Energy Conservation and Management Division
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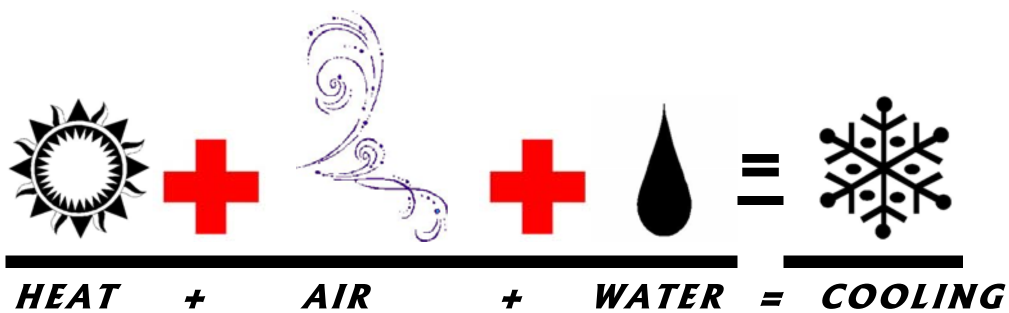

EVAPORATIVE COOLING DESIGN GUIDELINES MANUAL

FOR

NEW MEXICO SCHOOLS
AND COMMERCIAL BUILDINGS

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Lesson :

HEAT + AIR + WATER = COOLING

PREFACE

This ***Evaporative Cooling Design Guidelines Manual for New Mexico Schools and Commercial Buildings*** was prepared for the New Mexico State Energy Minerals and Natural Resources Department, Energy Conservation and Management Division (EMNRD-ECMD). EMNRD's goal is to conserve energy, design schools that are comfortable, and also save money for educational benefits.

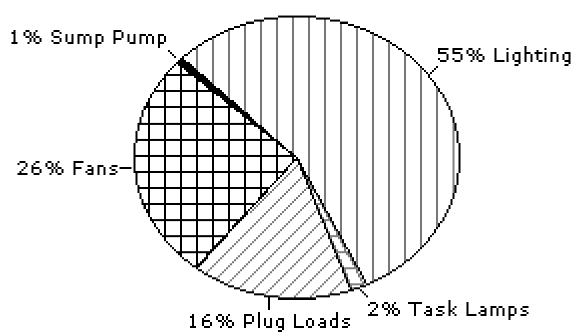
The purpose of this manual is to inform and educate New Mexico's building owners and school administrators, their staff, and facilities maintenance personnel, and their facility design teams about the proper application, control, maintenance, and comfort expectations of evaporative cooling in New Mexico schools and commercial buildings. This manual is intended to be used as a tool for the design of successful and efficient evaporative cooling systems and will allow engineers to specify and design evaporative cooling systems with confidence. This manual is also intended as an overview of evaporative cooling principles and equipment for the non-technical reader, with technical terms shown in bold print and defined in the glossary. Review of this manual may suggest design features that may be used to improve the economy of operation, comfort, reliability appearance, serviceability, and service life of evaporative cooling systems.

EXECUTIVE SUMMARY

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 many times over 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 pie charts in Figure 1 reflect typical percentages used by all the electrical equipment in a conventional New Mexico school. This comparison is for a direct evaporative cooler using rigid media and a self-contained rooftop refrigeration unit with an EER = 10. The electricity used for air conditioning is the sum of the space cooling (sump pump for and EAC; compressor and condenser for refrigerated A/C) and the ventilation fans. The cooling totals 27% of the total utility use for evaporative cooling and 33% of the total utility use for refrigerated cooling.

DIRECT EVAPORATIVE COOLING **REFRIGERATED AIR CONDITIONING**



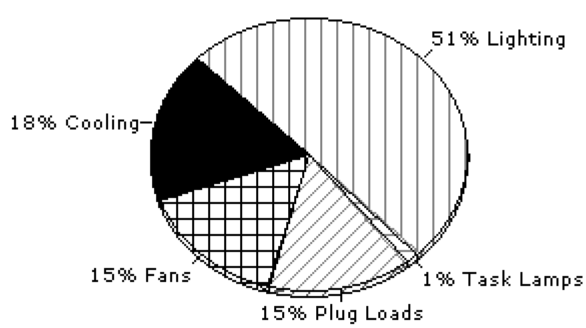


Figure 1: Comparative Electricity Annual Use for a Direct EAC and Refrigerated Air

The benefits of using evaporative cooling in New Mexico 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 Design Guidelines Manual for Evaporative Cooling addresses the relative advantages of evaporative cooling compared to other common cooling methods, and guides the reader through design issues, economy and efficiency factors, case histories, and operation and maintenance information. An accompanying O & M Section and Field Guide are included to assist maintenance personnel in maintaining evaporative efficiency, comfort and economy.

INTRODUCTION

How Evaporative Cooling Works

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**, or 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, yet most efficient, law of nature has been used by humans for comfort cooling systems since the days of ancient Egypt and the Persian Empire. Famous examples of evaporative cooling in the past are from Egyptian architect Hassan Fathy's work where he used 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. Indigenous uses of this strategy appear in Persian gardens, where water was sprayed from fountains to evaporatively cool the air.

Types of Cooling Systems

There are two basic types of evaporative air coolers (EAC's). New Mexicans are most familiar with **direct EAC's** that are also commonly used for residential cooling. Developments in the evaporative cooling industry have reliably increased the efficiency or **effectiveness** of the cooling media. <u>All direct EAC's use 100% outside air</u>. 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. IEAC's use electricity for the supply fan motor, a 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, <u>refrigeration air conditioners typically re-cool more than 80% of the room air.</u> 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.

Utility Costs

Schools typically operate with limited budgets; but are expected to provide a quality education in a comfortable learning environment, regardless of the budget. School operating costs have been categorized into three selected categories: total utility costs, educational materials, and athletics. Of these, utility costs are the most variable largely due to the weather conditions. However, utility costs are usually one of the most controllable.

Many schools and commercial buildings have successfully used energy conserving options such as evaporative air conditioning, changing to more efficient lighting or using Energy Saving Performance Contracts (ESPC's). ESPC companies provide a total approach to energy conservation implementation using existing utility budgets. Twenty-nine New Mexico school districts have lowered their electricity consumption by using ESPC's.[1] However, at least one school reported that their utility bills doubled when they shifted from evaporative cooling to refrigerated cooling.[2] The New Mexico Energy Minerals and Natural Resources Department, Energy Conservation and Management Division (EMNRD-ECMD) has summarized these costs per student for three school district sizes. The utility cost per student is compared for small, medium and large school districts.[3] These graphs are presented in Appendix B. It is important to note that utility costs are the highest of the three expenditures, and that utility cost per student is highest for the smallest districts. Also of note, is that a less energy efficient district paid three times more dollars per student for utilities than for educational materials, and 1.7 times more than for athletic programs. The same source reports that the 1999 total public school electricity cost is three times more than the natural and propane gas costs. When a school district can save money on energy, they can better use these saved dollars on educational materials, and are less of a tax burden on the community.

A study for a southwest utility company looked at the life-cycle cost of evaporative cooling vs. refrigerated air conditioning, and reported that over a thirty year period the total present cost of "installing and operating a residential evaporative cooler would cost between $21,000 and $25,500. The total costs of installing [owning] a refrigeration unit comparably sized for the same cooling requirements would be between $33,000 and $34,500. … The results of this analysis do not show that the promotion of refrigerated air conditioning over evaporative cooling in this climate would be to the customer's benefit."[4]

A Natural Resource

New Mexico has 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 school and commercial buildings. Moreover, since many schools are not in session during the wettest part of the year, they are particularly well suited to using evaporative cooling. The comparatively low ambient humidity levels which occur during normal classroom hours 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 New Mexico 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 New Mexico 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 New Mexico

- 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 school 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 in New Mexico, 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"[6].

- 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.

PART I: EVAPORATIVE COOLING DESIGN

SYSTEM TYPES

Background

There are two basic types of evaporative air coolers (EAC's) used to cool New Mexico schools and commercial buildings, direct and indirect. They can be used separately or in combination.

Because EAC performance is dependant on the weather, one cannot state an equipment efficiency factor or Energy Efficiency Ratio (EER) as with refrigerated cooling. Refrigerated cooling performance also depends on weather but there are standard test conditions. 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*, or 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, your body, 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 <u>direct EAC</u> 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 <u>indirect EAC</u> 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 is assumed that the outside air has fewer contaminants than the indoor air (see the section on Air Quality). This may not be 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. Diagrams of these systems are shown in the pages below.

This manual addresses fixed and stationary applications for cooling school 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.

The United States Department of Energy has published a document *Energy Design Guidelines for High Performance Schools for Hot and Dry Climates* which includes recommendations for energy efficient design of most all energy and water using systems used in schools. A free Internet download is available at the website noted in footnote 6. Under their Cooling Systems section they state, "Consider cooling systems appropriate for hot and dry climates that match the building loads and are not over-designed. … For hot and dry climates, consider the use of direct or indirect evaporative cooling equipment, which can reduce the need for mechanical cooling. The requirements for proper maintenance of these systems should also be evaluated."[7]

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 90% of New Mexico homes and school systems like the Albuquerque Public Schools (APS). One APS engineer stated, "the average life of a aspen pad cooler [unit] is 10 to 15 years, and with good seasonal maintenance, 15 to 25 years is not too hard to do".[8] Refer to Figures 3 and 4 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 manufacturers stated 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 in New Mexico is known as rigid media, or by trade names like Munter's media or Cel-Dek. 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, this media is rigid, so it does not sag and reduce cooling performance. It is available in various thicknesses between 2 and 24 inches, but 12-inch thick media is common for school and commercial building air handling units. As shown in the section on evaporative media, the manufacturers ratings of effectiveness of rigid media is 75% to 95%, depending on the thickness and **air velocity** through the media. Rigid media is washable, and with good regular maintenance will last 7 to 10 years.

