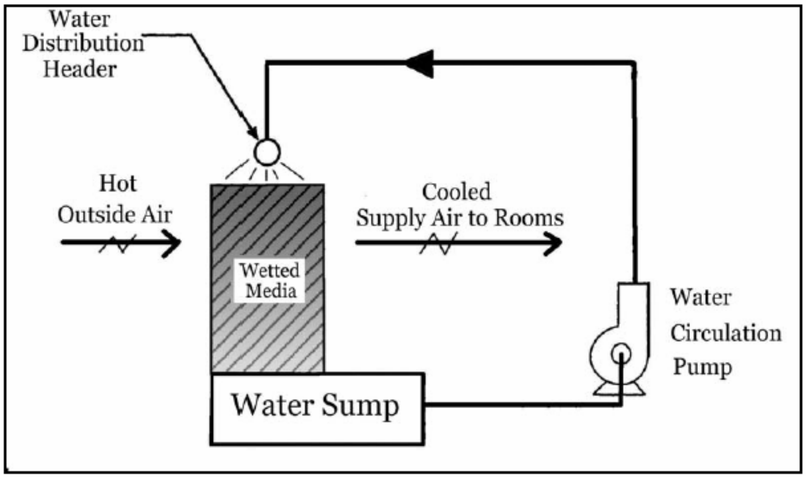


Figure 1: Direct EAC Schematic

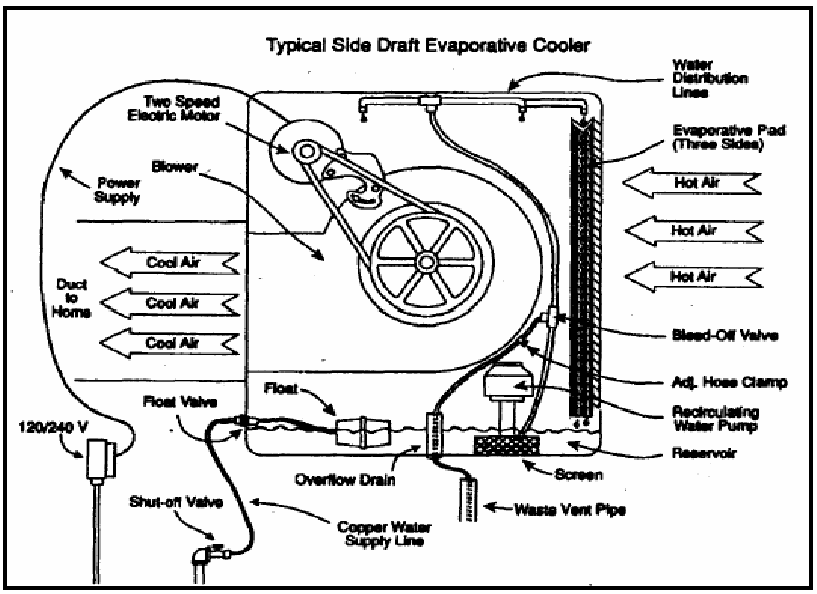


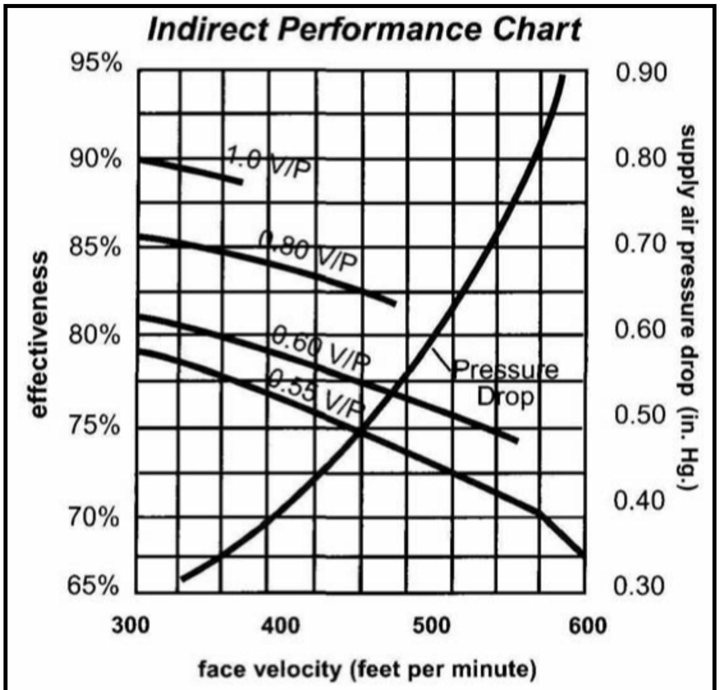
Figure 2: Typical Wetted Aspen Pad Cooler

Indirect Evaporative Cooling

Indirect EAC's (IEAC's) have been in use for over 20 years and have gained recent acceptance because of better manufacturing techniques that have lowered their cost and improved performance. IEAC's use a heat exchanger, and do not add moisture to the room air stream (known as **sensible cooling).** There are four different types of IEAC's, and all of them use the same evaporative cooling process as direct evaporative cooling, known as adiabatic cooling. The main kinds of IEAC's predominately in use are:

- Air-to-air heat exchangers
- Combination IEAC and refrigerated systems
- Cooling tower "free cooling"
- Refrigerant migration

The rated effectiveness of the IEAC section alone will range from 60% to 78% depending on the configuration and the air speed past the heat exchanger (see Figure 3: IEAC Performance). The four curves on the left represent the effectiveness curves for different values of V/P (V/P = Vaporizer air per Primary air, or exhaust cfm per supply cfm). IEAC's can be used in combination with direct evaporative cooling, in combination with refrigerated air systems or as a stand-alone system. When combined with direct EAC's the effectiveness is additive. Typical indirect/direct evaporative air coolers have a rated effectiveness of 120 to 130 percent. It is important to note that none of the indirect evaporative cooling methods add moisture to the room air stream and do not increase the room humidity level; indirect evaporative coolers can re-circulate the room air. This is significant because the IEAC unit's return air temperature will be around 75 to 85 degrees F-db, instead of the hotter summer outside air temperature of 90 to 110 degrees F-db used for direct EAC operation. Because of this lower temperature difference between the entering air and the room air, the IEAC requires less overall cooling capacity to maintain comfort conditions.



T_{db} Out = T_{db} In - [Eff(T_{db} In - T_{wb} Vap)]

Figure 3: IEAC Performance

Figure 4 is a schematic view of an indirect evaporative cooling section located upstream of a direct rigid media cooler. The air supplied into a conditioned room by the main supply fan is called the primary air stream. IEAC heat exchangers transfer heat (or cool) across sheets of plastic or metal configured to keep the two air streams from mixing. A smaller fan pulls the wetter air through the secondary side of the heat exchanger. Air-to-air heat exchangers (some which can also recover heating season energy from the exhausted room air) are used to transfer heat from the primary space supply air stream to the evaporatively cooled secondary air stream. Figure 5 shows a section through an IEAC combined with a direct EAC. Maintenance requirements for this type of cooler are similar to that required for a direct evaporative cooler.

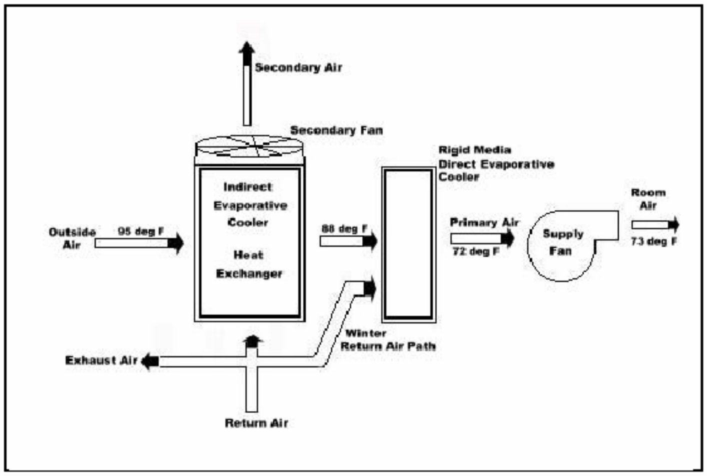


Figure 4: Indirect Cooler Schematic

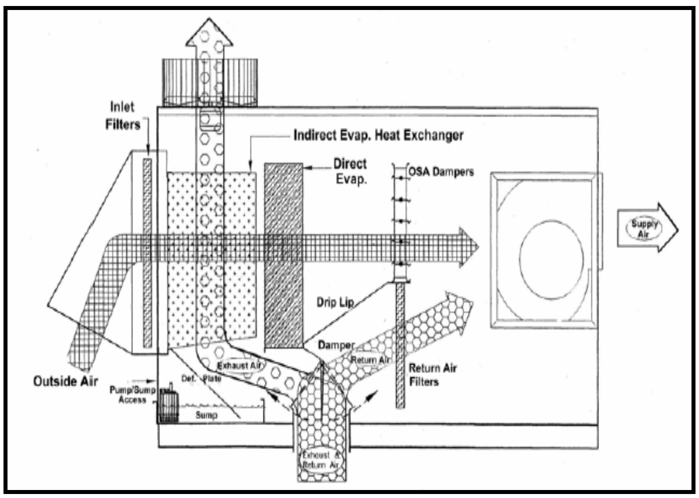


Figure 5: Air-to-Air Heat Exchanger Indirect + Direct EAC

Table 1 can be used to estimate leaving air temperature from direct, indirect and indirect/direct EAC's based on local conditions.

Table 1: Leaving Air Temperature Chart

LEAVING AIR TEMPERATURE CHART

EAT ! DB = 95				100			105			110		
	D	I	I	D	I	I ! D	D	I	I ! D	D	I	I
EA/ WB	LEAVING AIR TEMPERATURE											
V	DB	DB ! WB	DB ! WB	DB	DB ! WB	DB ! WB	DB	DB ! WB	DB ! WB	DB	DB ! WB	DB !
60	63.5	69/50	52/50	64.0	70/48	50/48	64.5	71/46	49/46	65.0	73/44	47/44
62	65.3	70/52	54/52	65.8	72/51	58/51	66.3	73/49	51/49	66.8	74/48	51/48
64	67.1	75/55	57/55	67.6	73/54	56/54	68.1	74/52	54/52	68.6	75/51	54/51
66	68.9	73/59	61/59	69.4	75/57	59/57	69.9	76/56	58/56	70.4	77/54	57/54
68	70.7	75/62	63/62	71.2	76/59	61/59	71.7	78/59	61/59	72.2	78/58	60/58
70	72.5	76/64	65/64	73.0	78/63	65/63	73.5	79/61	63/61	74.0	80/60	92/60

72	74.3	78/67	68/67	74.8	79/66	67/66	75.3	80/64	66/64	75.8	82/63	65/63
74	76.1	79/69	70/69	76.6	81/68	69/68	77.1	82/67	69/67	77.6	83/66	68/66
76	77.9	81/72	73/72	78.4	82/71	72/71	78.9	83/70	71/70	79.4	85/69	71/69
78	79.7	82/75	76/75	80.2	84/72	73/72	80.7	85/73	74/73	81.2	86/72	73/72

EAT = Entering Air Temperature
DB = Dry Bulb, degrees F
WB = Wet Bulb, degrees F
D = Direct evaporative cooling
I = Indirect evaporative cooling
I / D = Indirect and Direct evaporative cooling

Leaving Air Temperatures based on:
75% Indirect effectiveness
90% Direct effectiveness
Outside vaporizer (secondary) air is not based on Total Energy Recovery

The IEAC section can be configured to recover energy from the relief air stream in the cooling and heating season. This added benefit makes IEAC's more economically appealing. Figure 6 shows published performance for the heat recovery efficiency. The efficiency varies with air flowrate, air velocity, and manufacture.

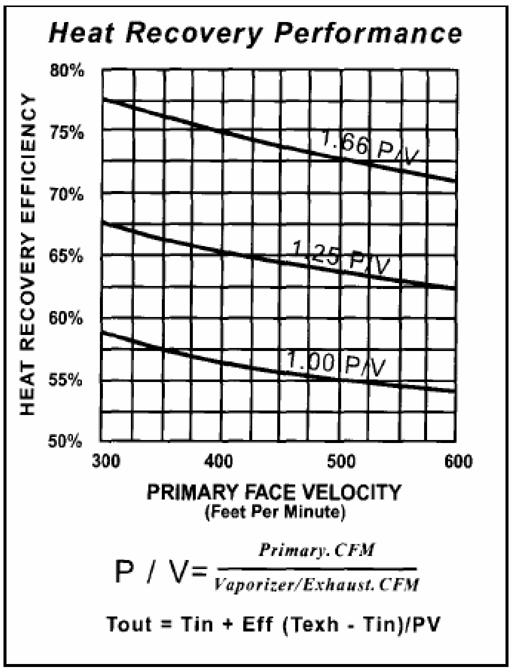


Figure 6: Heat Recovery Performance

Combination Systems

Direct and indirect evaporative air cooling components are commonly packaged together in the same cooling unit. The main advantages of using both types of evaporative cooling systems are the lower supply air temperature, increased reliability and more available comfort hours. Another first cost advantage is the ductwork installation cost will be lower for a combination unit since they supply cooler air and require smaller ducts.

The IEAC is usually located upstream of the direct EAC to first cool the entering air without adding moisture. This arrangement is convenient since both systems have similar maintenance requirements. The direct EAC section will cool the air more than the indirect section due to the losses of the IEAC heat exchanger.

IEAC's are also used in combination with refrigerated air systems, because they do not add moisture to the air stream. The reduction in air temperature due to the indirect evaporative section comes at a much lower cost than cooling the same air with a refrigerated system alone. The return air from the room can be re-circulated past both the IEAC and the refrigerated coil, or the IEAC can be located to pre-cool only the required outside air (see figure 7). There are times during the spring, fall, and summer mornings when the IEAC will be able to meet the cooling load without energizing the refrigeration compressor.

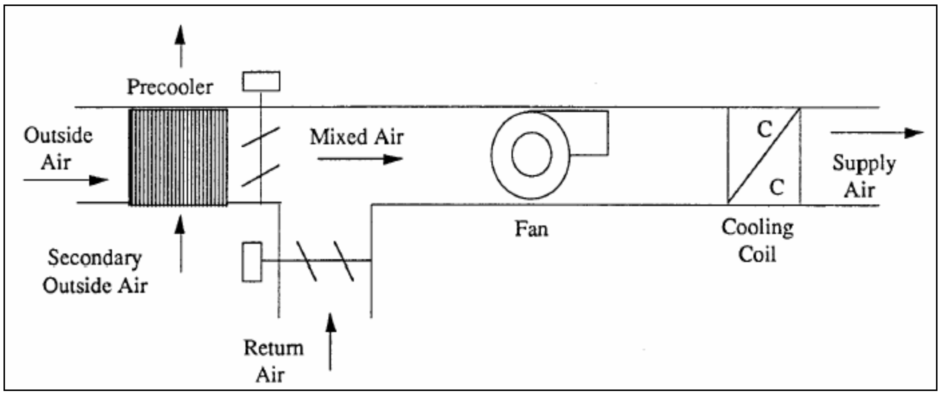


Figure 7: Combination Evaporative and Refrigerated Cooling System Schematic

Cooling Tower Free Cooling

Another type of indirect evaporative cooling system called a waterside economizer and often used in conjunction with a chiller system that use evaporative cooling tower(s). When the humidity level is low (known as a low wet-bulb temperature) the evaporative cooling tower system will leave the chillers off (which cost much more to operate) can be kept off. The indirect system uses a water-to-air cooling coil in the room air stream, similar to some refrigerated chilled water systems (shown in Figure 8 and 9). The IEAC cooling water circulated through the coil is cooled by spraying water in a commercially built cooling tower. This cool sump water is then pumped through a strainer or a heat exchanger to keep the room air coils from becoming clogged. This evaporatively cooled water in the cooling tower sump can get very cool, especially when the air is dry. Depending on the design parameters of the system, this water can be within 3 to 6 degrees of the wet-bulb temperature. (See Psychrometric Section). When a fan blows warm air past this cooling coil, the exiting air will be cooled without increasing the humidity level of the room air.