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

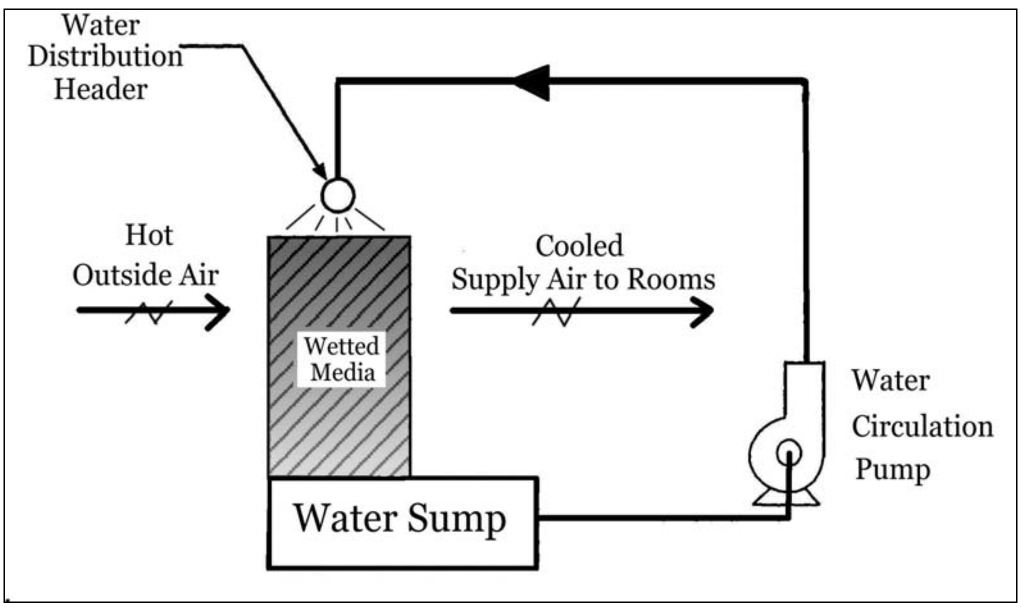


Figure 3: Direct EAC Schematic

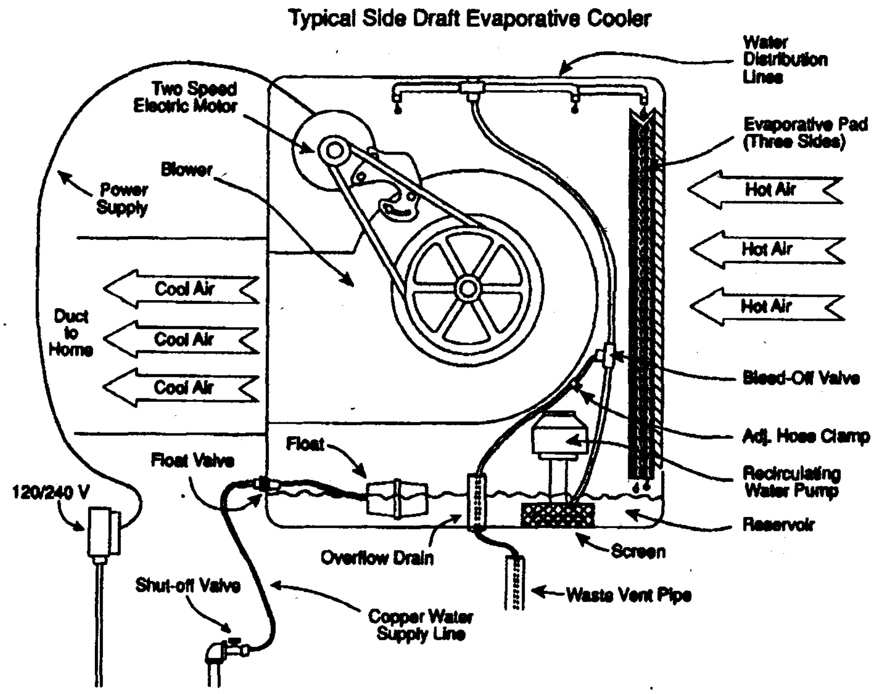


Figure 4: Typical Wetted Aspen Pad Cooler

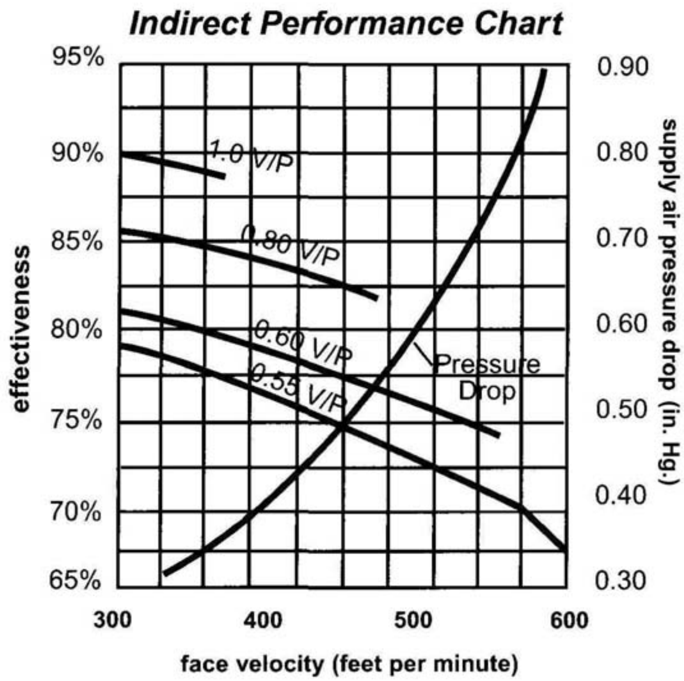
Indirect Evaporative Cooling

Indirect EAC's (IEAC's) have been in use for over 20 years, but 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 manufacturers 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 5: 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".[9] 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; so <u>indirect evaporative coolers CAN</u>

recirculate 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 5: IEAC Performance

Refer to Figure 6 for 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. This type of air-to-air heat exchanger (some which can also recover heating season energy from the exhausted room air) is used to transfer heat from the primary space supply air stream to the evaporatively cooled secondary air stream. The diagram in Figure 7 shows a section through an IEAC combined with a direct EAC. The maintenance requirements for this type of cooler are similar to that required for a direct evaporative cooler, (see Maintenance Section).

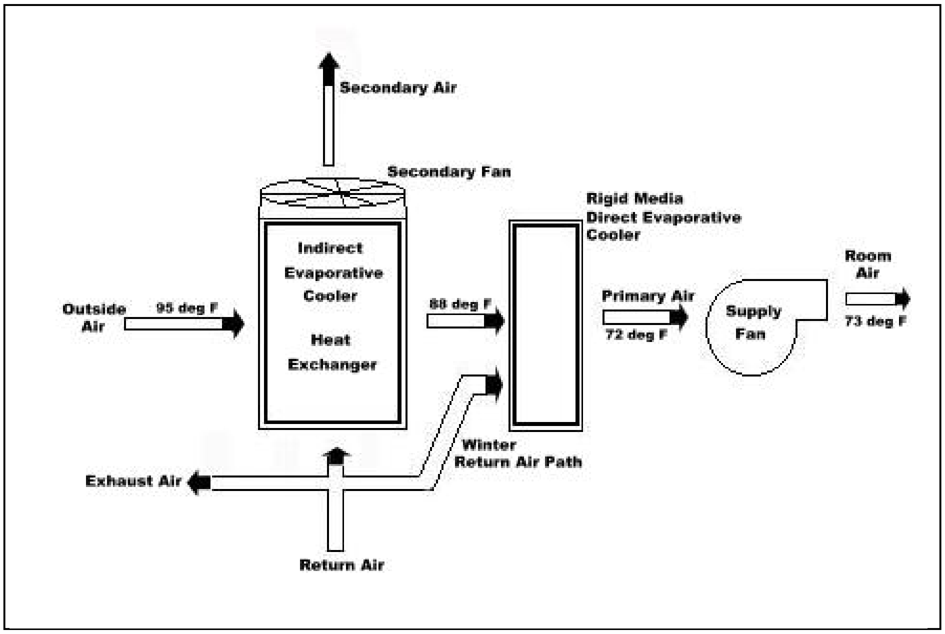


Figure 6: Indirect Cooler Schematic

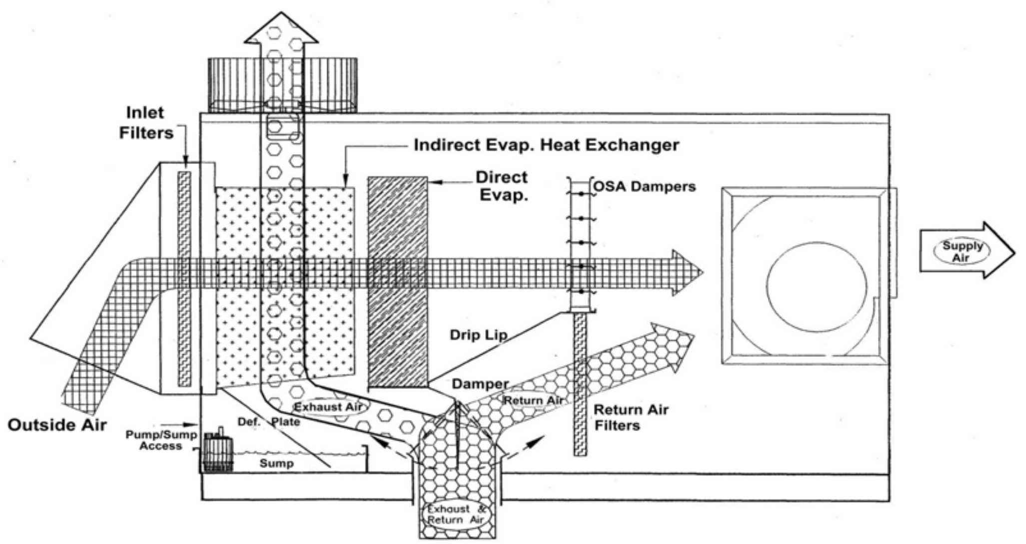


Figure 7: Air-to-Air Heat Exchanger Indirect + Direct EAC
Adapted from Spec-Air, Inc.

The following Table 1 from manufacturers literature can be used to estimate leaving air temperature from direct, indirect and indirect/direct EAC's based on local conditions.[10]

Table 1: Leaving Air Temperature Chart

LEAVING AIR TEMPERATURE CHART

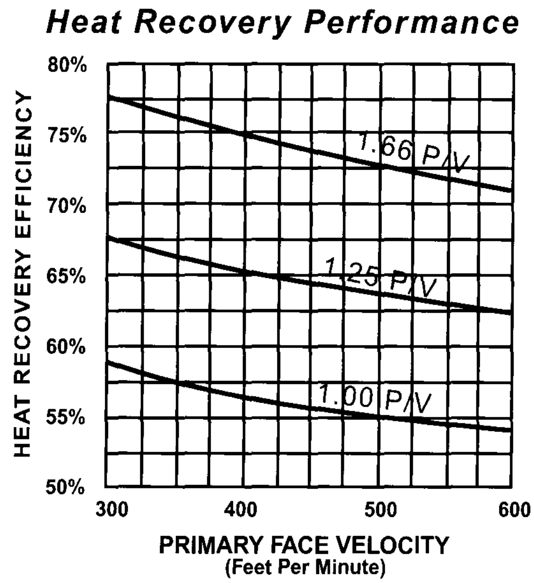
EAT / DB =	95			100			105			110		
	D	I	I / D	D	I	I / D	D	I	I / D	D	I	I / D
EAT / WB	LEAVING AIR TEMPERATURE											
V	DB	DB / WB	DB / WB	DB	DB / WB	DB / WB	DB	DB / WB	DB / WB	DB	DB / WB	DB / WB
60	63.5	69/50	52/50	64.0	70/48	50/48	64.5	71/46	49/46	65.0	73/44	47/44
62	65.3	70/52	54/52	65.8	72/51	58/51	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

Adapted from: Spec-Air product literature.