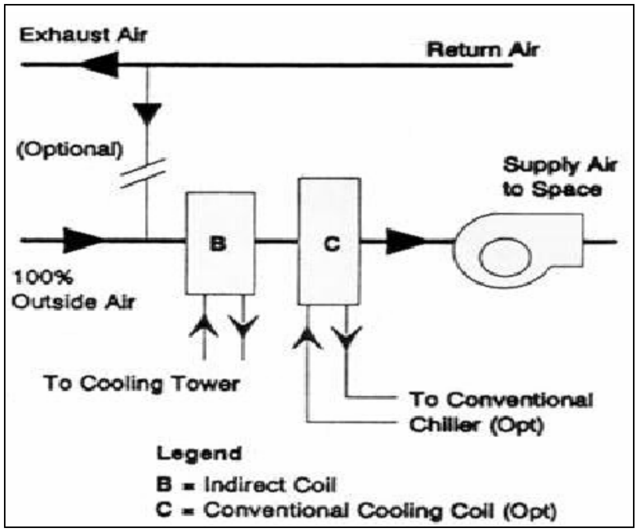


Figure 8: Water Coil Indirect EAC Schematic

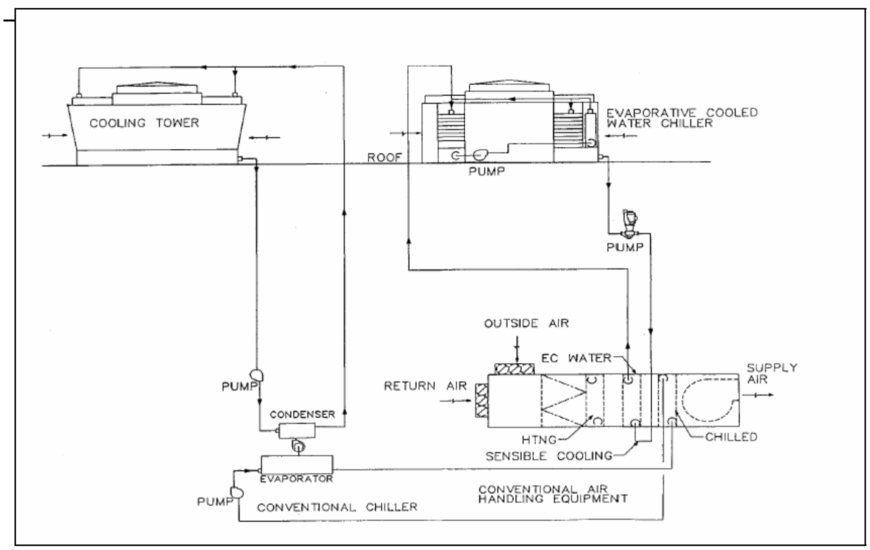


Figure 9: "Free Cooling" Evaporative and Refrigerated Combination System

Water-side economizer

Another related type of combination system uses the evaporative cooling energy from a cooling tower's sump water to precool the warmer "used" return chilled water before it enters the refrigerated chiller. This will decrease the load on the chiller and saves energy. As efficient as these systems are they require cooling tower fan and pump energy, heat exchanger, maintenance and computerized controls systems.

Condenser Pre-cooling

Direct evaporative cooling is also used to increase the efficiency of refrigerated air systems by pre-cooling the air, which is drawn through the outdoor air-cooled refrigerant condenser. This additional temperature reduction at the condenser will decrease the energy required by the compressor and effectively increase the capacity of the unit, or alternately, a smaller and less costly unit can be specified. An added advantage is that the direct precooler will reduce head pressures and thus extend compressor life. This type of EAC is usually added on to the face of an existing condenser. Before adding, check to ensure that the velocity is low enough so that water is not carried over to the condenser coil to prevent scaling of the condensing coils, and that the resulting air pressure drop can be handled by the existing condenser fan.

Refrigerant Migration

Another type of indirect evaporative cooling that only works on certain types of large refrigerated air systems. This refrigerant-side economizer uses a centrifugal chiller's refrigerant vapor migration properties to do free cooling. If the chiller's condenser can be kept cooler than the returning circulating chilled water, refrigerant will passively migrate through the chiller to perform refrigeration and cool the chilled water loop without having to operate the compressor. The chiller's condenser heat exchanger is cooled by an evaporative cooling tower. This type of free cooling is typically used with centrifugal chillers over 300 tons capacity. Under favorable conditions, cooling by refrigerant migration can supply up to 45 percent of the chiller's design capacity. This can amount to 120 tons from a nominal 300-ton chiller. This approach can be combined with other IEAC systems so that the chiller's compressor is only operated during the peak annual cooling hours. It also adds to the systems reliability since it is a redundant cooling source that can be used in the event of a compressor failure.

Evaporative Media Types

There are several types of evaporative pads and rigid media. Standard EAC pads are usually 3/4" to 1" thick and made of aspen shavings. Aspen is a very absorbent and unreactive material. This media should be flushed with water prior to turning on the fan to wash away any fines and factory applied stiffening agents and to prevent odors from entering the building. Other types of replacement pads are available which have greater surface area, or are more rigid when wet. There is a hypoallergenic pad that is made from green cut paper, or a plastic fiber matrix that includes bits of sponge material, and is washable and reusable. Shrinkage and settling of the media during the cooling season will allow the air to take the path of least resistance and partially blow by the pad without passing through the wetted media and will decrease the effectiveness of the EAC. It is recommended that aspen pads be changed twice per season depending on water quality and the solids buildup control. There are also a 2, 3, and 4" thick rigid cellulose media pad which fits into existing frames, is treated to resist degradation, and has greater area and improved water flow characteristics.

Rigid media can also be made of different materials. The standard cellulose media (similar to a cardboard box kraft paper) can be purchased from verious manufacturers, who offer various paper thicknesses, high resin content in the binder glue, and different curing methods that improve the tensile strength and crush strength. Rigid media is also available as a fiberglass type material which has improved smoke generation and flame spread characteristics where required by insurance companies. Both fiberglass and cellulose rigid media have fluted (small tunnels) passages for air and water to flow through. It is important to note that there are two flute angles, 45 and 15 degrees, when viewed from the right or left sides of a section of media. Media installation can be reversed which may allow some carryover of the water droplets into the fan section, and should be avoided. Always consult the manufacturer's installation instructions for the correct orientation.

Rigid media is used in direct evaporative coolers that use a fluted cardboard or fiberglass media. This media can be obtained in different thickness (the dimension in the direction of air flow), and is usually 6", 8”, 12" or 18". Typically, 12" thick rigid media is used, and it provides 123 square inches of surface area per cubic foot of media. Because of this large evaporative surface area, rigid media coolers have a higher effectiveness, typically 85 to 93% depending on the media thickness and the speed of the air as it passes the wetted media. See Figure 10: Direct EAC Effectiveness for Rigid Media. Rigid media is also more effective at removing particulate from the air stream (see the Air Quality Section, and Appendix B). Advantages to the rigid media EAC are a lower discharge air temperature which means lower air flowrates, and lower energy use than conventional EAC, reduced pressure drops, cleaner air, a longer service life (5 to 25 years, depending on maintenance), simple controls and low-tech maintenance. The disadvantag is a higher first cost than aspen pad coolers.

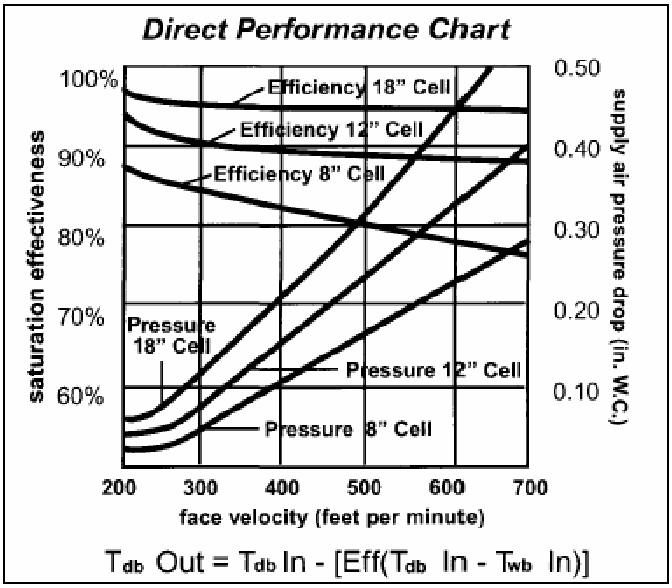


Figure 10: Direct EAC Effectiveness for Rigid Media

The "slinger" or "air washer" is an older version of a single face EAC that doesn't use a water pump. Instead, it has a motor that whips a rotor across the sump water surface to create a spray that saturates a downstream fibrous pad that the air passes through. Disadvantages of the "slinger" evaporative cooler are uneven pad wetness which allows the warm air to pass by the dry sections of the pad without cooling, and the likelihood of water being pulled past the wet section into the fan and ductwork (known as carryover).

Psychrometrics Basics

Knowledge of the internal combustion engine is not necessary in order to drive a car. This section discusses a technical topic that is used by engineers in the design process. For others, it is interesting to learn about, but is not required to operate an EAC. Psychrometrics is the study of the properties of moist air (i.e.: temperature and humidity).

As air encounters water, it absorbs it. The amount of water absorbed depends largely on how much water is already in the air. The term humidity describes the level of water in the 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.

When the air contains large amounts of moisture, the humidity is said to be high. If the air contains only a small amount of moisture, the humidity is low. When the air holds as much moisture as possible at a certain temperature, the air is saturated. At saturation, the temperature and the dew point are the same. The amount of humidity varies according to the temperature and location. The warmer the air, the more moisture it is able to hold.

The amount of water in the air compared to the amount required for saturation is called relative humidity. If the air contains only half the amount of moisture it can hold when saturated (at the dew point line), the relative humidity is 50%. Another method of referring to the amount of moisture in the air is absolute humidity. Absolute humidity is the amount of water in the air measured in pounds of water per pound of dry air. This is the variable on the right Y-axis of the psychrometric chart shown on Figure 11.

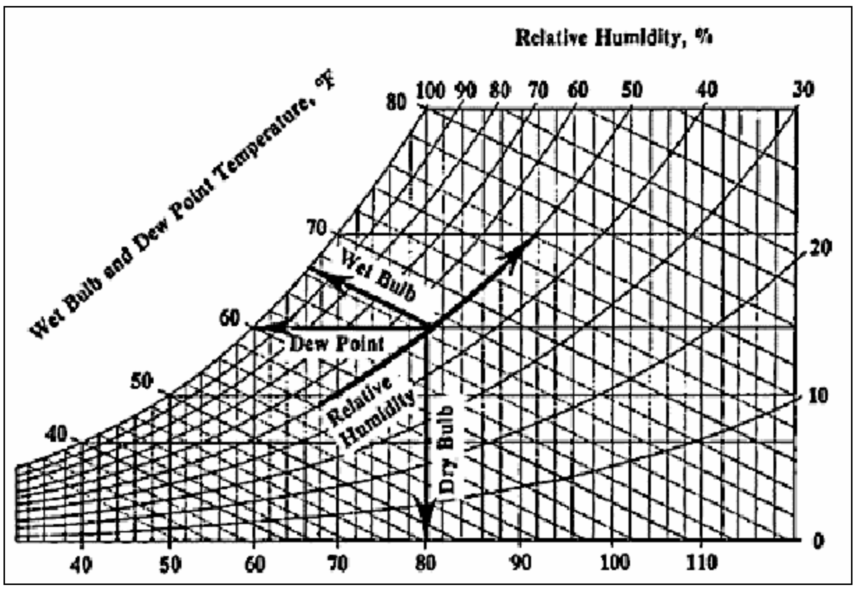


Figure 11: Psychrometric Chart

To facilitate engineering computations, a graphical representation of the properties of moist air has been developed and is known as a psychrometric chart. This chart (see Figure 11: Psychrometric Chart above) is used to illustrate the various properties of air and how they are affected by changes from a heating, cooling or humidifying process. Some of the variables shown are dry-bulb temperature, wet-bulb temperature, relative and absolute humidity, dew point temperature, and enthalpy which is a measure of the energy contained in a specific volume of air, measured in Btu/lb-dry air. It is easy to measure the dry and wet-bulb temperatures using a “sling psychrometer”.

A cubic volume of air at a certain temperature has the ability to hold a certain amount of moisture. In the morning, the humidity may be high, but as the day passes and the temperature increases, the relative humidity will naturally decrease. The extent to which relative humidity changes through the day can be affected by weather systems and proximity to large bodies of water. If a weather system moves in that has a lot of water associated with it already, the midday drop in humidity will not be as great.

Relative humidity drops as air temperature increases. For every 20° rise in temperature, the moisture holding ability of air doubles. For instance, if the temperature of the air was 70° F. and the relative humidity was 100% at 5:00 A.M. and the temperature increased to 90° F. at noon, the moisture holding ability of the air would be twice as much. As a result, the air would now hold only half of the moisture it is capable of holding and the relative humidity of the air would drop to 50%.

The hotter the day, the dryer the air becomes, and the more cooling that can take place through the evaporation of water. When the day gets hot enough to require cooling, the relative humidity will be much lower than in the morning and allow evaporative cooling to work more efficiently. The evaporative cooling process does not change the total energy in the air. The air temperature drop across an evaporative surface occurs because the sensible heat in the air is used to evaporate water and is converted to latent heat. Figure 12 shows how the sensible heat is transferred to latent energy in the moist air.

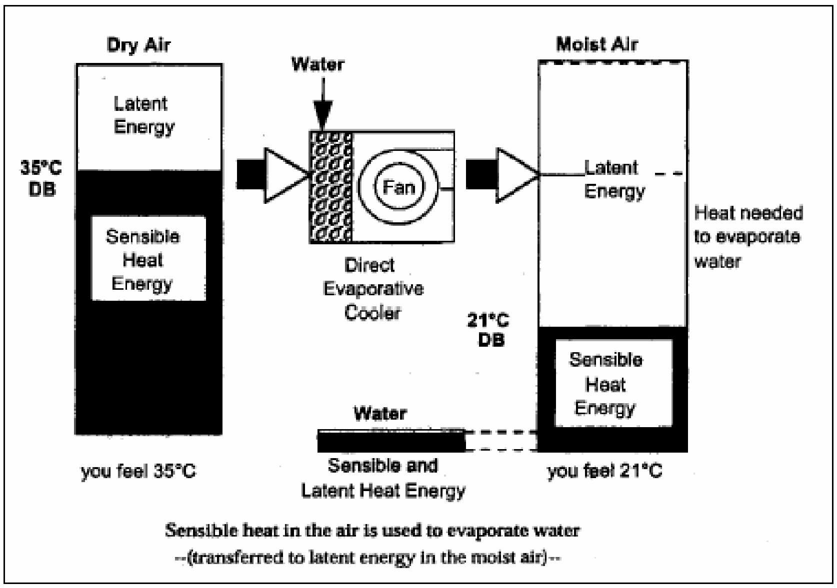


Figure 12: Simplified Evaporative Air-Conditioning Process

The capacity of air to hold moisture also depends on barometric pressure, and therefore, elevation. Psychrometric charts are available for various elevations. To analyze evaporative cooling performance in Albuquerque and Santa Fe, one should use psychrometric charts for 5,000 ft. and 7,000 ft., respectively.

The efficiency of any evaporative cooling device is directly related to its ability to evaporate water (cool) at a given relative humidity. EAC's with low effectiveness will cool usefully only at low relative humidity levels, while a high efficiency unit, such as a rigid media EAC, can achieve useful cooling at higher humidity levels.