As noted earlier, 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 8 shows one manufacturer's published performance for the heat recovery efficiency. The efficiency varies with air flowrate and air velocity.



$$P / V = \frac{Primary.CFM}{Vaporizer/Exhaust.CFM}$$

Tout = Tin + Eff (Texh - Tin)/PV

Figure 8: Heat Recovery Performance

Combination Systems

Direct and indirect evaporative air cooling components are commonly packaged together in the same cooling unit by the manufacturer. 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 schedules and requirements. The direct EAC section will usually 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 recirculated past both the IEAC and the refrigerated coil, or the IEAC can be located to precool only the required outside air as shown schematically in Figure 9. There are times during the spring and fall and summer mornings when the IEAC will be able to meet the cooling load without energizing the refrigeration compressor.

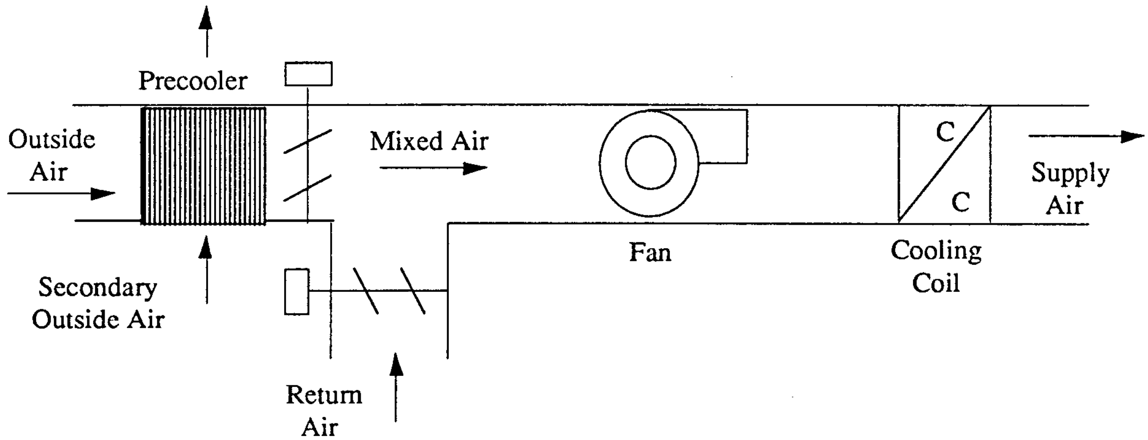


Figure 9: Combination Evaporative and Refrigerated Cooling System Schematic

Cooling Tower "Free Cooling"

Another type of indirect evaporative cooling system, sometimes called a waterside economizer and is often used in conjunction with a chiller system that would already use evaporative cooling tower(s). When the humidity level is low (also known as a low wet-bulb temperature) the evaporative cooling tower system works so well that the chillers (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 10 and 11). 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.

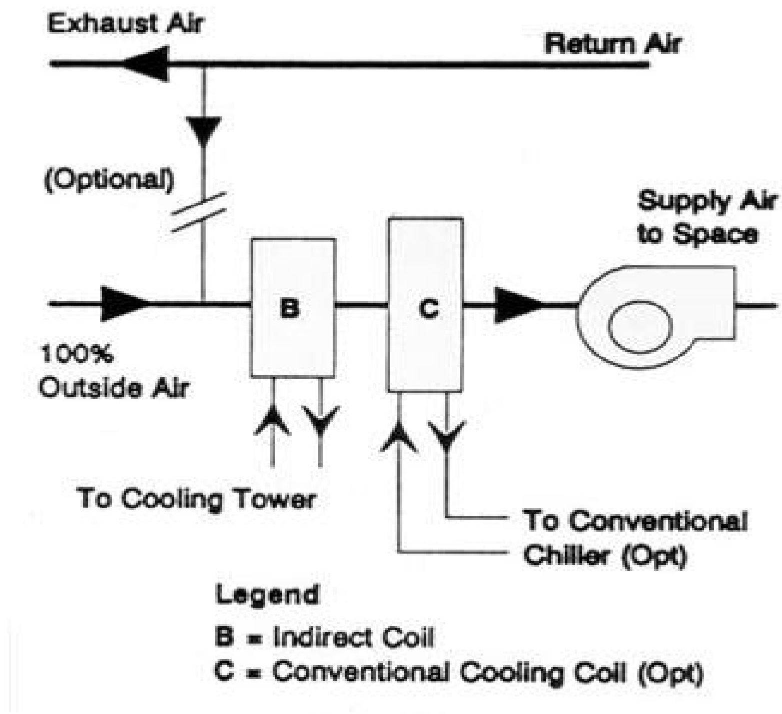


Figure 10: Water Coil Indirect EAC Schematic

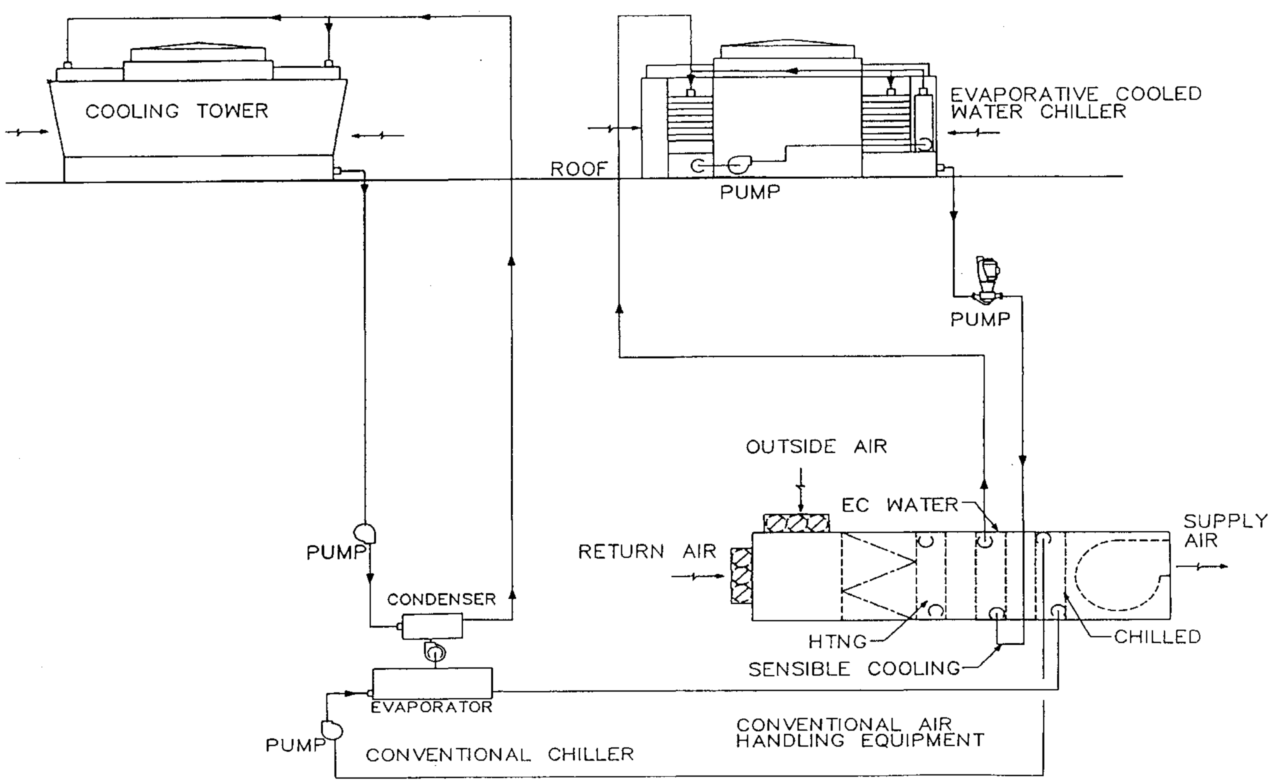


Figure 11: "Free Cooling" Evaporative and Refrigerated Combination System

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 decreases the load on the chiller and saves energy. As efficient as these systems can be, they do 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, an engineer should 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.

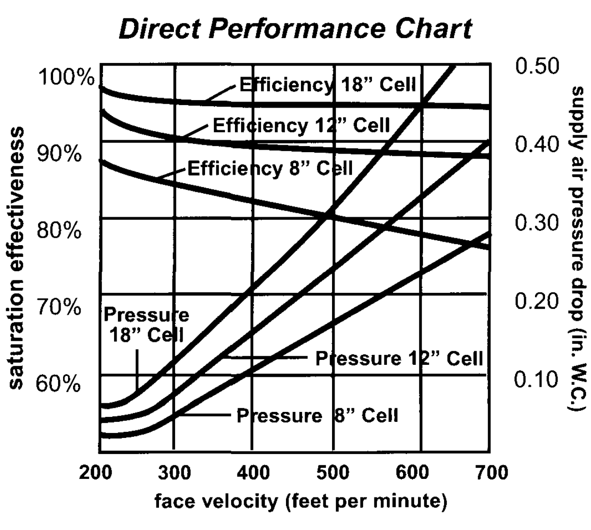
Refrigerant Migration
Still another type of indirect evaporative cooling only works on certain types of large refrigerated air systems. This "refrigerant-side" economizer uses a centrifugal chiller's refrigerant vapor migration properties to do "free cooling". "If the chiller's condenser can be kept 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. "[11]. 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 and brands of evaporative pads and rigid media. Standard EAC pads are usually ¾" to 1" thick and made of aspen shavings. Aspen has been found to be a very absorbent and unreactive material. As with all cooler pads it 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 usually is made from green cut paper, and another that uses 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. Manufacturers recommend 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 (Munters 5090, see Appendix B) which fits into existing frames, is treated to resist degradation, and has greater area and improved water flow characteristics.

Rigid media can be made of different materials as well. The standard cellulose media (resembling a cardboard box kraft paper) can be purchased from different manufacturers such as Munters, Kuul, and Glacier-Cor, 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. Some of this information is included in Appendix B, Manufacturers Information.

Rigid media (also known as Cel-dek or rigid extended 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[12]. 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 12: 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.



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

Figure 12: Direct EAC Effectiveness for Rigid Media[13]

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

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 said to be 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 on Figure 13.

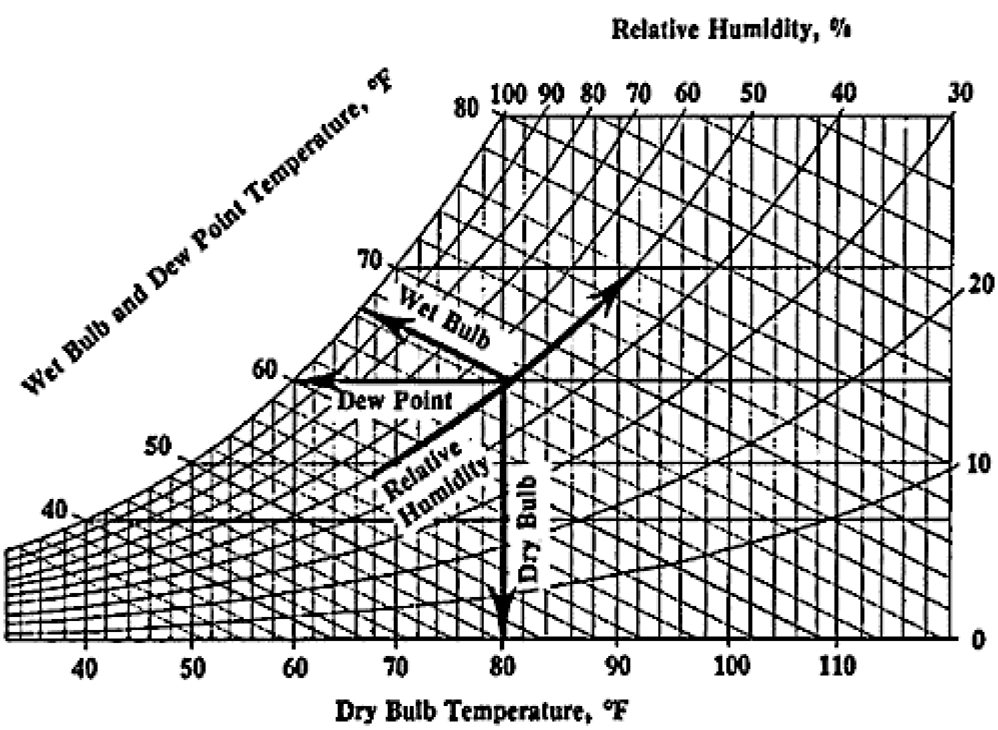


Figure 13: Psychrometric Chart

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 13: 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 14 shows how the sensible heat is transferred to latent energy in the moist air.

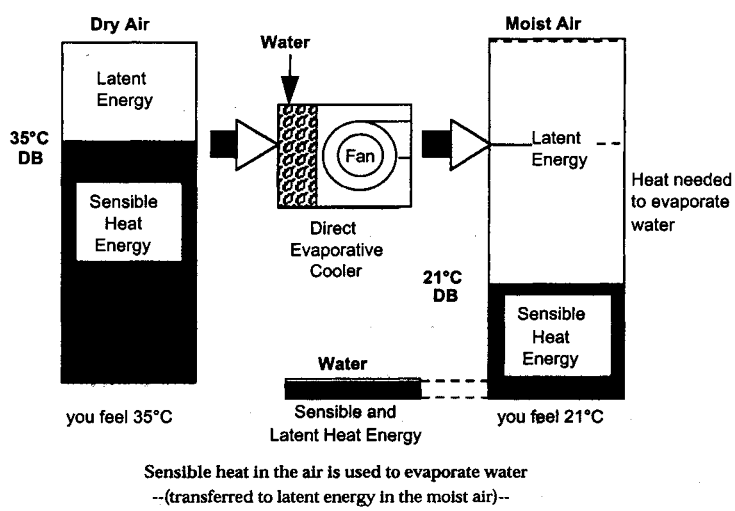


Figure 14: Simplified Evaporative Air-Conditioning Process[14]

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.

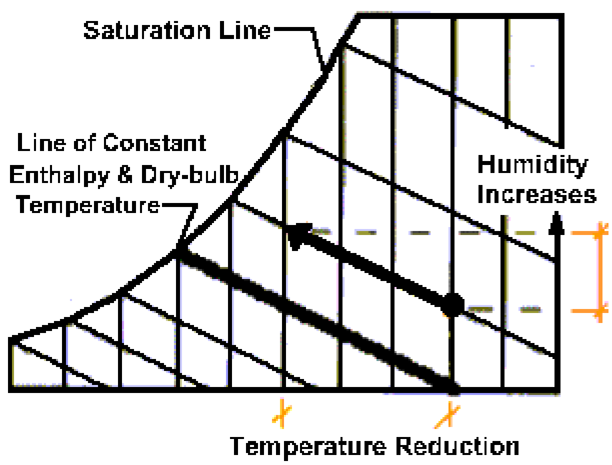


Figure 14: Adiabatic Cooling Process

The direct evaporative cooling process is shown on a "skeleton" psychrometric chart in Figure 14. 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.

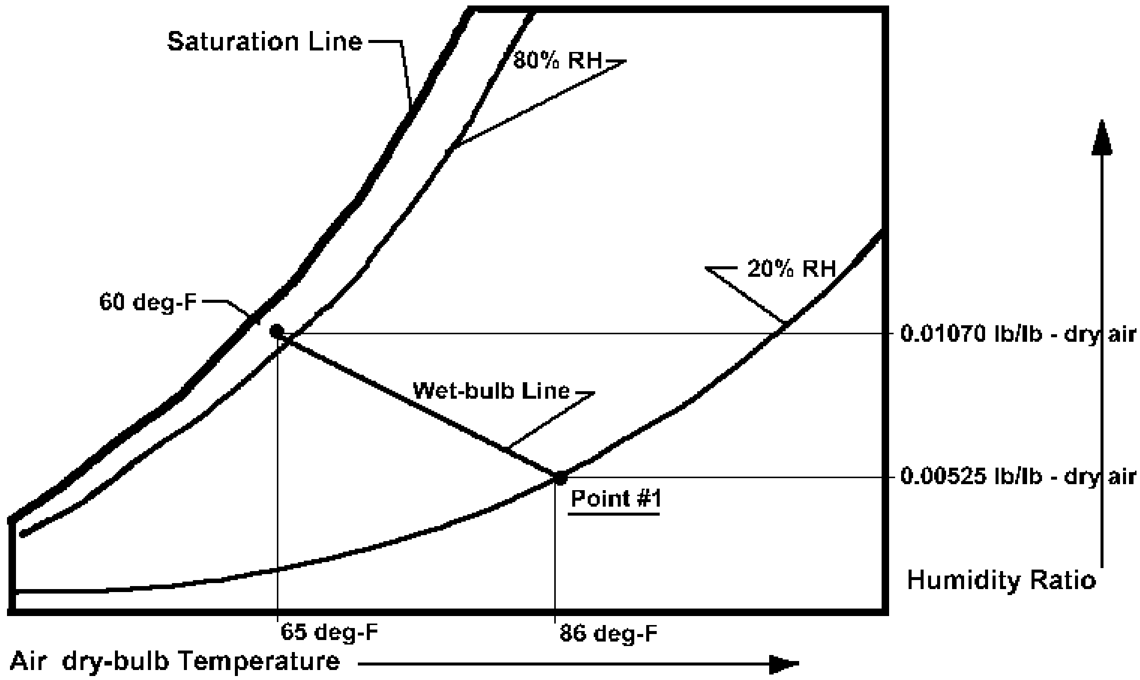


Figure 15: EAC Cooling

Figure 15 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.

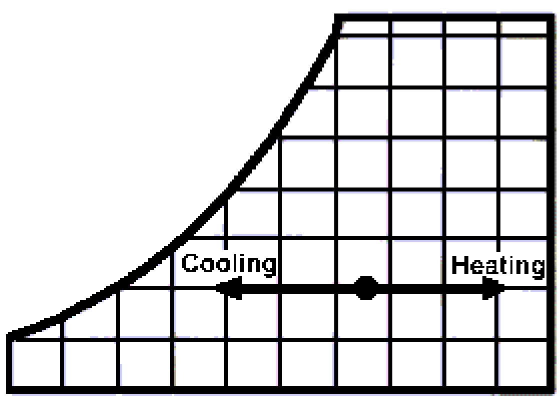
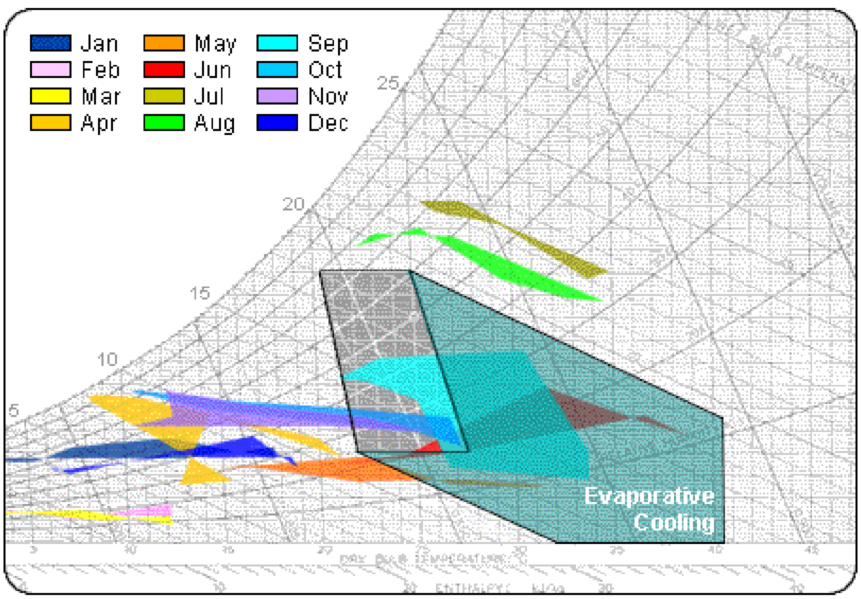


Figure 16: Sensible Cooling Process

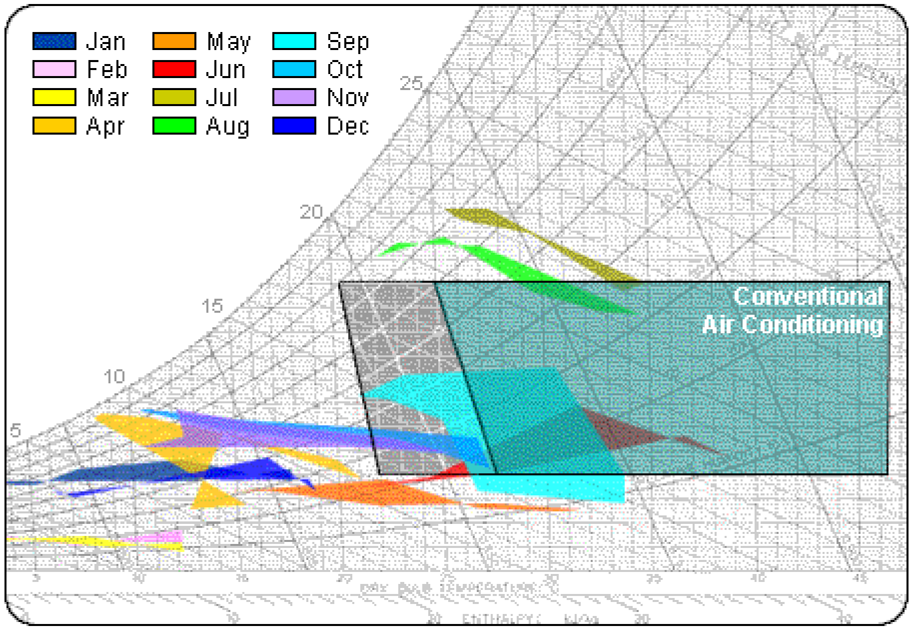
Similarly, the sensible heating and cooling processes are shown in Figure 16. This horizontal line starting to the right and moving horizontally to the left (decreasing dry-bulb temperature) represents the **sensible cooling** process. The sensible heating process is the horizontal line to the right (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.