Enthalpy values are shown along the left border of the psychrometric chart lines, just left of the heavy curved line or saturation line. Lines of constant enthalpy (and nearly wet-bulb temperature) are the diagonal lines that run from the upper left from that curved left border line to the bottom right, and end at the flat line along the bottom. These lines of constant enthalpy describe an adibatic process, or one where no heat is gained or lost (or the Btu/lb-air does not change). These are also nearly lines of constant wet-bulb temperature. The direct evaporative cooling process is also called adiabatic cooling because it closely follows these lines of constant enthalpy on a psychrometric chart. The reason for this is that the heat used to evaporate the water comes from the heat already contained in the air, and that is why the dry-bulb temperature decreases. The latent heat of vaporization of water at 65 °F is 1057 Btu/lb. Another way of saying this is one pound of water, evaporating in one hour, is capable of providing .09 tons of evaporative cooling. Because this is a Law of Nature, this cooling process is dependable and economically advantageous to use.

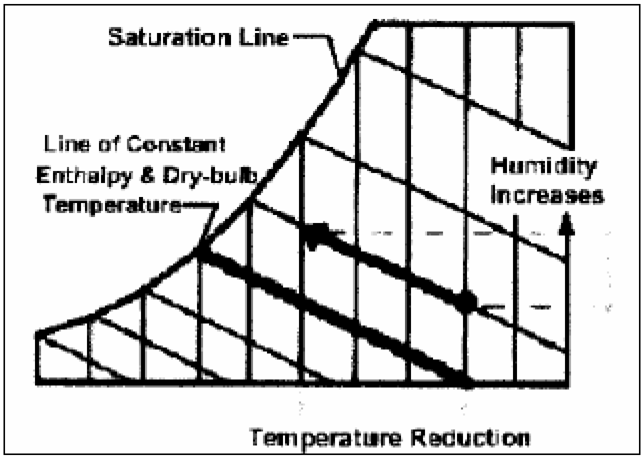


Figure 13: Adiabatic Cooling Process

The direct evaporative cooling process is shown on a “skeleton” psychrometric chart in Figure 13. When the point of intersection of the outside air's dry-bulb and wet-bulb temperature is followed up and to the left toward the saturation line curve along a line of constant enthalpy, this line describes the direct evaporative cooling process. Practically however, an evaporative cooler can't reach all the way to the saturation line. The saturation effectiveness (typically 0.65 to 0.95) is the percent of the length of that line from the point of the dry-bulb and wet-bulb temperature intersection toward the saturation line. This second point (where the line stops) is important because reading straight down on the bottom horizontal dry-bulb temperature scale, is the predicted discharge temperature of the direct EAC air.

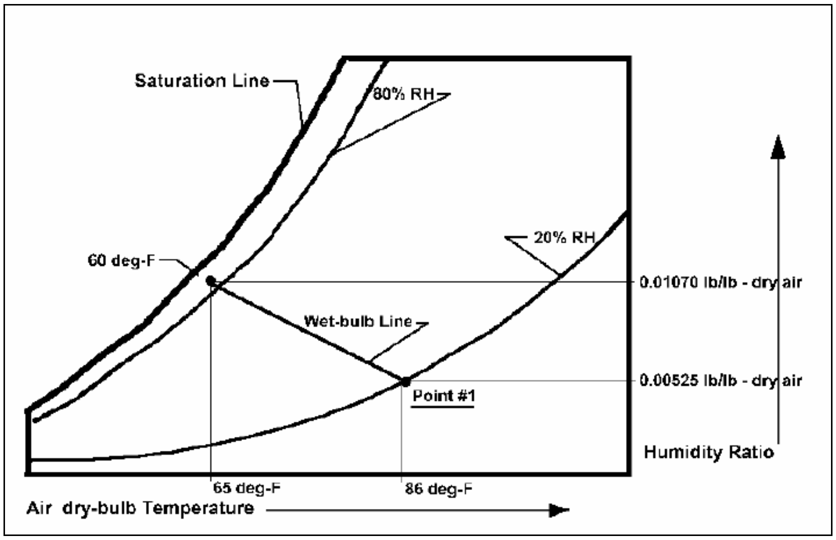


Figure 14: EAC Cooling

Figure 14 shows another example of the adiabatic cooling process used by EAC's, but with more detail. Point #1 was measured with a sling psychrometer at 86°F-dry-bulb and 60°F wet-bulb. Point #2 is determined by following a constant wet-bulb line, stopping 90% (saturation effectiveness = 0.90) of the total distance to the saturation line. Reading vertically down, the discharge air temperature of 65°F is predicted. The scale on the right side shows the increase of moisture in the air of 0.00545 lb. of moisture per lb. of dry air.

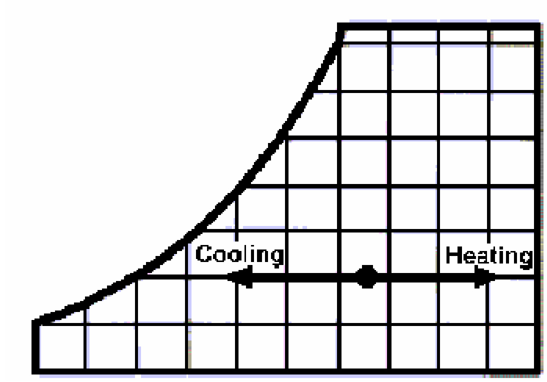


Figure 15: Sensible Cooling Process

Similarly, the sensible heating and cooling processes are shown in Figure 15. This horizontal line starting to the right and moving horizontally to the left (decreasing dry-bulb temperature) represents the sensible cooling process. The sensible heating process is the horizontal line to the right (constant humidity ratio). Indirect EAC's do not add moisture to the air, so this sensible cooling process would start at the same dry-bulb and wet-bulb temperature intersection, and proceeds horizontally to the left. The same is true about a refrigerated air process. Also, note that for this type of cooling, the value for the absolute humidity (the scale of the vertical axis on the right) does not change.

Environmental Considerations

This section compares the environmental impact of EAC's to refrigerated cooling. EAC's use water as the coolant working fluid, where as refrigerated A/C's (also known as vapor compression cycle) use different types of coolants as organic working fluids. The vapor compression cycle provides cooling by alternately condensing and compressing (or liquefying) and then evaporating the refrigerant inside of a closed loop piping and air-coil system. When the refrigerant evaporates in the AHU coil, it takes in the heat of vaporization from the room air stream. It is then condensed back to a liquid and the room heat is rejected to the outdoor air. The piece of heat rejection equipment can be a condenser or possibly a cooling tower. It is similar to the coil on the outside of your refrigerator. These refrigerant working fluids are also known as CFC's (chloroflurocarbons) and HCFC's (hydrogenated chloroflurocarbons).

The two most important environmental considerations in favor of using EAC's are the reduced CO_2 and other power plant emissions, and the reduction of use of CFC's and HCFC's, which have been proven to reduce the ozone layer. The 4 million EAC units in operation in the United States provide an estimated annual energy savings equivalent to 12 million barrels of oil and an annual reduction of 5.4 billion bounds of CO_2 emissions. They also avoid the need for 24 million pounds of refrigerant traditionally used in residential VAC (refrigeration) systems.

Federal regulations now require that maintenance personnel who work on refrigerant systems be trained and certified to responsibly handle refrigerants to prevent any discharge of these coolants into the atmosphere. When compressor maintenance is required, all used refrigerant must be captured and recycled. There are significant monetary fines for anyone who bleeds refrigerant to the atmosphere. See the Maintenance Considerations subsection or the Economics section for more information on this.

EAC Water Use:

Monthly water bill would lead us to consider water use only at the building level. A more holistic approach to water conservation looks at the amount of water required to accomplish the desired result. Power produced by the electric utility at the power plant requires the use of water for the evaporative condensers or cooling towers that are used to reject heat. A refrigerated air conditioner uses more electricity than an EAC for a comparable cooling effect. The cost of water is usually less than the cost of electricity for this cooling, however water is consumed by both cooling processes.

Water use estimates vary based on equipment and location. Factors that will affect the water use are climate, media effectiveness, EAC media air velocity, water distribution system and bleed rate. Typical EAC water use estimates are presented in Table 2. This table also shows that a significant amount of water can be saved by using an intermittent sump dump device. The bleed rate required to control solids buildup on the EAC media will depend on local water conditions. A high continuous bleed rate is only required under the most severe water quality conditions. Using inexpensive aspen media could allow the alimentation of a continuous bleed, and instead allows for the replacement of pads once or twice a season.

Table 2: EAC Water Use Estimates

Water Use Estimate		
System	Gallon per Year with Bleed Off	Gallon per Year with Sump Dump
D EAC	9,667	6,284
D+I EAC	11,900	7,735
DX + I EAC	6,000	3,900

How does this compare to the water used to make the electricity to operate an equivalent refrigerated air cooler? For comparison purposes, a steam Electricity Generating Station annual average water use for the evaporative cooling towers and other uses is approximately 500 gallons per mWh, or 0.5 gallons per kWh at the power plant. Summer temperatures can increase this amount to 0.95 gallons per kWh at the power plant. Inefficiencies inherent in electrical transmission will cause 15 to 30% of the power produced to be lost to electrical resistance inherent in the electrical transmission process. Peak water use for the electricity used to power a refrigerated air unit is 18.5 gallons per hour. This estimate is for a refrigerated air conditioner delivering 6500 cfm at design conditions, with an EER = 10. This is comparable to the water used for evaporative cooling, as shown in Table 3. The larger unit shown in this table (12,500 CFM) would more accurately reflect the increased airflow needed by an EAC to accomplish cooling comparable to the 6500 CFM refrigerated air unit.

Table 3: EAC Southwestern States Water Use Estimates

EAC Water Use Comparison										
EAC CFM	Ambient Tdb deg F (2)	MCWB deg F (2)	EAC % Eff.	Supply Air Temp. (1)	Gal/Hr Evap. (3)	Gal/Hr Cont. Bleed (4)	Gal/Hr WATER USE W/ BLEED	Gal/Hr WATER USE W/ Sump Dump	Equiv. Tons (5)	Ton-Hr / Gal.
6,500	97	61	68	72.5	19.1	5.6	24.7	21.1	11.8	0.56
6,500	90	61	68	70.3	15.4	5.6	21.0	17.4	9.5	0.55
6,500	85	61	68	68.7	12.7	5.6	18.4	14.7	7.9	0.54
6,500	80	60	68	66.4	10.6	5.6	16.2	12.6	6.6	0.52
6,500	75	59	68	64.1	8.5	5.6	14.1	10.5	5.3	0.50
12,500	97	61	85	66.4	45.9	11.7	57.6	50.0	28.4	0.57
12,500	90	61	85	65.4	37.0	11.7	48.7	41.1	22.9	0.56
12,500	85	61	85	64.6	30.6	11.7	42.3	34.7	18.9	0.55
12,500	80	60	85	63.0	25.5	11.7	37.2	29.6	15.8	0.53
12,500	75	59	85	61.4	20.4	11.7	32.1	24.5	12.6	0.52

Although evaporative cooling uses water it does not waste water, it uses water to provide an environment that is more comfortable and promotes well-being and increased productivity. Water use can be regarded as another extracted fuel like gas or coal for electricity. Although the cost of pumping and treating water (exclusive of infrastructure and administration) is typically one-third the charge for the water, this study will consider the total water bill cost. Wasting fuel or water is costly since there are no substantial results from use of the resource. An example of using water versus wasting water is that of one flush toilets that use 3 gallons per flush. This water use performs a useful function, but the same appliance can also waste water if it is not maintained well. The New England Waterworks Association cites that one leaky toilet alone can waste as much as 200 gallons of water a day. Trees provide shade for buildings, which will lower the comfort cooling requirements and provide an evaporative cooling effect through a process called evapotranspiration, which will also provide beneficial cooling. Nevertheless, consider that large trees will evapotransporate 300 gallons of water per day.

System Problems and Solutions

Problems with evaporative cooling system operation can often be traced to poor initial EAC installation and/or supply air design; untrained EAC operators; insufficient maintenance; and atmospheric conditions. There is often a problem of perception of the capabilities of evaporative cooling. Some building occupants are so accustomed to the "flip-a-switch" world that they expect to be able to maintain comfort conditions under any conditions. This is not the case for either evaporative cooling or most refrigerated air systems. Acceptance of the trade-off between occasional under-cooling for lower energy bills, better air quality and reduced pollution is common in the dry southwest.

APPLICATIONS

Comfort Cooling

“Human comfort” depends on a variety of factors ranging from temperature, humidity and air movement to clothing and culture. What is comfortable for one person in one society may be entirely uncomfortable for another. Someone who has long lived without refrigerated air conditioning may find an artificially air-conditioned environment uncomfortable, whereas people who take refrigerated air conditioning for granted in their homes and workplaces may avoid being outside during hot weather all together.

Residential

Residential applications of evaporative cooling are common throughout the hot and dry areas in the southwest. Residential EAC's are typically smaller than commercial units but the basic components of a supply fan, water sump, sump pump, water distribution header and both pad and rigid wetted media are very similar. Many residences use direct evaporative coolers, but the addition of indirect coolers are becoming more accepted by users who want lower discharge temperatures and more available cooling hours. The Evaporative Cooling Institute reports that approximately 90% of residential and around 40% of commercial installations use evaporative coolers.

Commercial

Evaporative cooling is a well recognized method of cooling offices, shops, warehouses, laundries, kitchens and institutional facilities located in the southeast. Most new facilities use commercially available units that have 12" thick rigid media. Some have also include an indirect evaporative cooler section for better cooling performance. These units are often controlled with thermostats to further increase energy savings. Facilities that require tight temperature control and use refrigerated air can add an indirect EAC to precool the air upstream of the refrigeration air coil. Another widespread use of the evaporative effect in the commercial sector is evaporative cooling towers and evaporative condensers, which are used to reject heat from a refrigeration chiller. The latent heat of vaporization will drastically increase the heat transfer rate of these heat rejection devices.

Process Cooling

Examples of process cooling include kitchens where the 100% EAC air is exhausted by the large hoods over the cooking appliances, greenhouses, industrial laundries, factories, warehouses and animal housing facilities. The economics of evaporative cooling is attractive especially for processes that require large amounts of outside air, have high heat loads and use water cooled manufacturing equipment. Many high heat processes such as welding, milling and forging use EAC's to flush the hot air outdoors with cleaner evaporatively cooled air. Evaporative cooling is used for comfort spot cooling in large factories, power generation, fabrication and electronics assembly facilities. A very efficient use of evaporatively cooled air is for pre-cooling air that goes through gas fired turbine engines for electrical generators. The lower temperature plus the increased density and humidity in the air dramatically improves the performance of these units.

Humidification

Some buildings that are used for production, assembly, laboratories and other processes require the addition of moisture to the air for dimensional, static electricity and comfort control. The evaporative process is often used to satisfy these humidification needs because it will use less energy than other methods such as steam or compressed air atomization. This evaporative air treatment can be done by conventional EAC’s or with in-duct centrifugal air atomizers. The operation of the sump pump or atomizer is usually controlled by a humidistat in the conditioned space. Note that heating season evaporative humidification will often require additional heat to compensate for the evaporative cooling effect.

PERFORMANCE and ENERGY CONSUMPTION

Opportunities for both energy efficiency and comfort exist in many southwestern cities. First cost and operating costs are usually different budget items, so it is important to evaluate the annual energy use of the different types of air conditioning systems prior to any design or construction efforts. Once an A/C system is installed, the cost of changing it over can be 2 to 3 times as much as the original installation and often is not economically practical. Retrofitting from an EAC to a refrigerated A/C will usually require extensive ductwork and electrical modifications. A refrigerated unit will always require more energy than an EAC (3 to 5 kW compared to 0.5 to 1.5 kW), so wiring and other electrical components must also be upgraded.