The following Figures 17 and 18 are shown for illustration purposes. View the source for a complete explanation and other examples. These charts combine the psychrometric **comfort zone (see the section on Air Quality about the ASHRAE Comfort Zone)** with 12 monthly plots, which represent only the ambient dry-bulb temperatures and corresponding relative humidity. The shaded area to the right of the comfort "box" represents areas in which comfort is possible depending on other conditions such as solar shading (trees), wind and ambient absolute humidity. Note that the months which are above the comfort zone (in this example), are school summer session months. Also note that in the example for conventional air conditioning, comfort may also be compromised during periods of high humidity. This is because sensible cooling capacity is decreased due to the high latent or moisture load in the air.



Source: http://capla.arizona.edu/architecture/academic/graduate/peyush/anal/anal2.html

Figure 17: Typical Evaporative Cooling Comfort Zone and Monthly Hours



Source: http://capla.arizona.edu/architecture/academic/graduate/peyush/anal/anal2.html

Figure 18: Typical Refrigerated Cooling Comfort Zone and Monthly Hours

Environmental Considerations

This section compares the environmental impact of EAC's to refrigerated cooling. EAC's use water as the coolant working fluid, while refrigerated A/C's (also known as vapor compression cycle) use different types of freon® type of coolant 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 earth's ozone layer. "For example, 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."[15]

Federal regulations now require that maintenance personnel who work on refrigerant systems become 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:

Water use by EAC's is an important environmental consideration in the hot and dry climate of the southwest. To gain some perspective on water use, consider schools use water for many uses such as restrooms, showers, janitorial, cafeteria, site irrigation and cooling. The New Mexico State Engineer Office estimates that schools use 15 to 25 gallons per person per day, depending on their facilities.[16] In addition to this site water use, the process of generating electricity uses water for many functions, the largest being the rejection of heat by evaporative cooling towers. Therefore, when electricity is used to pump natural gas or water to a site, water consumption is always implicit, and the cost for that water is included in the utility bill.

The 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, but water is consumed by both cooling processes.

Water use estimates vary from different sources. Factors that will affect the water use are climate, media effectiveness, EAC media air velocity, water distribution system and bleed rate. A water use analysis was performed by the author for a typical school system with 17,000 cfm direct EAC, a direct/indirect EAC, and an equivalent DX refrigeration/indirect EAC combination. The results 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. Some users of the inexpensive aspen media will eliminate the continuous bleed, and instead will replace the pads once or twice a season.

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

Table 2: EAC Water Use Model

How does this compare to the water used to make the electricity to operate an equivalent refrigerated air cooler? For comparison purposes, PNM's San Juan Electricity Generating Station annual average water use for the evaporative cooling towers and other uses is 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. This quantity does not include the water needed to mine, process and deliver the coal used to generate the electricity. 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 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

NOTES

1) Evaporative Cooler Supply Air Temperature
DB-out = DB-in - (Evap. Eff. X (DB-in - WB-in))

2) Weather Data for July in Albuquerque, NM. Source:
New Mexico Climate Manual, NMERDI 2-72-4523

3) Based on the evaporation formula: GPH = (1.2 X CFM X (EDBT - LDBT))/10,000

4) Based on a continuous bleed rate of 12 oz./min. small unit and 25 oz./min. large unit.

5) Based on the equation Q = CFM X AF X (TDBin - TDBout)

Evaporative cooling 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[17], 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. As an example of using versus wasting water is that one flush of a toilet uses 3 gallons. 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 cottonwood trees will evapotransporate 300 gallons of water per day.[18]

System Problems and Solutions

Most 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 (as discussed in the section on Performance). 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. Some of the common issues related to operation and maintenance of EAC's are summarized in Table M1: System Problems and Solutions in Part II – Maintenance and Operations, along with proposed solutions. That section also lists maintenance responsibilities and recommended frequency of maintenance tasks.

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."[19]

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 "in New Mexico, 90% of residential and around 40% of commercial installations use evaporative coolers.

Schools

New schools in New Mexico are required to evaluate evaporative cooling during the design stage, per the requirements of the "Energy Efficiency Standards, Construction and Remodeling Procedure for Public School Buildings" dated September 1995. This requirement does allow IEAC's and refrigerated cooling systems to be used in hybrid systems with EAC's; or for small additions to an adjoining existing space which is already refrigerant cooled; and to cool a space which experiences a high cooling load for very few hours, e.g. an auditorium. This applies if the construction cost of the refrigerant system is much lower than for evaporative cooling, or evaporative cooling would not have a ten-year payback. Justification must be documented with calculations.[20] Schools located in the hot and dry areas of the state will benefit from the lower utility bills and the increased comfort from using 100% outside air. In addition, many schools are not in-session during the hottest and wettest months of the year so evaporative cooling is a good fit for New Mexico schools. Conversely, expanding the school year into August or June increases energy consumption and/or the classroom comfort level.

Schools are a high-density occupancy. In order to comply with the nationally accepted ASHRAE ventilation air Standard 62, schools must supply around 15 cfm/person of outside air to maintain acceptable indoor air quality (IAQ) during all occupied hours. This can be 20% to 40% of a refrigerated air system's total airflow. This outdoor air must be cooled from the high 90's °F to the low 50's °F, and then after going through the building once, must be exhausted. This ventilation air requirement can be very costly in terms of refrigeration energy use. Certain areas in schools that require high amounts of ventilation air such as kitchens, cafeterias, gyms, locker rooms and auditoriums greatly benefit from using EAC's. These areas have high cooling and heating loads and high

CFM requirements and are well suited to evaporative cooling which uses 100% OSA, or a combination DX + EAC unit.

Some schools use conventional aspen pad coolers units on a per-room basis for summer cooling. They offer a low first cost, easy installation, simple controls and economical operation. Disadvantages to using these smaller EAC's are the additional maintenance requirements because of the greater number of units, lower evaporative cooling effectiveness, more roof penetrations and shorter evaporative media life.

Rigid media units with and without indirect evaporative cooling sections have been used to expand comfort conditions. These units can serve small or large areas; have longer media life and less maintenance hours because of fewer units required than with smaller capacity aspen pad coolers. Evaporative effectiveness is greater due to the larger surface area of rigid media, as discussed previously in the section on Evaporative Media Types.

Other variations are used to combine refrigerated and evaporative cooling systems. One common approach uses IEAC's (which do not add moisture the air) as a precooler to the refrigerated cooling coil. This allows recirculation of the conditioned air past the evaporative cooler section. Another approach is to evaporatively help the refrigeration systems air-cooled condenser operate more efficiently, but this may not reduce compressor run hours. This evaporative pre-cooling of a refrigerated system's air-cooled condenser will save energy but adds to maintenance costs. However, evaporative pre-cooling may reduce compressor maintenance due to lower operating pressures and temperatures.

Another current approach combines direct and indirect evaporative cooling sections along with exhaust air heat recovery plus a refrigerated air coil in one unit. One school that has successfully used this hybrid type of evaporative/refrigerated air conditioning system is the Rio Rancho High School in Rio Rancho, NM. Electronic microprocessor controls are used to monitor 35 rooftop units, their room temperatures and to report alarms. The building maintenance personnel emphasize proactive maintenance, and have never had to replace the rigid media in seven years of operation. New buildings often have indoor air quality problems, but he has never had an IAQ complaint. A summary of this system’s equipment and comfort comments by the building engineer is included in Appendix A.

These hybrid cooling systems use controllers that integrate the EAC control points with the refrigerated air controls. This allows the controller to automatically maintain space comfort under most weather conditions. Microprocessor controls can monitor the outside air, return air and supply air temperatures and humidity levels to automatically control the direct and indirect EAC's, refrigeration coil, and air dampers to use any combination that is most efficient. They also close all outside air dampers during unoccupied periods. Naturally, these full-featured air handlers cost more and require better trained maintenance technicians than common EAC units. However, the life-cycle cost of these units can be less than conventional units. Up front investments in energy efficiency will save money over the life of the building. It has been estimated that the operating costs of air conditioning will be approximately 35 times as much as the first cost over the life of a building.

Commercial

Evaporative cooling is a well recognized method of cooling 40% of New Mexico offices, shops, warehouses, laundries, kitchens and institutional facilities. 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 of New Mexico's cities. Once cooling equipment is installed in a school, the energy consumption limits are somewhat fixed. First cost and operating cost money 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 for the most electricity a building will demand for it's 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 or six months (depending on your service agreement). These demand charges can be a significant portion of the monthly electricity cost. That 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

EAC energy use is like turning on a light bulb. 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 may help 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, we must describe the level of humidity relative to the type of sponge we are referring. Is it a 50° F sponge or an 80° F sponge? An 80°F sponge will hold more water than a 50°F sponge at 50% humidity.

Refrigerated Air Conditioning

A refrigerated air conditioner will be 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. For both EER and SEER, the higher the 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 New Mexico. 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 New Mexico roofs) will increase the energy use over that predicted by the EER rating. The high New Mexico elevation above sea level will also decrease the performance of a refrigeration condenser. EER ratings are calculated for sea-level, but at 5,200 ft. elevation (Albuquerque) 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 around 11% 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. See the System Sizing section for other sizing limitations that will affect the refrigerated A/C performance.

Another factor to consider when estimating the energy consumption of a refrigerated air system is although the room air supply fan may stay on during occupied periods (like an EAC), the refrigeration compressors are allowed to cycle off under part-load conditions. Sometimes these units' 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 feature to slow down the chiller to reduce the cooling capacity during part-load conditions.

Mixing EAC and Refrigerated Air:

Direct evaporative cooling 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. 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 caught by the wet media, and to prevent the buildup of solids that may be in the water supply. As discussed in the Environmental Considerations section, 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.

There are three options for water bleed systems. They are presented in order of increasing water use:

1. No water bleed off.
2. Intermittent water bleed off.
3. Continuous 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 as described in the section on EAC media.

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. The manufacturer states that use of a "Clean Machine" sump dump pump with integral controller will "use almost 70% less water than bleed-off systems"[21]. Another more expensive method of flushing the sump water intermittently uses water conductivity sensors to initiate the flush when a predetermined value is sensed.