In addition to the utility charge for consumed electricity, billed as kilowatt-hours (kWh), there is usually another monthly charge called peak demand for its busiest daytime hour. This peak demand is billed as the maximum kilowatts (kW) for a particular month. In addition, many utilities include a “ratchet clause”, which means that the maximum demand for electricity (usually occurs during the summer air conditioning season) will set the demand charge for the next three, six, or twelve months (depending on the utility and service agreement). These demand charges can be a significant portion of the monthly electricity cost. The spike that sets the peak demand is usually the result of refrigeration compressors starting. Since EAC’s do not use compressors, large fans, pumps, and lighting will likely set peak demands when evaporative coolers are used.

Evaporative Air Cooling

The electric components of an EAC consist of a supply fan motor (1/3 to 50 horsepower, depending on the air flowrate), a small (usually fractional horsepower) sump pump and a low-voltage control thermostat. When an EAC system is energized, there is no variability to the amount of electricity use. The exception to this is when a two speed or variable speed fan motor is used on the supply fan.

When trying to understand evaporative cooling, it is helpful to think of air as a type of sponge. Like a sponge, as air comes into contact with water, it absorbs it. The amount of water absorbed depends largely on how much water is already in the air. After all, how easily you clean up a spill depends on how dry a sponge you are using. The term ‘humidity’ describes the level of water in the air. If the air holds 20% of its capacity, the humidity would be 20%. A humidity of 100% indicates that the air is holding all the moisture it can. The lower the humidity, the more water the air can hold, and the greater amount of evaporation that can take place.

When describing the amount of moisture in the air, the term relative humidity is used because the sponginess of air changes relative to air temperature. The warmer the air, the spongier it becomes and the more water it can hold. As a result, the level of humidity relative to the type of sponge must be described. An example of this is an 80°F sponge will hold more water than a 50°F sponge at 50% humidity.

Refrigerated Air Conditioning

Refrigerated air conditioners are rated in terms of a Seasonal Energy Efficiency Ratio (SEER), or Energy Efficiency Ratio (EER) if the unit capacity is greater than 5 Tons of cooling (1 Ton of cooling is 12,000 Btu/hr). A typical EER for refrigerated air units is 10 to 14. The EER is a ratio of the Btu's of cooling to the total watts consumed by the unit. The higher the EER and SEER number the more efficient the unit. Another way to interpret this EER number is 12/EER = kW/Ton, which is a common measurement for cooling energy requirements. Although this number is a guide for anticipated energy consumption, it can underestimate the energy that would be used in many parts of the southwest. The total energy use is related to the condenser temperature. The condenser is the refrigeration component that rejects the room heat to the outdoor air. A condensing temperature greater than 95 °F (which is not unusual on many southwestern roofs) will increase the energy use over that predicted by the EER rating. High elevation above sea level will also decrease the performance of a refrigeration condenser. EER ratings are calculated for sea-level, but at higher elevations the number of air molecules moved across the condenser coil by the fixed speed condenser fan (that noisy propeller fan which is always outdoors) is less than at sea-level. As a result, less heat is rejected from the condenser coil. This will make the unit work harder to reject the heat and use more energy.

Another factor to consider when estimating the energy consumption of a refrigerated air system is the room air supply fan that may stay on during occupied periods (like an EAC), the refrigeration compressors are allowed to cycle off under part-load conditions. Sometimes these compressors can be staged, modulated down or partially turned off to try and match the load conditions. Compressor cycling can cause increased wear and tear on the compressor parts, but does save energy under part-load conditions. The larger capacity refrigeration chillers (over about 450 tons) can include a variable frequency drive (VFD) to slow down the chiller to reduce the cooling capacity during part-load conditions.

Mixing EAC and Refrigerated Air:

A direct evaporative cooling system works by the evaporation of water, adding moisture or latent energy into the supply air stream. Because the air can only hold so much moisture (at a given temperature and atmospheric pressure), direct EAC's cannot recirculate the room air like heating or refrigerated cooling systems do. All the air cooled must be exhausted or otherwise relieved from the building.

Direct EAC's should not be used to concurrently cool rooms that use refrigerated air conditioners or systems. Also, if adjacent rooms use refrigerated cooling (i.e. computer rooms and some offices), connecting doors should be kept closed, or air locks installed. The reason for this is that refrigerated air conditioners can extract moisture from the air, while EAC's add moisture to the air. The result of mixing these two air streams is that the refrigeration capacity will be used to dehumidify the air instead of lowering the dry-bulb temperature, and comfort cooling capacity will be decreased. This mixing does not occur in combination units that are manufactured.

Water Consumption

Water is used in two different ways in EAC's. Primarily water is used as the EAC working fluid, so it is dissipated in the evaporation process. this water use will vary with the type of media used, supply air volume, temperature and humidity content of the outside air and the number of operating hours. When the air is hot and dry, more water will be used and the evaporative cooling effect is the greatest. The second way water is used in an EAC is to control the buildup of solids that are naturally in the water. This bleed-off method will dilute the sump water in order to wash away the dust and other particulate matter caught by the wet media, and to prevent the buildup of solids that may be in the water supply. There is some variability of the water use of an EAC system. Factors that cause this are the existence of a bleed-off system, the rate of bleed-off dilution, and the method of controlling solids buildup.

Three options for water bleed systems, from the most to least water usage, are listed below.

1. Continuous water bleed off.
2. Intermittent water bleed off.
3. No water bleed off.

The no-bleed option may be practical in areas with little naturally occurring minerals, and on aspen media EAC's used in areas that are experiencing a drought. Since the aspen media has a low replacement cost, it can be replaced periodically depending on water conditions. In addition, some thin-pad EAC media is washable.

A common alternative to a continuous water bleed that can reduce overall EAC water use is using an additional sump pump, which is periodically energized to completely empty the sump. This has the advantage of using fresh rather than the more concentrated sump water, and a more complete flush of the accumulated dust. Uses of a sump dump pump with integral controller will use approximately 70% less water than bleed-off systems. Another more expensive method of flushing the sump water intermittently uses water conductivity sensors to initiate the flush when a predetermined value is sensed.

The continuous bleed method uses more water this is the simplest method of solids control. This water can be routed to a plumbing vent on the roof. However, for environmental, energy, and life cycle cost considerations this water should be routed to an area landscaping pond for water conservation purposes.

Clean sump water is important for maintaining consistent cooling, good IAQ, and extending the service life of the evaporative media. Mineral buildup on evaporative cooling pads directly decreases life and the saturation effectiveness of the pads. Most direct evaporative coolers recirculate their pan water, while increasing the concentration of dissolved minerals. Typically, a bleed off system is employed with these coolers to remove minerals as they accumulate. Obviously, a bleed off system will also increase overall water consumption of an evaporative cooler. At some point, increased water consumption has little effect on reducing scale. The goal is to optimize scale control while using a minimum of water for such purposes.

Commissioning of Evaporative Cooling Systems

System commissioning is an important project stage that will improve the performance and energy efficiency of a newly installed cooling system. Commissioning is the process of ensuring that systems are designed, installed, functionally tested, and capable of being operated and maintained according to owner's operational needs. The commissioning requirements are detailed in the project specifications for a new building or a system retrofit project. Proper commissioning will bring about verifiable energy savings, improved temperature and relative humidity control, improved air balance, improved indoor air quality and reduced occupant complaints. It will also help the project to have fewer change orders and improved communication between the design team and the building operating staff.

Commissioning is a systematic process that begins, ideally, in the design phase of a building retrofit project and lasts at least one year after the project is completed. However, it is never too late to commission a commercial building. Existing equipment can also be commissioned to ensure that it operates efficiently and meets the building owner's and occupants' current needs and expectations. Commissioning is usually performed at a building owner's request. Often the owner may hire or assign a representative, who acts as a proxy, and spearheads the project.

Owning and operating a commercial building requires a substantial financial investment. Poor performance means building owners may be losing money. Excessive repair and replacement costs, employee absenteeism, inadequate indoor air quality (IAQ), and tenant turnover costs building owners and employers millions of dollars each year. Building commissioning reduces this unnecessary loss of money by restoring equipment and building systems to a high level of performance. It ensures that new buildings or systems begin its life cycle at optimal operational levels and improves the likelihood that the equipment will maintain this level of performance throughout its life.

Commissioning should not be confused with testing, adjusting, and balancing (TAB), the measurement of building air and water flows. The commissioning process, which is much broader in scope, involves functional testing and system diagnostics. Diagnostics and functional testing of equipment and systems helps determine how well building systems are working together. It also helps determine whether the equipment meets operational goals or needs to be adjusted to increase efficiency and effectiveness. A proper commissioning will result in fewer installation callbacks, long-term tenant satisfaction, lower energy bills, avoided equipment replacement costs, and an increased profit margin for building owners.

SIZING EAC SYSTEMS

Typical EAC System Sizing:

EAC capacity can be sized using various methods. The most common method used in design is a building heat balance using manual calculations or a computer program. Summing the heat gains from solar, lights, computers and other office equipment, people and the heat gain from the building envelope will give a heat extraction rate which is used to size the cooling equipment.

SOLAR HEAT + HEAT FROM EQUIPMENT & PEOPLE = HEAT REMOVAL REQUIREMENT BY EA C

The other side of the heat balance equation depends on which type of evaporative media is used. Rigid media is more effective than aspen media, so the discharge temperature will be cooler. This means that less airflow is required to remove the same amount of heat from the building.
The equipment is typically not sized to meet the worst case conditions, but to satisfy the peak loads for 98% of the time. ASHRAE provides an historical base of temperature design values in the .4%, 1%, and 2% (of annual hours) column of their "Climatic Conditions for the United States" table. EAC

manufactures can provide energy analysis and sizing information that will help the engineer estimate the energy and water use.

Wet-bulb Depression

EAC's are sized based on the wet-bulb temperature. Engineers are familiar with a fluid filled thermometer with a bulb on the bottom. This thermometer will measure the "dry-bulb" (or sensible) temperature. If a small fabric sock was placed over the bulb on the bottom, and then sock is wetted and air is moved pasted it, the evaporative effect will cool the sock and the bulb and decrease the temperature reading on the thermometer column. The value that is read from the column would now represent the "wet-bulb" (or latent) temperature.

Because EAC is not sensible cooling, one cannot state an equipment efficiency factor or Energy Efficiency Ratio (EER) as with refrigerated cooling. Instead, there is a term called "**saturation effectiveness"** sometimes referred to as evaporative effectiveness, which can be used to predict the performance of EAC's. See Equation 1: Saturation Effectiveness. This effectiveness is calculated as the ratio of the change in dry-bulb temperature divided by the difference between the outside air dry-bulb and the wet-bulb temperature (or **wet-bulb depression).** This saturation effectiveness varies with media type and has been tested and measured for different types of EAC's. Knowing these values it is possible to solve for the EAC discharge temperature T-2, see equation 2. This equation is shown below.

[Equation 1:]

$$SE = 100 \text{ X } \frac{(T1 - T2)}{(T1 - T3)}$$

Where:

SE = Saturation Effectiveness (per cent)
T1 = Dry—Bulb Temperature of Entering Air
T2 = Dry—Bulb Temperature of Leaving Air
T3 = Wet—Bulb Temperature of Entering Air (usually the mean coincident wet bulb-MCWB)

[Equation 2:]

$$T2 = T1 - [SE \text{ X } (T2 - T3)]$$

Where:

SE = Saturation Effectiveness (per cent)
T1 = Dry—Bulb Temperature of Entering Air
T2 = Dry—Bulb Temperature of Leaving Air
T3 = Wet—Bulb Temperature of Entering Air (usually the mean coincident wet bulb-MCWB)

Table 8 below compares the discharge temperature downstream of the evaporative media for different saturation effectiveness for typical conditions in the Southwestern States. The effectiveness is also dependent on the air velocity through the evaporative media, which normally range from 400 to 700 feet per minute. A lower velocity results in a higher effectiveness, less fan power as discussed below, and longer media life. A higher velocity results in less residency time between the air and the water, thus decreasing the effectiveness. Velocities over 600 fpm will require mist eliminators to prevent water carryover, and are not recommended. High media face velocities along with insufficient water flow also accelerate mineral buildup.

Table 8: EAC Effectiveness Comparison

EAC Effectiveness Comparison

Ambient Tdb deg F (2)	MCWB deg F (2	EAC % Effectiveness	Supply Air Temperature (1)
97	61	**6**	**75.4**
97	61	**6**	**73.6**
97	61	**7**	**71.8**
97	61	**7**	**70.0**
97	61	**8**	**68.2**
97	61	**85**	**66.4**

NOTES

1) Evaporative Cooler Supply Air Temperature DB-out = DB-in - (Evap. Eff. X (DB-in - WB-in))
2) Typical Weather Date for the Southeastern US

Air Velocity Through the Wetted Pad

Air velocity past the face of the media is an influential factor in EAC design. When the air is slow, the cooling effect is greater, and the air pressure drop is lower. However, the unit is larger and the first cost is greater. If the air is too fast, less cooling will take place and water entrainment into the air stream may occur. Any water buildup in the downstream ductwork can cause water damage and other associated problems. Most equipment is designed around 500 to 600 fpm face velocity. Mist eliminators can be put into the air stream over 600 fpm to try to catch the mist (also known as carryover), but these devices will use more fan power over the life of the unit. Media velocity is also increased when the buildup of solids in the water is not controlled properly.

High face velocities also incur higher airflow resistances and require more water flow for uniform wetting. Because evaporation rates may exceed certain strands' capillary powers to rewet themselves, high velocity in pads frequently causes dry spots, which admit hot air and clog rapidly. Pad clogging is clearly related to local velocity; the lower the general pad velocity, the more slowly and uniformly clogging progresses. Specifically, clogging is the depositing of clinging lime and dust on the pad fibers. It occurs principally where alternating wetting and drying are by turns bringing dissolved minerals and then evaporating the water and precipitating its mineral content. Midway in that drying process, impinging dust is not washed away but adheres permanently with the deposited lime.

Rough methods in EAC Sizing

An accurate sizing method will account for both internal and external building loads. The following rough sizing methods can be used to determine a sizing estimate for budget assessments.

An accepted EAC rough sizing method is based on the number of air changes per hour (AC/hr) to determine the airflow rate based on the heat load and the ambient (local air) wet-bulb temperature. This method is straightforward for use since the air change volume is easily calculated by multiplying the three dimensions of the conditioned space. This AC/hr method should only be used for rooms with an eight to twelve foot ceiling height. Therefore, it is possible to use this rough sizing method to determine the airflow capacity necessary to cool the space.

Sizing evaporative cooling equipment for an existing or planned production/warehouse type structure:

Step 1: ***Determine the Cubic Capacity of the structure or that portion of the structure to be evaporatively cooled.***

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.

In example of Step 1: A structure that is 100' wide x 200' long with an effective height of 16' would equal 320,000 cubic feet.

Step 2: ***Determine the number of air changes per hour required to maintain desired indoor temperatures.***

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. The best approach, short of a major engineering study of heat gains, etc., is a common sense approach of using the known conditions inside and outside the structure.

It is first necessary to know the climate design conditions of Dry Bulb (DDb) and Wet Bulb (DWb) for the location. This information is available from ASHRAE publications with a 1% scale if there is a weather reporting station in the area, I.E. design conditions for Phoenix, AZ., is 109(f) IDb and 69(f) IWb. This condition is only exceeded during 1% of the cooling season therefore the conditions are at the high end of the range. These conditions are concurrent meaning that they are present at the same time.

Using the formula to determine the predicted discharge temperature during these conditions the temperature of the air available to use in the cooling of the building will be known.

Discharge temperature = (ODb - OWb) x SE or 109 - 69 = 40 x .9 = LDb 36(f) temperature drop.

Where ODb = Outside Design Dry bulb OWb = Outside Wet bulb
SE = Saturation Effectiveness (%) LDb = Leaving Dry bulb

ODb - ODb = 109 - 36 = **73 degrees (f) Dry Bulb discharge temperature**.