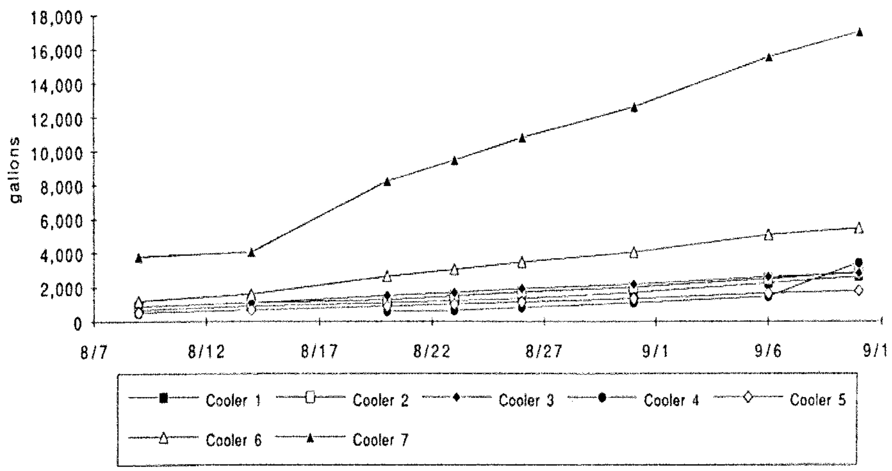
The continuous bleed method uses more water but is the simplest method of solids control. An accepted bleed rate for an aspen pad EAC is known as the "beer can" method because it uses 12 oz. per minute. This water can be routed to a plumbing vent on the roof, but is usually routed to the area landscaping for water conservation purposes.

Clean sump water is important for maintaining consistent cooling, good IAQ, and extending the service life of the evaporative media. This is discussed in more detail in the Maintenance Section. The following test information on water use was compiled in New Mexico, and compares EAC water use for seven different systems.

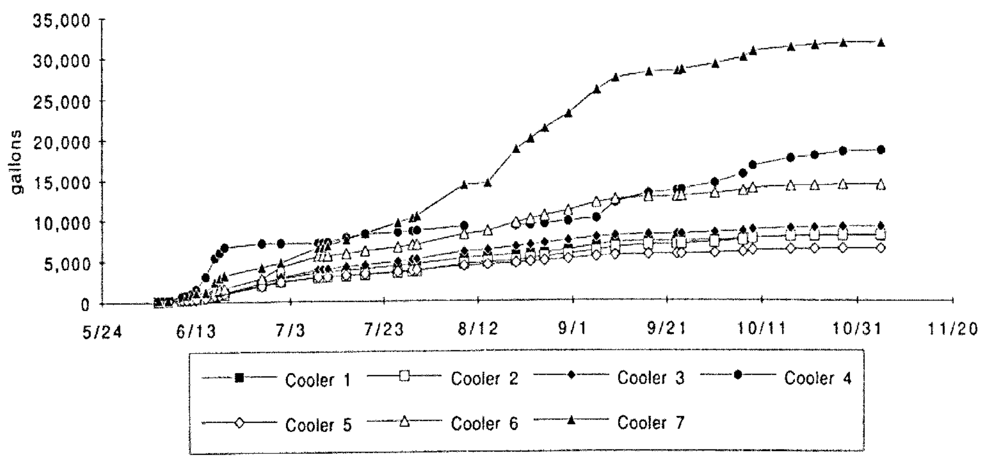
"Mineral buildup on evaporative cooling pads directly decreases life and the saturation effectiveness of the pads. Most direct evaporative coolers recirculate their pan water, while increasing the concentration of dissolved minerals. Typically, a bleed off system is employed with these coolers to remove 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.

Testing of seven direct evaporative coolers with different water supply systems was conducted by the Southwest Technology Development Institute (SWTDI) during the summer of 1991 in Las Cruces, New Mexico. The purpose of the tests was to determine the water consumption and pad-scaling of the different bleed off systems under normal operating conditions for the cooling season climatic conditions of southern New Mexico area under normal operating conditions for a greenhouse and warehouse. The data in this report shows how seven direct evaporative coolers operating at the same time under similar conditions performed with regards to water consumption and total scale deposition.

Cumulative Water Usage 7/31 to 9/10: 12 hours/day Operation



Total Cooler Water Usage for 1991 Cooling Season



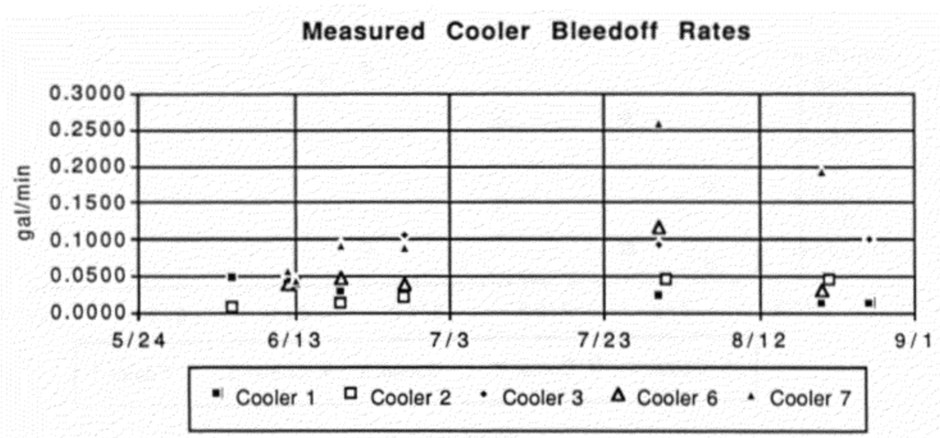


FIGURE 3

In Figure 3, measured spot checks of bleed off rates are shown over the summer. Cooler #7 bleed off rates increased over the summer, while cooler #1 bleed off rates dropped over the summer. Both units had identical standard bleed systems and demonstrated how these systems can fluctuate radically. Cooler #6 did not have a bleed off, but the water rates shown were spot checks of water quantities coming off the pad while the solenoid valve was open. Cooler #5 did not have a bleed off and flushing rates for cooler #4 were not measured."[22]

Adequate water flow over the evaporative media is an important factor in maintaining the maximum saturation effectiveness and extending media life. Inadequate flow will result in accelerated mineral buildup on the media and shorter media life. "With many fewer pump sizes than cooler models, water flow in pads is extremely variable. Excess wetting raises pumping costs slightly but cools better and helps wash dust into the sump, postponing clogging. Inadequate wetting, however, both reduces saturating efficiency and accelerates clogging. As noted, wherever individual fibers evaporate water faster than their rewetting rate, scale will be deposited. Because evaporating rates vary inversely with the entering air humidity, water-needs change widely with the weather, though pump outputs are almost constant. Optimum water rates are the minimum flows that ensure wetting all strands in driest weather at greatest airflows. They can be determined by simple tests. Because saturating efficiencies are governed by cooler design, adjustment, and condition, not weather, coolers whose saturating efficiencies fall in hot dry weather necessarily have strands that dry out, showing that their water flows are either inadequate or maldistributed. Constricted water lines, dirty troughs, or excelsior-dammed pump inlets may be responsible; if not, larger pumps may be needed. In general, tall, narrow pads show lower relative water needs than do broad ones whatever the air conditions and flow-rate… Thus, needed pump capacity to prevent any related drying in extreme weather is, for the assumed 6000 cfm output … is 6.0 gpm. That flow approximates 0.113 lbs of water per lb. of air, which greatly exceeds common usage. However, it should wash all dust from pads, postpone virtually all lime deposits in them, probably double the pad life, admit much less dust and pollen indoors and guarantee optimum cooling in all weathers, including the worst." [23]

Comfort and Energy Consumption Comparisons

Engineers now use computers to simulate building performance and energy use. These building modeling programs use weather history, insulation values, solar and internal heat loads, occupancy and other schedules, and HVAC system types to run calculations for a full 8,760 hours per year. A DOE-2 computerized simulation was used to model a typical new middle school that could be located in four different New Mexico cities. Different types of EAC, IEAC, and refrigerated air HVAC systems were modeled to compare their comfort levels and energy use. The results for Albuquerque are presented as Table 6 in summary while Comfort Conditions for Selected New Mexico Cities can be found in Appendix A, and detailed output in Appendix B.

SYSTEM	HOURS OVER 60% RH	ENERGY (KWH PER TON-HR)	POWER (KW PER TON)	MINIMUM SUPPLY AIR TEMPERATURE @ STANDARD DESIGN	% HOURS TEMPERATURE MAINTAINED
DIRECT EAC	125.00	0.1924	0.0566	66.4	94.7
DIRECT + INDIRECT EAC	123.67	0.1871	0.0725	62.5	94.9
DX REFRIGERATION	63.56	1.0525	1.17	55	97
DX + I EAC COMBINATION	63.56	1.0437	0.873	55	97.3

NOTES:

1. Data from DOE-2.1e eQuest, by DOE as maintained by J.J Hirsch and Associates, and KoolKalk, as developed and maintained by AdobeAir, Phoenix, AZ.

Table 6: Energy and Comfort Comparison

It is interesting to note that the refrigerated air model also did not consistently meet the setpoint temperatures. This is expected because it is not economically practical to design a unit that will satisfy the worst-case conditions. Design engineers typically use the ASHRAE Fundamentals 2% design conditions to calculate the cooling loads. 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 in New Mexico is the 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 and cool enough to remove all the heat from the building. Other factors that can cause a reduction in refrigerated air capacity and comfort levels are shown here and in the Performance and Energy Consumption Section, and below.

- Required outside air quantities controlled by the units inlet dampers can be improperly set.
- High ambient humidity levels cause more latent cooling and less sensible cooling.
- Open doors and windows, which allow increased quantities of hotter outside air to become mixed in with the conditioned air.
- A lack of proper maintenance can result in clogged air filters, which decrease airflow past the cooling coil.
- Faulty controls, sensors or calibration.
- Air duct leakage.

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.

A good source for information on building commissioning which includes case studies is available through DOE's Rebuild America at the referenced website. "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.

Why is commissioning important? 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 U.S. 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 a new building or system begins its life cycle at optimal operation and improves the likelihood that the equipment will maintain this level of performance throughout its life.

The process of 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 thorough commissioning effort results in fewer installation callbacks, long-term tenant satisfaction, lower energy bills, avoided equipment replacement costs, and an increased profit margin for building owners."[24]

Another source, the Seattle City Light has prepared a "Standard Commissioning Procedure for Evaporative Cooling Systems" which is a ten-page EAC commissioning report with examples. It is available from:
http://www.ci.seattle.wa.us/light/conserve/business/BdgComA/bca4.rtf. Sample pages are included in Appendix A.

EAC SYSTEM SIZING

Typical EAC System Sizing:

EAC capacity can be sized using different methods. The most common method used by engineers 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 can be used to size the cooling equipment.

SOLAR HEAT + HEAT FROM EQUIPMENT & PEOPLE = HEAT REMOVED BY EAC

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 98% of the time. The ASHRAE Book of Fundamentals 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. Some of this design information for selected New Mexico cities is shown in Appendix A. Some EAC manufactures offer free energy analysis and sizing programs that can help the designer estimate the energy and water use with their catalog information.

Wet-bulb Depression

EAC's are sized based on the **wet-bulb temperature**. Most people are familiar with a fluid filled thermometer with a bulb on the bottom. This thermometer will measure the "dry-bulb" (or **sensible**) temperature. Now if we were to put a small fabric sock over the bulb on the bottom, and then wet the sock and move air past 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, we 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. Refer to Appendix A for a complete explanation with examples for this calculation. This equation is shown below.

Equation 1: Saturation Effectiveness (“Efficiency”)

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

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: Evaporative Cooler Supply Air Temperature

T2 = T1 - (SE X (T2 – T3))

Table 8 below compares the discharge temperature downstream of the evaporative media for different saturation effectiveness for typical conditions in Albuquerque, New Mexico. 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.

EAC Effectiveness Comparison

Ambient Tdb deg F (2)	MCWB deg F (2)	EAC % Effectiveness	Supply Air Temperature (1)
97	61	**60**	**75.4**
97	61	**65**	**73.6**
97	61	**70**	**71.8**
97	61	**75**	**70.0**
97	61	**80**	**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) Weather Data Source:
New Mexico Climate Manual, NMERDI 2-72-4523

Table 8: EAC Effectiveness Comparison

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 manufactures will design their equipment 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". [25]

Yardsticks for EAC Sizing:

An accurate sizing method will account for both internal and external building loads. The following yardstick sizing methods can be used to determine a rough sizing estimate for budget assessments, but since they do not take loads into account, they are not recommended for system sizing.

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 to 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 ten foot ceiling height. The wet-bulb temperature referenced in Table 7 can be obtained from weather history tables (i.e.: ASHRAE Fundamentals). A table of dry-bulb temperatures and their mean coincident wet-bulb (MCWB) temperatures are provided for selected New Mexico cities in Appendix A. The capacity of EAC's is usually given in cubic feet of air per minute (CFM). Therefore, it is possible to use this rough sizing method to determine the airflow capacity necessary to cool the space.

The recommended air change rates for direct EAC's for different wet-bulb conditions are given in Table 7 below. "Note that these are general air change volumes used. It is not recommended to use less than one air change every 5 minutes for most applications."[26]

Table 7: Recommended Direct EAC Air Change Rates For Comfort Cooling

Wet-bulb Temperature (°F)	Minimum Air Change Rate (minutes)	Maximum Air Change Rate (minutes)	Minimum Air Changes per Hour (AC/hr)	Maximum Air Changes per Hour (AC/hr)
60.0	5.0	2	12.0	30
62.6	4.5	2	13.3	30
64.4	4.3	2	11.1	30
66.2	4.0	2	15.0	30
68.0	3.8	2	16.0	30
69.8	3.5	2	17.1	30

Another more general rule-of-thumb check for EAC system sizing is the quantity of air delivered per unit floor area, or CFM/SF. This value is usually between 1.5 (on low-speed) to 5 CFM/SF depending on the building loads, insulation values, etc. For instance, an aspen pad cooler serving a poorly insulated building with no exterior shading and many internal heat sources would typically use 4+ CFM/SF, while a rigid media cooler serving a well insulated building with large trees on the southwest, few internal heat sources and low occupancy would use 1.5 CFM/SF. More air delivery means larger ducts and more fan energy and may affect the acoustics of the room. If the airflow is insufficient, comfort cannot be maintained. A good design will include a two-speed fan (or a more expensive variable speed fan) so that the maximum air flowrate will only be delivered during peak load periods.

Another method of predicting performance of a direct or indirect EAC is described here. “Apart from using the rough measure of climate zones or the level of humidity, one can predict the effectiveness of EAC for a particular location fairly accurately using the locally prevailing wet-bulb temperatures (WB). Table 9 shows how these are measured. In brief, by adding about 9F to the WB, one knows the effective room temperature that can be reached with EAC. Because the WB varies over seasons and during the course of the day, it does not suffice to use average WB. Rather, one should consider the WB at the time when cooling is most important-for example, around noon.” [27]

Table 9: Relation between Wet-Bulb Temperatures and Effectiveness

Wet-bulb temperature	Type of EAC Unit	Typical supply air temps (Dry-bulb)	Cooling effectiveness
59-70 °F	Direct Indirect / direct	63-73 °F 62-71 °F	Real comfort Real comfort
70-73 °F	Direct Indirect / direct	73-77 °F 72-73 °F	Moderate relief Real comfort

Source: Adapted from the Evaporative Cooling Institute

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 many of the New Mexico mountainous areas 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. Consult manufacturer’s instructions for derating EAC’s (or refrigerated air units) when the site elevation exceeds 2000 feet. Some manufacturer information is included in Appendix B. Additionally, they 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 manual control switches, and sometimes damper controls and programming schedule. Manual 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 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 stand-alone 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. A sample of a microprocessor-based thermostat ("MasterStat Model CC2000A) that is designed for EAC systems is shown in Appendix B.

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 common 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.

Another more accurate but more 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 chart, [Figure 19: Quick Reference Chart for Water Quality] notice that 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."[28]

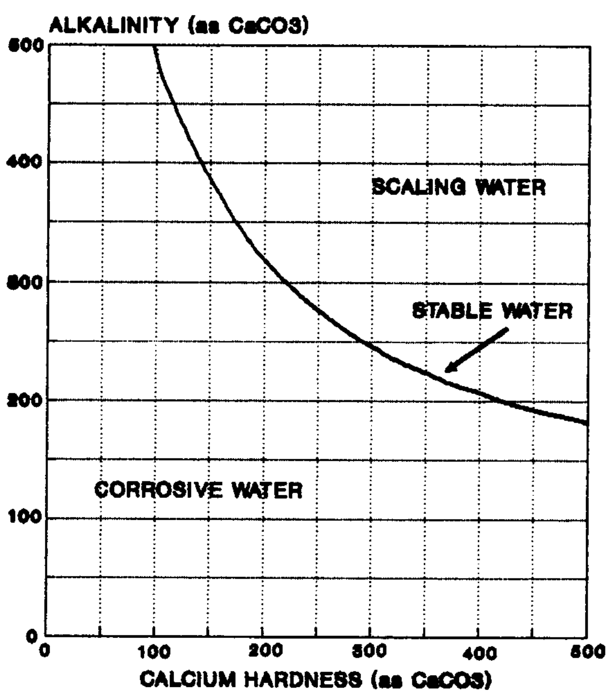


Figure 19: Quick Reference Chart for Water Quality [28]

Solids Control Methods:
Older systems often use a continuous water bleed-off. This 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 usually 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. One 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 manufacturer's system runs 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 simple 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. More information on sump dumps systems is included in the Appendix B.

It is a good idea to pipe this water to area landscaping to minimize wasted water when allowed by local codes. Refer to the section on Water Consumption for more information.

A manufacturer of rigid media offers a coating 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.

The new MI-T-edg media edge coating was developed to address some of the needs of the evaporative cooling industry. These include:

- Wettability: MI-T-edg 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 MI-T-edg 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: Does not allow algae or minerals to anchor themselves into the substrate. Algae and minerals slough off when dried.

- Tough and Resilient: The MI-T-edg 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 synthetic MI-T-edg 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."[29]

Bio-Growth Control

In New Mexico, alkalinity in the water 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. Other manufacturer's recommendations include 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.

Additionally, some manufacturers recommend the use of various chemicals added to the sump water too control algae. The Munters Corporation suggests the following. "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. Read the label to determine the nature of these ingredients. Never use any chemical that is not labeled for use in evaporative coolers or do not list the ingredients. Remember, there are no miracle chemicals."[30] It is possible to void the manufacturers media pad warranty if you use unapproved chemicals.

There are other products available such as zinc anodes, which claim 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. Refer to the Maintenance Section for other algae control methods.

AIR QUALITY

Outdoor and Indoor Air Quality

The quality of the air inside a school is critical to the health and performance of children, teachers and staff. A high performance school 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. Children are particularly vulnerable to such pollutants because their breathing and metabolic rates are high relative to their size. Maintaining a high level of indoor air quality is therefore critical for schools. Failure to do so may, according to the EPA, negatively impact student and teacher performance, increase the potential for long and short term health problems for students and staff, increase absenteeism, accelerate deterioration and reduce efficiency of the school's physical plant, create negative publicity that could damage a school's image, 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. A well recognized method of controlling indoor air pollutants is to circulate more outside air in the school." according to the U.S. EPA.[31]

The term air quality can refer 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. That is why the 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 ft. 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. We 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 an important source of particles. Examined through a microscope, dust collected from schools is composed largely of paper dust, skin flakes, fabric fiber, and soil particles. However, each gram of dust also contains hundreds of thousands of fungal spores and also may contain pesticides and heavy metals."[32]

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.

One historical name for some types of EAC's is an "air washer". Although some older versions of air washers 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. The 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, according to test information from Munters Corp., a manufacturer of rigid media. “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”.[33] See Figure 20 for the for the particle size efficiency graph.

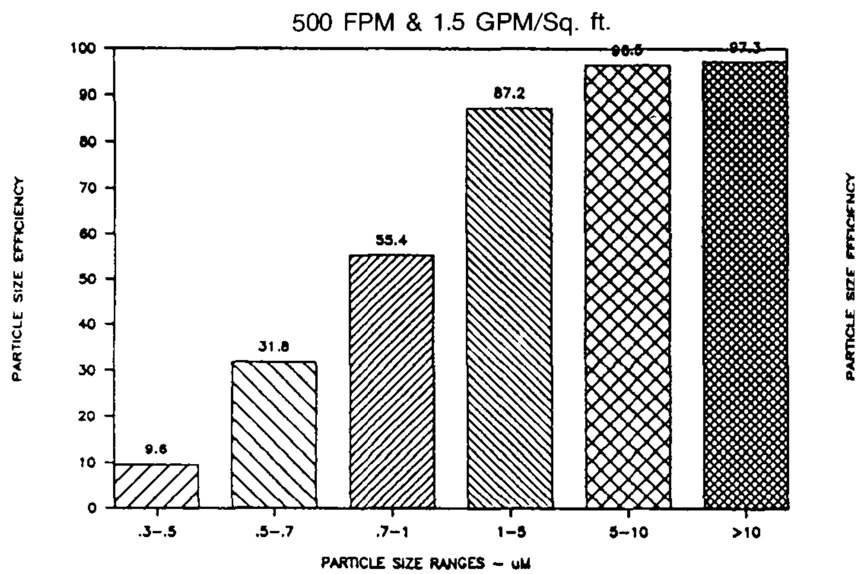


Figure 20: Filtration Efficiency for Various Particle Sizes for 12” Rigid EAC Media

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 we all breathe out, 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.