The air temperature of 73 degrees (f) is necessary to know for the next part of step 2. (Note: This procedure does not take into consideration the density ratio which would have to be considered in higher elevations).

Refer to table 7 to determine the proper number of air changes.

Table 7 Air changes Per Hour

Suggested air changes per hour		
Leaving Air Temperature	**Temperature over ambient***	**Air Changes/Hr****
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

* Average amount indoor temperature exceeds the outdoor temperature when evaporative cooling is not in use at design conditions or interpolation/extrapolation of these conditions.

*It is common practice to cool only to the height actually used and needs cooling. It is not bad to have a heat layer at the roof level provided the cool air coming into the structure does not flow through this layer. Most cooling installations will extend the discharge duct to the height above the floor where cooling is preferred and the capture area of the exhaust ducts likewise start at this level. This method does not disturb the heat layer.

Using the above table and a leaving discharge temperature (into the building) of 73 degrees (f) and determining that the indoor air temperature (ambient Db) and the outdoor temperature (ambient Db) is 120 and 109, the difference is 11 degrees (f). Referring to the above table, we see that we should plan approximately 12 to 20 air changes per hour. The reason for the range of air changes is to allow for other conditions not being considered. Among these other conditions not being considered is human comfort cooling as compared to equipment cooing, etc.

In summarizing what has been determined so far, the cubic capacity to be cooled is 320,000 cubic feet, the discharge temperature required is 73 degrees (f), the number of air changes is between 12 and 20, and assume that this structure is heavily populated with people. Therefore, consider the greater number of air changes (20) to assure the best human comfort level without increasing costs more than what is absolutely necessary.

To determine the total Cubic Feet per Minute of air flow required to cool this structure as indicated, multiple 320,000 (cubic feet) by 20/ 60 = 106,666 Cubic Feet per Minute (CFM). (Remember to express the requirement in the same unit of measure as the capacity. In this instance, that is Cubic Feet per minute rather than per hour and that is why it is "divided by 60" within the formula). The CFM can be rounded off to 107,000 CFM. In fact if the number of air changes was reduced to, say 18 changes per hour, the amount of CFM would decrease to 96,000 CFM. One can readily see why the number of air changes is important to the CFM required.

It is common practice to refer air changes as “minutes of air change” (I.E. in this instance, the 20 changes would be expressed as one (1) air change every 3 minutes). Another way to prove the process is to multiple the CFM by the air changes (107,000 X 3 = 321,000 CFM which is close enough) Remember, the example is dealing with climate conditions that are exceeded only 1% of the time during the cooling season.

Next, it must be determined how many individual coolers are required and the location of the equipment. Will ten (10) 10,700 CFM coolers be placed across the roof of the structure (to be mounted on the side or ground) or will two (2) 53,500 CFM coolers or perhaps five (5) 21,400 CFM units be used. The answer to this question lies main on the consideration of costs (i.e., cost of acquiring five (5) units in this example would cost less than either of the other options).

The air change method of sizing is considered a common sense approach. Since evaporative cooling quickly exhausts heat (in this case every 3 minutes), heat gain is considered in the above steps we took and is controlled by the number of air changes. It stands to reason that the indoor heat gain is reflected in the Dry Bulb difference between indoor and outdoor temperatures. This method automatically considers all the pertinent data by measuring the actual conditions in an existing structure that must be dealt with. This method is also useful in new structures to design the cooling system except the heat gain has to be determined in advance of having the structure available to measure.

After going through the above detail to approach the sizing of evaporative cooling, practice tells us that 1 air exchange every 3 minutes is more than adequate for any condition that would arise in Phoenix, AZ.

In new buildings, it is common to predict the outcome based on the known factors of discharge temperatures and outdoor Dry Bulb. Indoor heat gain would have to be determined to complete the process.

SENSIBLE HEAT REMOVAL SIZING METHOD:

To determine the amount of air volume (measured in CFM) required to remove indoor heat gain, the following formula can be used.

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

Where IDB = Indoor (Design) Dry Bulb LDB = Leaving Dry Bulb from Cooler

Example: An indoor heat gain of 144,000 BTUH at an altitude of 4000 feet. An Evaporative Cooler with 12" cooling media @ 500 FPM velocity is to be used to remove this heat gain. Outside design conditions are 94 Dry Bulb and 64 Wet Bulb with a design indoor temperature of 80^0 (f) Dry Bulb.

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.

The Density Ratio is determined from table 8. At 4000 feet elevation the Density Ratio is .864 (rounded to .87).

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

$$\frac{144{,}000 \text{ BTUH}}{1.08 \times (80 - 67.3) \times .87} = \frac{144{,}000}{11.933} = \text{SCFM } 12{,}067$$

Table 8 Air Density Ratios

AIR TEMP. (°F)	ALTITUDE IN FEET ABOVE SEA LEVEL												
	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000	15000	20000
	BAROMETRIC PRESSURE IN INCHES OF MERCURY												
	29.92	28.86	27.82	26.82	25.84	24.90	23.98	23.09	22.22	21.39	20.58	16.89	13.75
70	1.000	.964	.930	.896	.864	.832	.801	.772	.743	.714	.688	.564	.460
100	.946	.912	.880	.848	.818	.787	.758	.730	.703	.676	.651	.534	.435
150	.869	.838	.808	.770	.751	.723	.696	.671	.646	.620	.598	.490	.400
200	.803	.774	.747	.720	.694	.668	.643	.620	.596	.573	.552	.453	.369
250	.747	.720	.694	.669	.645	.622	.598	.576	.555	.533	.514	.421	.344
300	.697	.672	.648	.624	.604	.580	.558	.538	.518	.498	.480	.393	.321
350	.654	.631	.608	.586	.565	.544	.524	.505	.486	.467	.450	.369	.301
400	.616	.594	.573	.552	.532	.513	.493	.476	.458	.440	.424	.347	.283
450	.582	.561	.542	.522	.503	.484	.466	.449	.433	.416	.401	.328	.268
500	.552	.532	.513	.495	.477	.459	.442	.426	.410	.394	.380	.311	.254
550	.525	.506	.488	.470	.454	.437	.421	.405	.390	.375	.361	.296	.242
600	.500	.482	.465	.448	.432	.416	.400	.386	.372	.352	.344	.282	.230
650	.477	.460	.444	.427	.412	.397	.382	.368	.354	.341	.328	.269	.219
700	.457	.441	.425	.410	.395	.380	.366	.353	.340	.326	.315	.258	.210

Notes:
1. Unity Basis = Standard Air Density of 0.075 lb/ft^3
2. At sea level (29.92 inches HG barometric pressure), the unity basis is equal to dry air at 70°F.
3. Density is directly proportional to barometric pressure as established by the U.S. Standard Atmosphere-Altitude-Pressure relation.
4. Density is inversely proportional to absolute temperature.

This result indicates a need for at least 12,067 Cubic Feet per Minute of air flow @ 67.3^0 (f) to offset the indoor heat gain of 144,000 BTUH.

Manufacturers Catalog Data

Manufacturers of packaged EAC and combination units will usually show catalog data for several different models of EAC's. Their unit's cooling capacities are usually given for sea-level, but a cubic foot of the thinner air in higher elevations can't hold as many Btu's as a cubic foot of denser sea-level air. Air density, or altitude effects will also affect a fan's horse power requirements, duct friction and fan selection. Engineers should consult with equipment manufacturer's for de-rating EAC's (or refrigerated air units) when the site elevation exceeds 2000 feet. Manufacturer information will include data such as dimensional, weight, options and electrical. The selection options for EAC features will include:

- Type: Direct, Indirect, Combination units and media type and thickness. The evaporative saturation effectiveness is affected by the media type, thickness and air speed through the media.
- Construction features. These can be related to the length of the warranty period. These features include cabinet materials, method of welding, corrosion inhibiting treatments or coatings, motor speeds, bearing type, pump and distribution system, and fan voltage.
- Configuration: Options include side or down discharge, damper configuration, filters and heating options. Down discharge models should include a field supplied access door to allow inspection and repair of the duct and water connections located under the unit. The mounting options would include roof curb, skid mount, pad on-grade, etc.
- Capacity: For EAC's this is usually stated for sea-level in terms of airflow in CFM, and static pressure in inches of water, for a specific fan size or type and motor horsepower. The static pressure is usually given as the external static pressure (ESP), external to the unit, or it could be shown in total static pressure (TSP) in which case the media pressure drop should be added. An HVAC engineer should calculate the static pressure losses associated with the system ductwork, diffusers, grilles, relief air duct, relief air dampers and louvers. This consultant, typically a mechanical engineer, can also calculate the cooling loads, size the ductwork and apply corrections for altitude.
- Controls: EAC controls usually consist of a thermostat or course control switches, and sometimes damper controls and programming schedule. Course switch control will have a fan on/off, pump on/off, and often fan high/low speed. Division 15 of the project specifications or the mechanical drawings should include a Sequence of Operations to detail the exact order in which components should operate on a project-by-project basis. See the next section on Controls.
- Thermostat type: Thermostat type can be 1) a microprocessor based which usually has a digital display, and uses a battery or a low-voltage transformer, or 2) a 120 volt (referred to as line-voltage) thermostat which is not recommended because of their limited capability, high maintenance requirements and life safety factors associated when electrical arcs are used around flammable gasses. The thermostat will usually turn a supply fan on or off in response to the load, and some will also control two-speed fans. Although not recommended by most media manufacturers, some thermostats will cycle the sump pump on or off (often referred to as the cooler to vent cycle) to help control temperature while maintaining fan operation. The low-voltage microprocessor based thermostat will usually offer additional money saving and comfort improving options. Some of these

are the timed shut-off, night and weekend automatic temperature set-back/up, fan hours totaling, and a media pre-wet cycle. Some also control a gas or electric heating section as well.

- Damper controls for an economizer damper package used for “free” air cooling during the spring and fall. These dampers are also used for closing off the outside air dampers during unoccupied periods are recommended for energy conservation.

SYSTEM CONTROLS

Three EAC control points are typically used to control supply fan ON/OFF, fan HIGH/LOW speed and pump ON/OFF operations. Other types of EAC related controls include relief air interlocks, sump dump controls, and media pre-wetting cycles. It is assumed that seasonal maintenance will include winterizing the EAC, so freeze protection of EAC’s is usually not necessary.

EAC controls are an important means of maintaining comfort and conserving electricity. Turning things off when they are not being used is the lowest cost method of reducing utility bills. The types of control systems usually found on EAC’s are:

- Fan and pump switches (2 or 3 wall switches)
- Line voltage thermostats
- Battery powered individual microprocessor based thermostat
- Unit powered individual microprocessor based thermostat
- Central energy management control systems (EMCS).

EAC control type #1, Fan and pump switches, have no periodic maintenance. It is recommended that these systems include a sign posting “User Instructions for EAC Switch and Window Operation” attached to the wall near the switches.

EAC control type #2, Line voltage thermostats, should be periodically checked for excessive arcing and pitting of the electric contact points. Caution 120 Volts!

EAC control type #3, Battery powered individual microprocessor based thermostat, will require periodic (seasonally) review of the programmed on/off schedules, time change and clock accuracy check, recording of the summed fan run hours to the equipment log sheet (if so equipped) and periodic replacement of the batteries.

EAC control type#4, Unit powered individual microprocessor based thermostat, is essentially like type #3 except there are no batteries to change. Some control systems will feature a portable memory transfer device that can be used to transfer programming from a PC to the individual standalone controllers. Maintenance consists of a periodic (seasonally) review of the programmed on/off schedules, time change and clock accuracy check, and sometimes reprogramming on power loss.

EAC control type#5, Central energy management control systems (EMCS), is the most versatile of all these control systems. These systems have temperature, humidity and other sensors located in the EAC (and heating) units, and are also wired into the damper and/or valve motors. A personal computer is used to monitor and control all functions, and to alert you when values stray from preset values. Additional programming can perform temperature setback/setup, optimum start/stop, and control of various arrangements for the optimal sequencing of combination direct/indirect with refrigerated air conditioning. Additional software can help track, assign personnel, audit maintenance logs and more. Maintenance required on these systems consists of periodically replacing or repositioning sensors and backing up local data files.

EAC Thermostats:

Many small EAC systems use three wall-mounted switches for fan on/off, pump on/off and fan speed control. This type of user-operated control is inexpensive and simple to operate, but can waste energy by not tracking the room cooling loads. In addition, the EAC is sometimes left on for extended periods when the room is unoccupied. Some systems use a line voltage thermostat to control both fan and pump operation. These 120-volt electrical contacts soon wear out and require replacement. Newer controllers use low voltage thermostats along with electrical relays to control fan and pump, sometimes independently. The newer and more sophisticated microprocessor controllers often include extra functions such as fan speed control, temperature setback, timed shutoff, a pre-wet cycle, and timed sump dump initiation.

Relief Air Dampers

Interlocked relief air controls are an important part of a well-designed EAC system. Motorized relief air dampers and/or exhaust fans should be electrically connected to energize whenever the associated EAC supply fan is on, for good air circulation. See the Importance of Relief Air Dampers Section.

Fan Speed and Pump Switches

Turning things off when they are not being used is easiest and most effective way to conserve energy. The control of the EAC components can be the biggest factor affecting its annual energy consumption. EAC users have the option of turning the EAC fan off when they leave the room, using the fan at high speed, or at low speed. High speed will use more energy and water but provide a greater cooling effect. The sump pump typically uses a fractional horsepower motor, so it doesn't significantly affect energy consumption to cycle it off for temperature control. In fact, most manufacturers recommend that the sump pump not be cycled to minimize mineral deposits on the evaporative media.

Another method of controlling supply and relief fans is to use timers. These mechanical or electronic add-on timer switch modules can significantly reduce fan energy use by only using fans using occupied periods. Occupants must be instructed on how to best use the timers to maintain comfort and minimize waste.

A more accurate but costly method of fan control for larger systems is to use a variable volume supply air fan. Different methods of volume control are used, such as vane or scroll dampers, variable pitch fan blades and variable frequency drives. Of these, variable frequency drives (VFD's,) are the most energy efficient for fan motors over three horsepower. VFD's are also used on the relief/exhaust air fans to accurately control air relief and building pressurization. The cost of a VFD is comparable to the cost of the traditional relief air dampers with motor, and a VFD can also eliminate the need for a motor starter. This method is most reliable and requires the least maintenance. VFD's are usually tied into a buildings' energy management system computer so that all control is automatic. The computer will sense the load and vary the fan speed to maximize comfort and minimize energy use.

Solids Buildup Control

Control of solids accumulation in the EAC sump water is important for extending the evaporative media life and maintaining peak evaporative effectiveness. Some systems have been installed with no bleed-off dilution system. These systems will experience lower evaporative effectiveness, decreased media life and a higher air pressure drop across the media which causes reduced airflow.
"When water evaporates, only pure water is released. The dirt and harmful chemicals are left behind with the water on the pads and in the sump. Eventually, the water becomes so contaminated that it is harmful to the pad and gutters. Quarterly cleaning and flushing of the pads will increase their service life.

Common Scale Forming Minerals

- Calcium Carbonate
- Calcium Sulfate
- Calcium Phosphate
- Iron Oxide
- Silica (Si02)

In most systems, calcium carbonate and silica are the most troublesome scale formers. The silica is the most straight forward. It must be kept at a concentration less than 150 PPM. Calcium carbonate scaling is more dependent on alkalinity (an indication of pH). Its solubility can be simplified to a curve of calcium carbonate concentration versus alkalinity.

On the following chart, Figure 16 (Reference Chart for Water Quality), the stable water is represented by the narrow line. Water quality to the right of the line forms scale. Water to the left of the line is scale dissolving or corrosive. It is difficult to keep water perfectly balanced. Instead, try to keep the water reasonably close to the line so that it fluctuates between scale forming and scale dissolving.

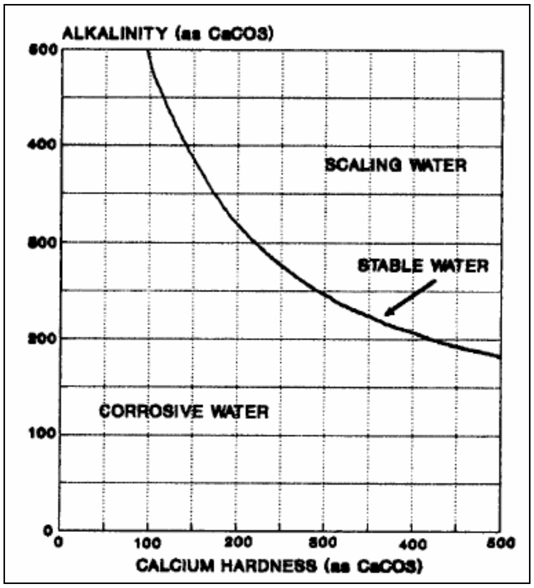


Figure 16: Reference Chart for Water Quality

Solids Control Methods:

Older systems use a continuous water bleed-off. There usually is a valved branch off the sump pump discharge line to the cooler pads. This method is effective at controlling solids build-up, but drains more water than necessary. Also, since it is a dilution solution, it never completely empties all of the dust and impurities in the sump water. A better option is to use an automatic sump drain, which can be interlocked with the supply fan to drain on fan shut down or controlled by a timer.

Newer system controls use water conserving sump dump controls to periodically energize a separate dedicated sump pump. One method is to run the sump dump pump six minutes for every six hours of fan operation, to completely pump out the water that has collected dust and mineral deposits. The pump controller can be a stand-alone timer installed on the pump at the cooler, or it can be included in with a microprocessor based thermostatic controller.

There are other water saving non-electrical devices which will gravity drain the sump water whenever the sump pump is turned off. This will save water if the EAC sump pump is typically energized all day, but may waste water if the sump pump is cycled for temperature control.

It is a good water management to pipe this water to a retention pond for use for landscape irrigation to minimize wasted water when allowed by local codes.

Some of rigid media is coating up to the leading edge of the media, which is designed to minimize the accumulation of solids. “It is very important to protect the air entering face of evaporative cooling media. This face is exposed to the harshest part of the ambient climate. Furthermore, the first one half inch of media gets more abuse than the rest of the media combined. This first half inch is where the air is the hottest, driest, where the greatest amount of evaporation takes place, and where the resulting concentration of minerals and contaminants is the greatest. It is also where the dust and sand loading is the most intense.

Media edge coatings were developed to address some of the needs of the evaporative cooling industry. These include:

- Wettability: The coating has been formulated with special wetting agents to prevent water beading. Water spreads over the surface of the coating as a thin film.
- Quick Drying: The coating surface dries out quickly when the water is turned off. This drying inhibits the growth of micro-organisms (especially algae), which require moisture to live.
- Non-porous: The coating does not allow algae or minerals to anchor themselves into the substrate. Algae and minerals slough off when dried.
- Tough and Resilient: The coating surface can be repeatedly cleaned.
- Weather Resistant: Inlet louvers may be eliminated. The louvers may be necessary, however, to inhibit alga growth in situations where the coolers are poorly maintained.
- Improved Life Expectancy: The coating extends the life of the media pad over that of non-treated pads. Heavy mineral deposition, and frequent abrasive cleaning will shorten the useful life of any media pad.

Bio-Growth Control

Alkalinity and low organic content in the water makes bio-growth on a pad that is pre-filtered and shaded from direct sunlight, easier to control. Manufacturers of evaporative media recommend that the evaporative pads be shaded and allowed to dry out every 24 hours while the fans are running to help curb algae growth. This is easy to do with an automatic controller, which can be programmed to dry out the pads during unoccupied hours. Monthly cleaning and disinfections of the sump, the use of mist eliminators on high-velocity systems, and not locating the EAC air inlet near the outlet of a refrigeration cooling tower is recommended.

Chemicals added to the sump water too control algae. However, continuous use of algae treatment chemicals is not recommended. Besides being potentially harmful, they will not control algae without periodic cleaning and flushing of the system. After cleaning and flushing the evaporative cooling system, it can be treated with certain algae control chemicals. There are many control chemicals commercially available. Most contain one, or a combination of, certain active ingredients. Never use any chemical that is not labeled for use in evaporative coolers or do not list the ingredients. It is possible to void the manufacturers media pad warranty if unapproved chemicals are used.

Zinc anodes can be used to inhibit metal casing and sump pan corrosion while controlling bio-growth. These types of systems require periodic replacement and should not be used with stainless steel casings.

AIR QUALITY

Outdoor and Indoor Air Quality

The quality of the air inside a building is critical to the health and performance of the occupants. A high performance building should provide superior quality indoor air by:

- Eliminating and controlling the sources of contamination;
- Use appropriate filtration methods for the predominant air contaminants;
- Providing adequate ventilation;
- Preventing unwanted moisture accumulation; and
- Implementing effective operations and maintenance procedures.

The concentration of pollutants inside a building may be two to five times higher than outside levels. Maintaining a high level of indoor air quality is somewhat critical. Failure to do so could negatively impact the occupants, increase the potential for long and short term health problems for, increase worker absenteeism, accelerate deterioration and reduce efficiency of the physical plant, create negative publicity, and create potential liability problems. To eliminate or control contamination, select materials that are low emitters of substances such as VOC's (volatile organic compounds) or toxins.

Air quality refers to the amount of pollutants in the outdoor air or the indoor air. Outdoor is generally accepted as being healthier (fewer pollutants per unit of air volume) than indoor air. ASHRAE Standard 62 recommends the constant dilution of indoor air with a percentage of outdoor air during occupied hours. One important design consideration to control outdoor contamination is to prevent short-circuiting of air by locating EAC air intakes 10' to 20' from cooling tower discharge plumes and generator or kitchen exhaust. Pollutants generated indoors include out gassing of building materials, carpet adhesives, furniture and the occupants themselves. People breathe in oxygen and exhale carbon dioxide that must be diluted with breathable oxygen. In addition, other natural and artificial odors must be exhausted. Dust is also a source of particles. Each gram of dust may contain hundreds of thousands of fungal spores and also may contain pesticides and heavy metals.

Outside air is usually cleaner than indoor air, but can also contain particulate and odors that can be filtered out. This is the function of the filter section, which is included in all air handlers upstream of the coils. If dampers, coils and other heat exchange surfaces become dirty, their efficiency is reduced. Typical filter efficiency is around 30%, but other charcoal or HEPA high efficiency filters are used for clean room type applications. Commercial rigid media EAC manufacturers will usually offer different types of filter banks (such as 30%, pleated, HEPA and charcoal) to deal with most outside air contaminants, but each method will add an additional pressure drop to the air stream, and require more horsepower and electricity to operate. However, most EAC's will filter some particulate from the incoming air stream.

Older EAC's, called air washer, were not very efficient at cleaning tiny particulate from the air stream, they would catch and wash down some dust and larger particulates. Newer evaporative pads with denser media are better at washing the air, but still are not as efficient as typical air filter media. The tradeoff for high filtration efficiency is the pressure drop across the filtering media that the supply fan has to overcome, thus using more fan energy. Newer 12 to 18" thick (in the direction of air flow) rigid media is much more efficient at filtration because it has two methods of air filtration. First is the fluted bend inside the cardboard media that makes the air change direction slightly. When the air molecules change direction, the heavier dust particles can't turn as fast, and impact on the media wall (known as an inertial mass separator). The second stage to the filtration is the wet surface where the dust particle impacted. Through surface tension, it holds on to the dust, and eventually is washed into the sump (known as a viscous impingement filter**,** like your nose). While evaporative media is not designed to operate as a filter, the 12" rigid media when wet will capture over 90% of particles 5-10 microns or larger, Fungus spores are usually from 10 to 30 micron, while pollen grains are from 10 to 100 micron, with many common varieties in the 20 to 40 micron range. Particles larger than 8 to 10 micron in diameter are separated and retained by the upper respiratory tract. See Figure 17 for the for the particle size efficiency graph.

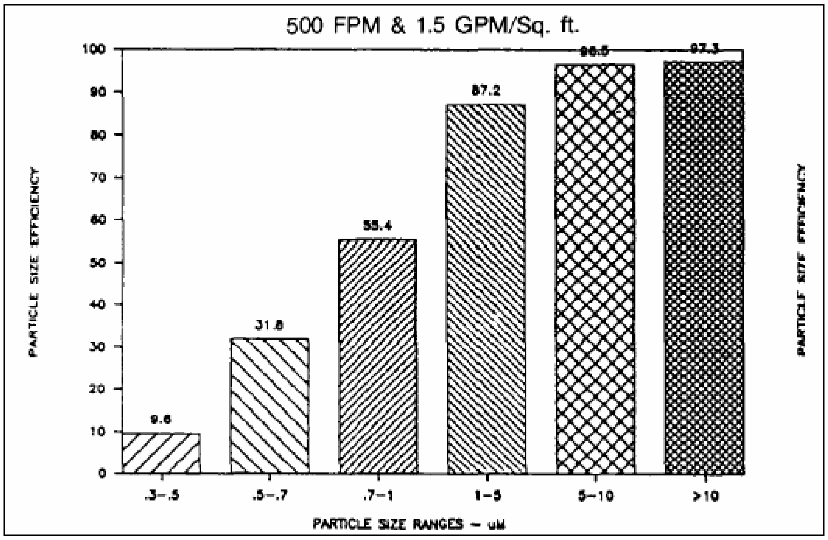


Figure 17: Filtration Efficiency for Various Particle Sizes for 12" Rigid EAC Media

An EAC uses 100% outside air (OSA) versus approximately 20% OSA for a refrigeration air conditioner. 20% is a typical minimum OSA requirement to control the buildup of odors, germs and the carbon dioxide, and to maintain a slightly positive air pressure in the building to prevent infiltration of unconditioned air.

ASHRAE Comfort Window

Comfort Issues

Comfort is a very subjective index. It can depend on a number of factors like the amount of clothing worn, the occupant's metabolic rate and activity level, and the temperature and humidity conditions. "Human comfort depends on factors ranging from temperature, humidity and air movement to clothing and culture. What is comfortable for one person in one society may be entirely uncomfortable for another. Someone who has long lived without refrigerated air conditioning may find an artificially air-conditioned environment uncomfortable; whereas people who take refrigerated air conditioning for granted in their homes and workplaces may avoid being outside during hot weather all together.

Standards

The comfort zones are often shown on standard psychrometric charts and have been developed to indicate regions where a person is comfortable (for more on psychrometric charts see PDH course M135). In the United States, the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) has developed comfort zones based on psychrometric charts. However, these standard types of comfort charts have changed over the years and now have more limited relevance related to evaporative air-conditioning. First, standard comfort zones are based on air velocities typical of vapor-compression air-conditioning systems, not the higher air velocities used with evaporative air-conditioners. Second, the traditional comfort zones used today (unlike those of the past) have horizontal, constant humidity-ratio (constant dew point) lines supposedly aimed to minimize respiratory diseases, mold growth, and similar problems. Relative humidity boundary lines are just as effective (and were previously used) and would distort comfort analysis less. Tests have shown that human comfort is a continuum, not confined between dew-point lines. Consequently, the standard comfort zones commonly used face shortcomings relative to EAC.

The Modified Comfort Standard for Evaporative Air-Conditioning

The effect of a given air stream on a person can be determined by an effective temperature chart, the same technique commonly used when calculating wind chill. By increasing the velocity of movement, air feels cooler. For evaporative air-conditioning, it is more reliable to consider a comfort zone bounded by relative humidity and extended to take into account the cooling effect of increased airflow different to ASHRAE's comfort zone, as shown in Figure 18.

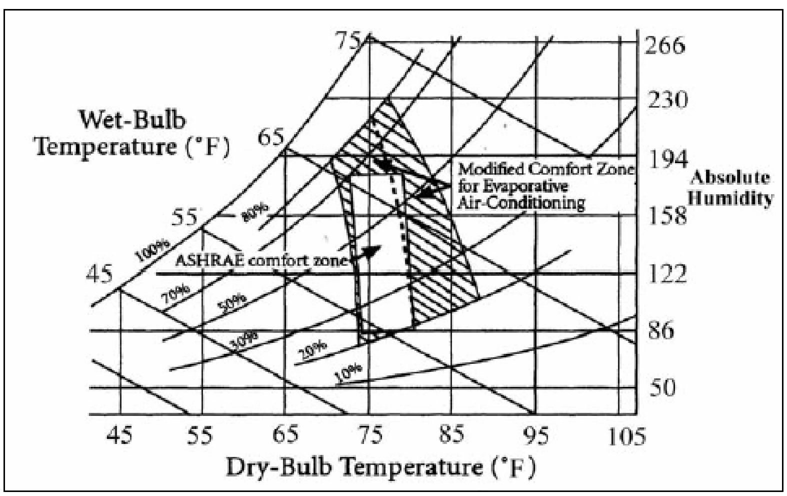


Figure 18 Modified Comfort Zone for Evaporative Air Conditioning

Actual Comfort

The actual comfort derived from EAC for a given dry and wet-bulb temperature depends on the following factors:

- Supply air temperature. Saturation effectiveness of the evaporative air conditioner. Only the theoretical 100 percent saturation effectiveness can reduce the leaving air temperature to the wet-bulb temperature. The EAC room temperature of an actual installation will depend on the condition and quality of the evaporative media, heat losses from the motor, fan, and pump, and heat absorbed because of the exposure of the air-conditioner cabinet to direct solar rays. Actual typical saturation efficiencies range between 60 and 90 percent for commercially available media.

- Room air temperature. Heat absorption of the space to be cooled affects the radiant temperature of the interior surfaces. This depends on exposure of walls and roof to solar gain, shading, number, size, and location of windows and construction materials.
- Heat generation in the space. Number of people present in the room, and the presence of heat generating equipment such as copy machines, stoves, television, and computers.
- Initial sizing of the EAC unit.
- Proper installation and airflow balancing. Cooled air should be properly divided and directed to most effectively "wash" the space and occupants to be cooled.
- The air velocity on occupants. The air moving past the occupants' skin adds to the cooling effect. The evaporation of small amounts of moisture on the skin is a localized evaporative cooling effect which Nature has perfected.
- Activity level of the occupants. Sedentary people require less cooling than physically active persons.

In some locations, EAC may be acceptable for users willing to experience less than full comfort from the EAC for a few hours on the hottest days of the year because the slight discomfort does not outweigh the extra costs associated with VAC (vapor-compression air conditioning).

The American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) used several studies of physiological considerations to develop "comfort zones" which can be shown graphically on a psychrometric chart. This makes it easier to visualize the acceptable comfort limits for temperature and humidity. They have used studies with statistical connections between comfort level, temperature, humidity, sex and length of exposure.

There are different comfort charts for different conditions such as the generalized comfort chart (Fanger Chart), which is used for common refrigerated air systems, a chart for sedentary occupants and a modified evaporative air-conditioning comfort zone. This comfort zone accounts for the increased airflow of EAC systems as compared to vapor compression air-conditioning. In a smaller way, this is analogous to the wind chill factor announced on the weathercast. This wind chill changes the size of the comfort zone, which resembles a box with rounded lines, to be larger for the evaporative comfort zone, or a wider range of perceived comfort. In addition to air velocity, there are other factors such as the amount of clothing worn, and time spent in the environment.

Relief Air Dampers

A very important aspect of proper operation of EAC systems is the releasing or relieving of the used evaporatively cooled air from the building. As the cool EAC supply air moves through a room, it gets heated by the people, lights, equipment and solar loads. Direct EAC's only work correctly when using once-through supply air. Two effective methods of discharging this air are by relief openings and exhaust fans.

Relief air openings can be exterior operable windows, or openings with dampers in the ceiling/roof or a high wall. Opening a window is the easiest way to route EAC air through a room. The supply fan air is pressurizing the interior of the building. This air will take the path of least resistance to leave the building. When an open window is located across the room from a supply air diffuser, the cool air must cross the room to be relieved. Varying the area of the window opening allows the occupant to control the cooling airflow into that room. This simple “open window area” to “air flow management” relationship is not always obvious, especially to occupants unfamiliar with EAC systems. Consider adding a wall-mounted sign that instructs occupants on how and when to operate the windows and thermostat or wall switches for maximum comfort, energy savings and security.

Dampers should be closeable so that winter heat is not wasted by ‘gravitating” or naturally rising out of the building. Although spring-loaded or adjustable weighted "barometric" relief dampers (which use the pressure in the supply air fan to open the dampers) are commonly used, they should be avoided since they can get dirty or worn and stick in the open or closed position. A better choice is to relieve air through insulated motor operated dampers, which are interlocked electrically with the EAC supply fan motor. This method insures proper air relief regardless of the wind conditions. When these methods are used, additional supply fan static pressure is required to push the air to, through the dampers, and out of the building.
A more reliable method of relieving the air is to use exhaust fans that are interlocked to energize with the supply fan. Kitchen, restroom or other exhaust fans will also help to relieve air, but attention should be given to the proper heating, ventilation and air conditioning (HVAC) design, so that the EAC is properly relieved under all occupied conditions.

An energy efficient route for the relief air is through a ceiling plenum or an unconditioned attic space. See Figure 19. Since the relief air is still cooler than the outdoor air, it can be used to displace the hot air in the attic and allow less of the solar heat gain to be transmitted into the room through the ceiling. This may also help with building security since some EAC systems depend on leaving operable windows open for an air relief path. One commercially available product for venting through a ceiling to an attic vent opening is called Up-dux®. These small (1000 CFM each) barometric dampers are mounted in the ceiling, where a sleeve protrudes through the ceiling insulation. A preferred method uses larger sets of electrically interlocked motorized, insulated damper blades, mounted in a duct collar with aesthetically pleasing ceiling grilles. These insulated dampers will minimize the heating season losses. The area of the attic vent openings or exhaust fans (which are required by code to prevent condensation) must be coordinated with the EAC design to minimize the pressure loss through the attic relief openings.

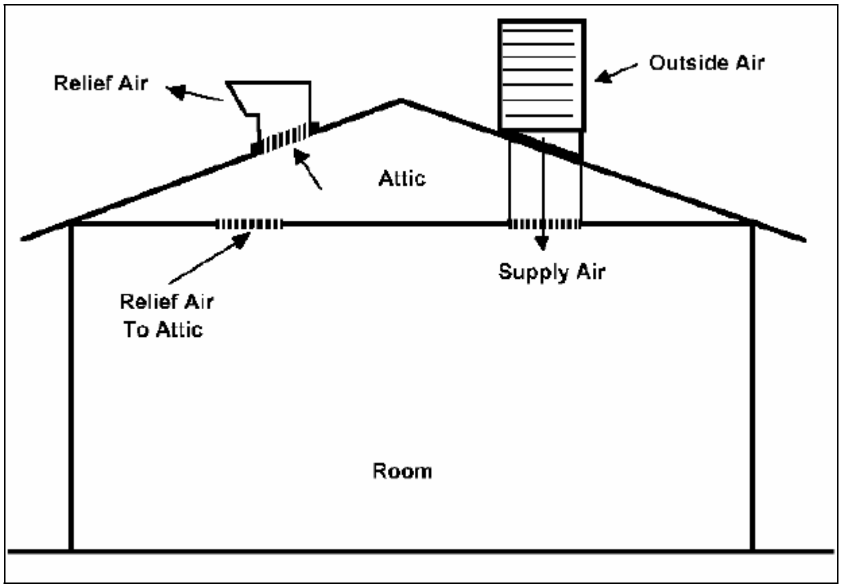


Figure 19: EAC Relief through Attic Space

Outside Air Requirements

The recognized authority for determining the amount of outside air is ASHRAE Standard 62. This Standard sets the minimum requirements for the amount of outside air necessary to maintain healthy IAQ conditions for various types of occupancies. Pollutants such as carbon dioxide, carbon monoxide, volatile organic compounds and ozone can be generated within the conditioned space, and are diluted with outside air. In order to comply with the ASHRAE Standard 62, which requires a minimum CFM per person of outside air to maintain acceptable indoor air quality (IAQ), outside air must be heated or cooled.

Refrigerated air systems usually take in around 20% outside air to meet these requirements. This air must be filtered, cooled, sometimes dehumidified, circulated through the room, and is then exhausted. Conditioning of ventilation air accounts for a significant portion of the annual energy consumption.

Conversely, EAC's must use 100% outside air for proper operation. EAC's will always deliver more outside air than the ASHRAE ventilation Standard 62 requires. Evaporatively cooled air is not as energy intensive as refrigerated air, therefore there is no additional energy cost penalty for providing this healthier breathing environment.

Humidity Control

For human comfort, relative humidity (RH) is generally considered acceptable when it is between 30% and 60% RH at normal room temperatures. For some materials and computers however, the rate of change of humidity also may be a critical factor because of the hygroscopic (water absorbing) properties of materials. Small computers do not require particularly low ambient temperatures or humidity. Humidity of 50% plus or minus 5% is considered ideal. The rate of temperature change is more important than ambient temperature.

The atmosphere consists of dry air plus water vapor. Dry air is a mechanical mixture of gases consisting of nitrogen, oxygen, argon, carbon dioxide, and several other constituents of decreasing significance. Humidification is the process of adding moisture to an air-vapor mixture. Water may be added in the form of liquid, which evaporates into the air-vapor mixture, or the water may be added in the form of vapor, which mechanically mixes with the air-vapor mixture.

EAC's can act as a humidifier due to there ability to add moisture to the air. Although this is incidental to the desired cooling effect, this moisture often will make the air more comfortable to breathe. Because the air is not recirculated through the building, there is no buildup of moisture. When ambient conditions are humid, the addition of more moisture can cause the air to rise above the 80% RH limit shown on the "Modified Comfort Zone for EAC's", however this often coincides with dry-bulb temperatures below 75 °F. During these humid periods, it is possible to leave the sump pump off, and run the fan alone. This ventilation cooling will still provide the "wind chill" sensation on the skin while flushing out the air which has been heated by the lights and occupants, and is sometimes preferable from a comfort standpoint.

Legionella, Mold and Corrosion Concerns

The control of microbial growth and fungi are not particularly serious issues in most dry regions of southwest. Areas for concern include refrigerated air coil condensate drip pans, wet ceilings or wet ductwork resulting from roof leaks, wet mechanical rooms, basements, carpets and poorly maintained plumbing fixtures and pipes. EAC's should be inspected and cleaned on a regular basis to prevent growth from forming on the wet areas. Evaporative media within EAC's should be allowed to dry completely once per day. Bio-contamination issues usually occurred in wet localities, and are more commonly found in the warm areas of evaporative cooling towers that are used with refrigeration cooling systems. Legionella growth is relative to the temperature of the water. It is active at a temperature range of 68° to 113 °F, with optimum growth occurring at about 98° to 105 °F. The bacteria are found to be dormant at temperatures of less than 68 °F and are retarded at temperatures above 120°F. It does not survive at temperatures above 140°F. Evaporative coolers most often operate with water temperatures less than 75 °F, or slightly above the wet bulb temperature and quite often below 68 °F where the Legionella bacteria are not active. Legionella bacteria require nutrients and optimum water quality to proliferate. While water temperature is an important factor in bacteria growth, other conditions must exist. These include the presence of nutrients, sediment and other microorganisms (particularly protozoa amoeba and/or algae) in the water. This reference also points out that components such as cooling towers and evaporative condensers that are used in refrigeration systems are potential Legionnaires' disease transmitters.

The routine application of various chemical and electronic methods for controlling bio-growth is common in the industry. For those moist localities, some EAC manufacturers recommend the use of advanced maintenance techniques and an approved biocide in the sump water. The three most common chemical groups are quaternary amines, oxidizing biocides and copper compounds. Note that these chemicals must be approved for use in EAC's. Do not use chemicals that are listed for evaporative cooling towers or condensers, since these systems are not intended for room supply air.
To most people, microbial contamination of indoor air is considered a nuisance. To sensitive individuals, children, or the elderly, it can cause asthma, trigger allergic reactions, and in extreme cases,

cause pneumonia known as legionnaire's disease. Poor air quality also causes lowered productivity and morale in the workplace.

Media pads should be allowed to dry out every 24 hours while the fans are running to help curb algae growth. Another way to minimize the chance of bio-growth is to keep the water sump and wet media out of direct sunlight. Sunlight is a growth stimulus for growing certain types of algae.

SUPPLY AIR DISTRIBUTION

Supply air is usually distributed to the rooms using sheet metal ductwork, which connects the EAC fan discharge to the room supply air diffusers. Sometimes ductwork will also route the relief air to the exhaust fans or relief dampers, but it is more common to send the relief air out through the ceiling plenum where it can remove some heat gain from the fluorescent lights and the solar roof load. Another relief air method that is common to single room EAC systems is to use operable windows. This method when sized correctly (500 fpm through screened window opening) and operated properly, will provide effective relief, but can pose security problems and can waste energy if windows are not closed at night. See the subsection on the Importance of Relief Air Dampers.

Ductwork sizing can be an issue if both heating and EAC systems use common ductwork. This is because smaller air quantities are required for forced air heating or refrigerated systems, typically 0.8 to 1.3 cfm/sf, whereas EAC's will supply 1.5 to 5.0 cfm/sf. High air speeds inside the duct (above 500 cfm) can cause objectionable windage noise if ducts have been sized for the smaller heating air flows. Conversely, low heating air discharge velocities at the supply air diffusers can keep the warm air from reaching the occupant level if the system is designed for the larger cooling airflow. Larger ducts have a higher first cost, but also have a lower operating cost because of their lower pressure drop.

One solution is to use separate duct systems for heating and cooling. This results in higher first costs, and a ceiling full of air diffusers. Another solution is to size the common heating/cooling ducts for the low speed cooling air volume, and accept some windage noise during the hottest days when the EAC operates at high speed. A slightly higher first cost solution is to use a variable speed drive on the EAC fan motor, with controls that automatically adjust the fan air volume to satisfy the rooms' cooling load.

Duct noise will be reduced by using smooth duct bends, transitions and branch take-offs. An accepted source of ductwork construction details, pressure loss factors and maximum velocity recommendations are published by the Sheet Metal and Air Conditioning Contractors' National Association, Inc. (SMACNA) in their book *HVAC Duct System Design.* Fan noise can be reduced by including two or three 90 degree duct elbows between the fan discharge and the discharge air diffuser.

Heat Loss

Heat loss is an important consideration in the design, maintenance and operation of an EAC system. Heating season losses can offset the savings associated with using EAC's. It is necessary to pay attention to these details during the design and construction of a facility since retrofits usually cost twice as much as original construction.

Duct Insulation

Duct heat loss can be a concern if uninsulated ductwork is used, and seasonal dampers are not tight. Adding exterior duct insulation to exposed rooftop ducts is a good idea since ducts become heated by the summer sun and can increase the supply air temperature 1 to 5 degrees depending on outside conditions and the exposed duct configuration. Long interior duct runs will also benefit from duct insulation applied to the duct exterior. It is also possible to apply insulation to the duct interior, but this is not recommended. This is because the insulation can collect moisture, which can help breed bacteria, and it will decrease the duct area and increase the air friction loss. Adjusting for these duct losses will require more fan motor horsepower and increase operating costs for the life of the system.

Seasonal Dampers

Minimizing wintertime losses from EAC ductwork is important for energy conservation. Seasonal slide dampers (sometimes referred to as "cookie sheet" dampers) are often used to seal off the supply duct from the EAC in the heating season and prevent warm room air from rising up and out through the cooler. See Figure 20 for typical locations and types of seasonal dampers. This damper typically consists of a single sheet of sheet metal roughly the size of the duct cross sectional area, which slides into the duct from a slot cut in the side. It is a good idea to have a place to store these removable slide dampers during the cooling season so that they do not blow off of the roof or create a safety hazard in the summer months. Another smaller strip of sheet metal is then screwed over the slot to minimize air leakage. The advantage of using a slide damper is that it blocks the air from reaching the roof mounted EAC and gravitating outside the building through a "chimney effect". Disadvantages are the potential for air leakage in both heating and cooling seasons, and that sheet metal is not an effective insulator for preventing heat loss past the damper.

There are better options for preventing heating season losses that can be used with minor design changes. One easy option is to apply insulation to the exterior side of outdoor ducts, and add an accessible, operable (course or electric) multi-blade damper in the duct downstream of the EAC fan. Insulated multi-blade dampers are available which would further minimize heat losses. Another approach uses an operable (course or electric) multi-blade damper located in the supply duct below the roofline in the accessible attic space. This configuration is more efficient at preventing heat loss because it places the heat barrier near the conditioned space.

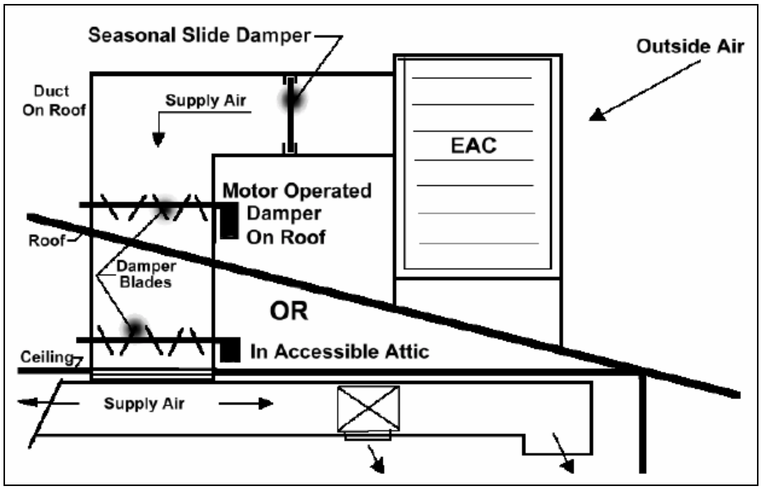


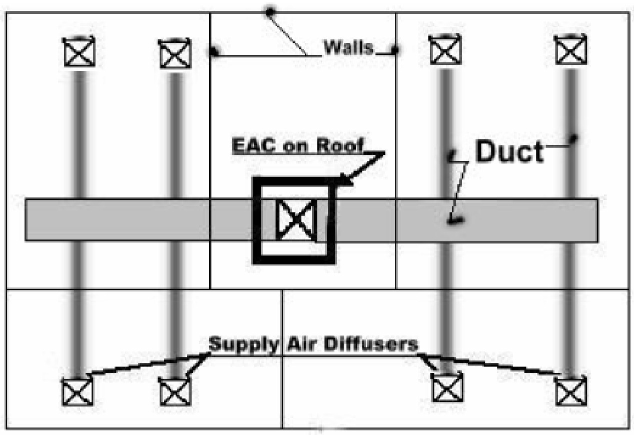
Figure 20: Seasonal Damper Typical Locations

EAC Ductwork and Air Diffusers

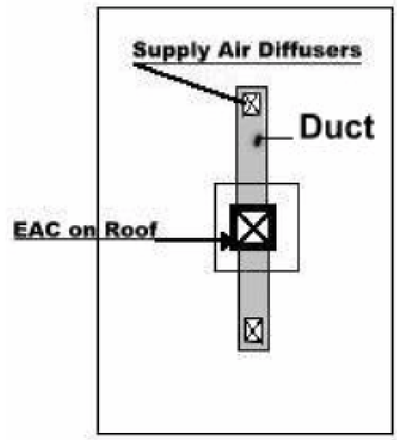
Supply air ductwork can be rigid, are usually made out of galvanized sheet steel or flexible, and made of pleated aluminum foil or a spiral wire wrapped with foil, plastic and insulation. Rigid duct usually has a lower resistance to airflow, and thus will use less energy over the life of the system. Under normal conditions, water should not be at the diffusers, due to the moisture laden air stream, diffusers used for EAC's are usually made of non-rusting aluminum.

Two methods of configuring ductwork for EAC air distribution are common in residential and commercial buildings. The short duct method is to route all the supply air into the conditioned space through one large duct and terminating with one or more air diffusers. Cool air is induced into an occupied zone by opening a nearby window as a relief air path. This method has the advantages of simplicity of design, lower first cost and user selectable cooling zones. Disadvantages include making the users aware of how to properly operate EAC controls and relief air, possible security issues when windows are left open and increased maintenance since this method may require more EAC units to cool a large building. The short duct method does work well in portable classrooms and other smaller buildings.

The long duct method usually serves a larger rigid media type EAC that ducts cool air into the different rooms served. Branch ducts route air from the main duct to several room air diffusers, which can be individually adjustable (see Static Pressure and Other Considerations section below) so that all rooms get their design airflow. Relief air is routed through the ceiling plenum, where it will remove some heat from the lights and the hot roof, to an exhaust fan or relief air dampers. The larger units will ordinarily use the longer life and more efficient rigid evaporative media, so supply air temperatures will be cooler. Advantages to the long duct system are fewer EAC units to maintain, and a more conventional air distribution system that can be designed to include other air conditioning components. Disadvantages are higher first cost, increased duct friction loss (see below), less zone control and more specialized control systems, which will require better maintenance staff training.



Long Duct Method



Short Duct Method

Both of the ducting methods mentioned above will benefit from using a straight section of ductwork at the fan discharge, which is three duct diameters in length, prior to the first elbow of branch duct takeoff. This will allow a laminar airflow pattern to develop and will reduce turbulence, pressure losses, power consumption, noise, and is easier to balance.

Static Pressure

The place many occupants will point to when referencing the cooling system is the ceiling mounted supply air diffuser. This is where the cool air comes into the room. This air can be constant volume, or variable volume. A two-speed fan motor or a variable speed drive (VSD) is commonly used to vary the air volume to meet the room cooling requirements or to maintain a preset room pressure relative to the adjacent spaces. These variable air volume systems can be used to minimize the infiltration of hot air or contaminants. Fan speed is controlled by relative space pressure sensors to automatically compensate for the opening of doors and windows.

The maximum air velocity (on high speed) past these diffusers should not exceed 750 feet per minute. Velocities above this value will result in increased windage noise and will produce high velocity air streams, which may be objectionable. EAC systems equipped with variable speed fans can vary the air flowrate so that maximum air is only used during peak cooling load periods. Another way of reducing windage noise during the design phase is to include three 90-degree duct bends between the supply fan and the first diffuser. To further minimize noise into the room, do not use a volume control damper at the diffuser, but instead use a spin-in damper at the rigid-to-flex duct connector in the ceiling plenum.

A good reason to limit duct and diffuser velocities is that more fan energy is lost to duct friction when airflow is highest. The air flowing in a duct will slow down because of friction against the duct wall. This will have the effect of reducing the amount of air supplied into the room, and requiring more fan energy.

A good EAC system design will account for these and other factors such as altitude. Since the high altitude air is less dense than air at sea level, more air needs to be delivered to get the same number of cooled air molecules into the space.

ECONOMICS

A DOE-2 computerized analysis of three different configurations of evaporative coolers and a common refrigerated air DX (direct expansion of the refrigerant) system were performed to compare energy use and comfort levels.

Life Cycle Cost Analysis

A life-cycle cost analysis was then done to compare the total owning costs for both types of systems. This analysis accounts for more than just energy use. It included costs associated with installation, energy, maintenance, salvage and the time value of money. The life of all the units was estimated at 20 years. The alternatives modeled are: DX = packaged refrigeration A/C; DX + IEC = packaged refrigeration A/C with indirect EAC added; D EC = direct rigid media EAC; and D+I EC = direct rigid media with an indirect EAC.

The following data was generated from the output files of the BLCC 5.1 Life-Cycle Cost analysis program. The input to the Life-Cycle Cost (LCC) analysis included DOE-2 building simulation, evaporative cooler analysis software. This includes the Installation Cost Estimates and the System Maintenance Cost Estimates. This analysis is Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A.

Table 10: LCC Comparison

Comparative Present-Value of Alternatives

*(Shown in Ascending Order of Initial Cost. * = Lowest LCC)*

Alternative	Initial Cost (PV)	Life Cycle Cost (PV)
DX	$408,972	$995,861
DX-IEC	$425,663	$1,095,976
DEC	S429,898	$713,780 *
D+I EC	$495,318	$746,772

The results indicate that the ECGM_DEC run which is the direct EAC is the alternative with the lowest life-cycle cost. The second lowest LCC alternative is the direct/indirect EAC combination. The

Indirect/DX EAC alternative had lower annual energy costs, but due to the higher first cost and the additional maintenance, had the highest LCC. However, in more temperate northern and high altitude areas, the Indirect/DX EAC alternative will have a reduced life-cycle cost due to integral heating with energy recovery. Combining the heat recovery savings and savings from not needing a larger heater improves the overall economics of these systems.

Comfort vs. Cost

Comparisons of comfort and cost are based on the ASHRAE comfort zone and a life-cycle cost analysis. There is another more subjective basis for this comparison that can be made as well. Perceptions of comfort can vary widely with age, gender, clothing, culture and expectations based on previous experience with comfort systems. It is easy to understand how a person who has always worked in a hot unconditioned environment will perceive even a ventilating fan as relative comfort. People who were raised in parts of the country where evaporative cooling cannot be used effectively will be accustomed to feeling comfortable in a refrigerated environment. A person from a humid environment will say that their skin is cracking in the dry southwest, and that refrigerated air conditioning makes them feel drier, whereas the evaporatively cooled environment feels more comfortable. Individuals with acute sensitivities to indoor air pollutants will equate comfort with the absence of symptoms such as nasal stuffiness or irritation, dry, itchy, or burning eyes, lethargy, headaches, and exacerbation of disorders such as asthma, eczema and sinusitis. Factors such as these are not reflected on a psychrometric chart.

A factor, which is not accurately reflected in the life-cycle cost analysis, is the life of the building. These models assume a 20 year lifetime, assuming that the equipment will be replaced after that period. Actual equipment life on the much of the major HVAC equipment is often greater than 20 years. Many facility managers have instead invested in resourceful maintenance personnel whose task is to maintain the units, and many times they do by replacing bad components. HVAC renovation funds are a budget line item to pay for deferred maintenance and equipment replacement. In many instances, renovation funds are related to availability, and managers have less control over this funding. As a result, the equipment can be kept running for much longer than originally anticipated.

Operation Expense

The relative importance of first cost is diminished when operating costs are considered. Operating costs include expenditures for energy, maintenance, taxes, permitting and periodic overhaul. Salvage costs are usually negligible. Maintenance costs between different HVAC systems may vary on paper, while in reality, the equipment maintenance employee will work the same number of hours per week regardless of the system installed. The largest variable of the owning cost for an air conditioner over its realistic lifetime is energy. If the up-front investment is made for a well designed HVAC system with modern controls, which will use a minimum amount of energy, that system will pay for itself many times over in lower utility costs.

"Evaporative cooling typically uses less than one-fourth the energy of vapor-compression (refrigerated) air-conditioning systems, while using no more water than a power plant uses to produce the electricity needed for the same amount of vapor-compression cooling. The cost of an evaporative cooling system may be higher than a vapor-compression chiller system, but payback is typically six month to five years depending on climate.

Peak summer hour electricity and water costs can be calculated to compare equivalent cooling costs applicable to the square foot (sf) of a space or building. Water is used at the EAC cooling unit and at the electric generating plant, the power plant water costs are embedded in the cost of electricity. This estimate includes the total cost of billed electricity and water. The estimated cooling utility costs for a peak-cooling hour per sf are:

Evaporative Cooler = $.00005 per hour Refrigerated
Cooler = $.00045 per hour

Maintenance Considerations:

Evaporative and refrigerated air conditioners both require periodic maintenance for proper performance, energy efficiency and to extend the life of the unit. The maintenance cost is included in the life-cycle cost comparisons. The requirements for EAC maintenance are detailed in the Operations and Maintenance Section. They include summer startup, winter shutdown and periodic inspections and adjustments.

The maintenance requirements for EAC's include many of the same inspections and adjustments as refrigerated air conditioners such as fan belt tension, damper adjustments and controls calibrations. Refrigeration air conditioners also require other maintenance tasks such as inspection of the evaporator coil drip pan and filter replacements can be performed by most HVAC maintenance staff. However, when compressor maintenance is involved, specialized training and certification is required by the EPA for compliance with Section 608 of the Clean Air Act. Significant fines are assessed if these requirements are not met. Violations are a serious issue with large civil penalties per day of violation. Criminal penalties include up to 5 years federal imprisonment for knowing or willful violations, and up to 2 years imprisonment for submission of false records or failing to report. This can make even replacing a simple seal or "O-ring" a complex task.

Refrigeration technician certification requires the maintenance personnel to pass an examination covering the following topics: Ozone Depletion; Clean Air Act and Montreal Protocol; Section 608 Regulations; Substitute Refrigerants and oils; Refrigeration; Three R's: Recover Recycle Reclaim; Recovery Techniques; Dehydration Evacuation; Safety; Shipping; Leak Detection; Leak repair requirements; Recovery Techniques; Recharging Techniques; Recovery Requirements; Refrigeration; Safety; Equipment room requirements under ASHRAE Standard 15 (oxygen deprivation sensor with all refrigerants). This last item addresses safety issues involved with using refrigerants in an enclosed space.

RELIABILITY

Weather Related Issues

The reliability of EAC's will depend on various factors such as the quality of the unit and the total installation, the type of media used, proper EAC sizing, control system, weather conditions and proper maintenance. The only uncontrollable factor is the weather. The capacity of the evaporative cooling process is dependent on the difference between the ambient dry-bulb and wet-bulb temperatures (wet-bulb depression)**,** or simply stated, the outside humidity level. The decrease in EAC cooling capacity under wet conditions is partially offset by the fact that periods of high humidity are usually accompanied by cloud cover, which will decrease the solar gain load on the building.

Comfort and reliability are improved with the use of combination units such as direct/indirect EAC and indirect/refrigerated coolers. Air conditioning units which combine both evaporative cooling and refrigeration cooling can provide more reliable and economical cooling than just a refrigerated unit, which, unless oversized will still not be designed to meet the worst case weather conditions. The costs for a combination system will be higher than using an EAC alone, but this type of system may be practical for certain applications such as administrative offices and board rooms or other areas which must maintain comfort or for process applications such as computer rooms. Some residents and commercial buildings have used combination systems and achieve operational savings and increased comfort associated with this 100% outside air system.

Combination systems use multiple cooling sections, so they provide a comfortable degree of redundancy. If one part of the cooler is down for repairs or maintenance, the remaining cooler section can still provide some cooling.

Comparison to Refrigerated Cooling

The capacity of a refrigerated air unit will be reduced with high humidity levels. EAC's did not meet all of the cooling load hours of the year. Refrigerated air units did not consistently meet setpoint temperatures. This is expected because it is not economically practical to design a unit that will satisfy the worst-case condition. Engineers should use the ASHRAE Fundamentals 2% design conditions when design systems. This means that the air conditioner is expected NOT to meet the loads for 2 % of the cooling hours. Another factor that affects a refrigeration unit's cooling capacity is altitude. Most off-the-shelf refrigerated air units are rated for use at sea level. During the hottest part of the year, the air moving past the condenser coil (the refrigeration component which rejects the room heat to the atmosphere, analogous to the coil outside of your refrigerator) may not be dense enough to remove all the heat from the building. Other factors that can decrease the performance of refrigerated air units are:

- Required outside air quantities controlled by the units inlet dampers can be improperly set.
- Open doors and windows that allow increased quantities of hotter outside air to become mixed in with the conditioned air.
- Lack of proper maintenance resulting in clogged air filters and decrease air flow.

If the airflow is impeded sufficiently, frost and ice can collect on the refrigerant coil, which will decrease cooling performance and can damage the compressor.

System Replacement Considerations

Everything mechanical will eventually wear out. A good quality EAC will be warranted for 5 years from rust and leakage on the cabinet of rigid media units, 1 year on electrical components, 5 years on the rigid media (with consistent, factory recommended maintenance), and 2 years on the motor. One manufacturer offers a lifetime rust and leakage warrantee on their heavy-duty units.[41] Most manufacturers offer options such as heavy duty construction, stainless steel construction, corrosion coatings and dielectric insulators which can extend the life of a unit to 10, 15 or 20 years depending on the degree of regular maintenance. EAC components such as fan belts, float valves, water tubing, fittings, fan motors, pulleys and sump pumps should be kept stocked in the mechanical room to minimize downtime during a component failure. EAC maintenance and parts replacement do not require any certifications or specialty tools and can be done by most maintenance personnel with a minimum of training. As with most mechanical systems, good maintenance habits will reduce the incidence of component failure, increase the life of the unit and provide greater comfort and reliability.

Corrosion Control

There are four major forms of corrosive attack to metal parts used in evaporative cooling equipment. These are:

- Pitting is the removal of metal at the surface in small, localized sites. These sites start out as inconspicuous flecks of rust or oxide, and eventually eat their way through gutters and pans in saucer like depressions. Pitting is usually caused by the presence of copper, sodium chloride, sulphur and other strong contaminants in the water. The chemicals in a droplet of water are the most concentrated as the droplet dries. Avoid wetting and drying cycles, splashing and dripping where water can become concentrated.
- Crevice corrosion occurs in lap joints exposed to air and moisture. For aluminum and galvanized steel, oxygen must be present for corrosion to occur. For stainless steel, oxygen will help form a protective layer on its surface. To avoid this form of corrosion, joints should be well caulked with a caulking compatible with the metal. Read the label carefully. Notice that some caulks should not be used with certain metals!
- Galvanic corrosion occurs when dissimilar metals are used in the same system. Even when they are not touching, the corrosion can occur through the water. Avoid mixing aluminum, stainless steel and galvanized steel in the same system. Pay special attention to pumps, screws, and valves. Use as much plastic as possible. When metals must be mixed in a system, the odd metal should have a heavy protective coating, and transition joints should be used.
- Poultice corrosion is due to contact with nonmetals. It may cause some serious problems. Materials such as cork, wood, cloth or paper provide moisture and air, which contribute to corrosion. If they have been treated with certain fire retardants or biocides (such as copper arsenite) the attack could be very severe. To prevent attack, coat the metal surface, or keep the porous material from becoming wet.

Availability of EAC Parts

The EAC parts that will require periodic replacement include the evaporative media, fan belt, sump pump, float valve, fan motor, pulleys, water tubing and various fittings. All of these parts are not expensive and are usually stocked at a major hardware store. The exception may be the 12-inch thick rigid media used in high-efficiency EAC's. While this media can be found at the large hardware stores, it is usually cut for a specific model of cooler. Rigid media replacement is usually supplied by the local manufacturers representative, or can be ordered directly from a manufacturer. Availability of rigid media is stocked regionally and can usually be delivered in a day to most cities. Some odd sized media is cut at the factory, and can take 1 to 4 weeks for delivery. This is not a big problem since unlike aspen pad cooler media which requires annual replacement, rigid media is washable and if well cared for can last ten years or more.

Evaporative Air Cooler's (EAC's) are very forgiving (unlike the refrigerated vapor compression cycle), and can provide cooling even without proper maintenance, however comfort will suffer. Most of the problems associated with inadequate cooling from EAC's can be traced to undersized units, inadequate relief air and poor maintenance. When design EAC's it should be remembered that they require specific maintenance at very regular intervals.