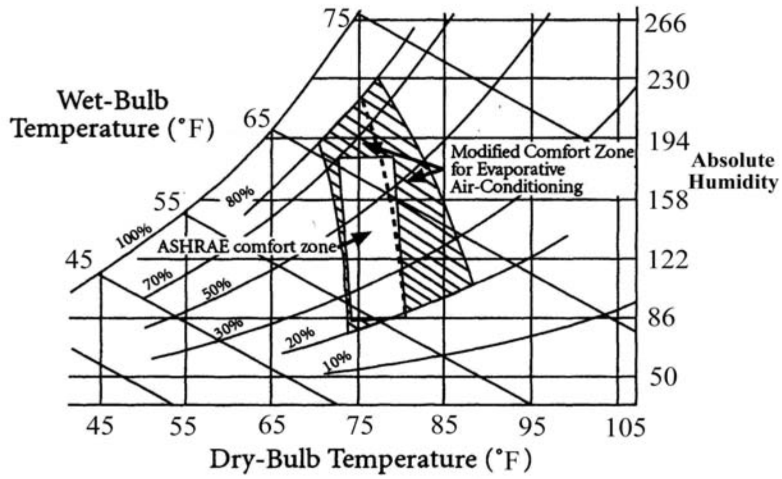
Standards

"Comfort zones" are often shown on standard psychrometric charts and have been developed to indicate regions where a person is "comfortable." 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, as is 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, as shown in Figure 2.1.

Figure 2.1 *Modified Evaporative Air-Conditioning Comfort Zone Taking into Account Increased Airflow Compared with ASHRAE Comfort Zone Based on Vapor Compression Air-Conditioning*



Source: Adapted from ECI.

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)."[34]

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** (see above for explanation of 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. "A study of short-term adaptation to comfortable temperatures for young adults of both sexes shows men feel warmer than women on initial exposure, but later feel cooler, approaching women's thermal sensations after 1 to 2 hours in an experimental chamber".[35]

Importance of 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 properly when using once-through supply air. Two methods of discharging this air are by relief openings and exhaust fans.

Relief air openings can be exterior operable windows, or dampered openings 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 21. 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.

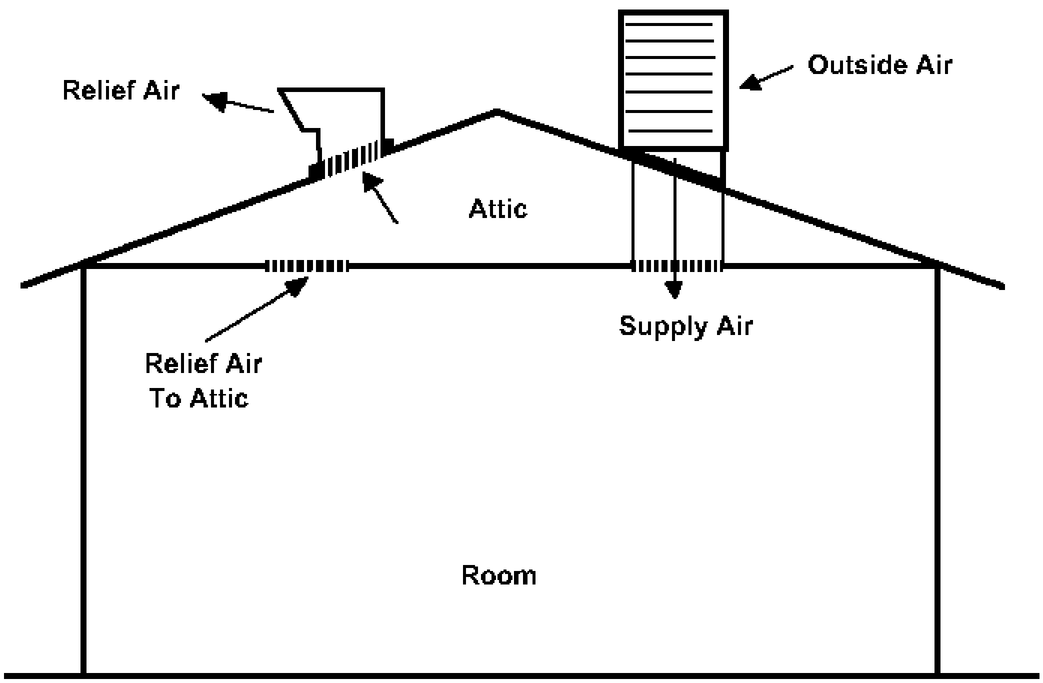


Figure 21: EAC Relief Through Attic

Outside Air Requirements

In New Mexico, the recognized authority for determining the amount of outside air is ASHRAE, who have compiled 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. Schools are a high-density occupancy (50 persons/1000 sf). In order to comply with the ASHRAE Standard 62, which requires approximately 15 cfm/person of outside air to maintain acceptable indoor air quality (IAQ), summer outside air must be cooled during all occupied hours.

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. This 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, so they will always deliver more outside air than the ASHRAE ventilation Standard 62 requires. Moreover, because the evaporatively cooled air is not as energy intensive as refrigerated air, 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-percent and 60-percent 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% +/- 5% is considered ideal. The rate of temperature change is more important than ambient temperature" [36]

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.

Direct EAC's act as a humidifier because they 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 (see section on ASHRAE Comfort Zone). 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", but 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 Considerations

The control of microbial growth and fungi are not particularly serious issues in most dry regions of New Mexico. Areas for concern include refrigerated air coil condensate drip pans, wet ceilings or wet ductwork resulting from roof leaks, wet janitor and mechanical rooms, basements, carpets and poorly maintained plumbing fixtures and pipes. As with any water appliance, EAC's should be inspected and cleaned on a regular basis to prevent growth from forming on the wet areas. EAC manufacturers recommend that the evaporative media be allowed to dry completely once per day. Historical bio-contamination issues have 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. As with all microbiological organisms, 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." [37] This reference also points out that components such as cooling towers and evaporative condensers that are used in refrigeration systems have been verified as 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 children, sensitive individuals 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 school and in the workplace."[38]

Manufacturers recommend that the media pad be allowed to dry out every 24 hours while the fans are running to help curb algae growth. Another recommendation for minimizing 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. Most manufacturers have incorporated louvers, metal filters or setbacks in their units. Further information about this is included in the Maintenance Section and in Appendix B.

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 (especially on high fan speed) 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 more expensive 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

The loss of heat 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 22 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 (manual 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 (manual 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.

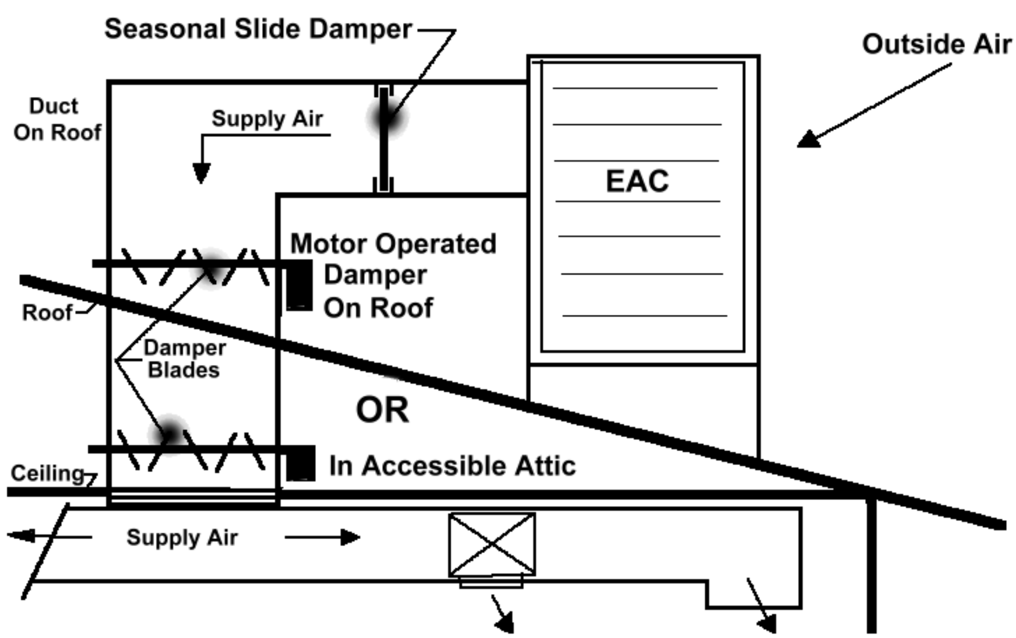


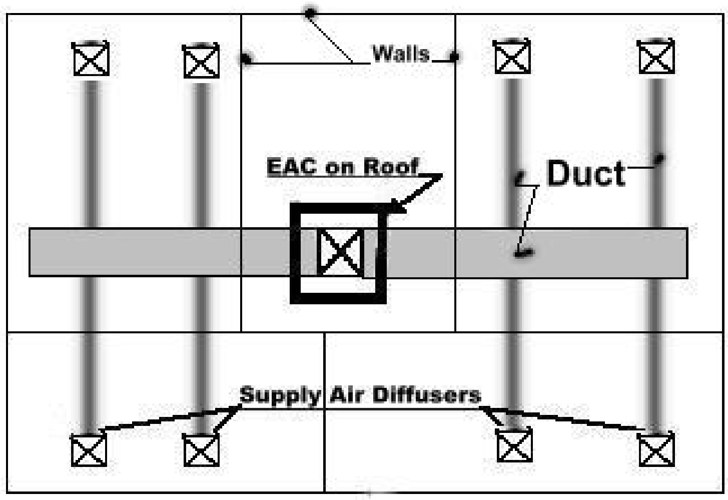
Figure 22: Seasonal Damper Typical Locations

EAC Ductwork and Air Diffusers

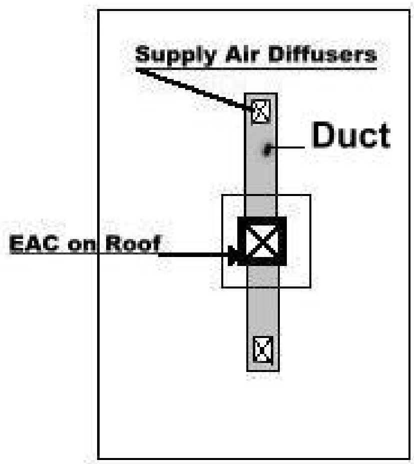
Supply air ductwork can be rigid, and usually made out of galvanized sheet steel, or flexible and made of pleated aluminum foil or a spiral wire wrapped with foil, plastic and insulation. Rigid duct usually has a lower resistance to airflow, and thus will use less energy over the life of the system. Under normal conditions, water should not be at the diffusers, but 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 schools 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 be easier to balance.

Static Pressure and Other Considerations

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.

Another good reason to limit duct and diffuser velocities is that more fan energy is lost to duct friction when airflow is highest. This will reduce the volume of cool air supplied to the conditioned space. A way to visualize this is to imagine a one-foot length of garden hose with water squirting one foot into the air. If you leave the water valve set and were to attach 10 more feet of hose, the water would not shoot up a full 12 inches. If you then added 100 more feet of hose, the water would shoot much lower. The water pressure is being used up by the friction against the wall of the hose. Similarly, 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. This analysis was then repeated for four different cities in New Mexico. An actual typical late 1990's middle school design was used as a model, which reflects the building and cooling equipment configurations and occupant schedules. The summer period was modeled as not in session except for a six hour administrative and janitorial staff. Night and weekend temperature set-back/up was included in all the models. No exterior shading was included. The results of this analysis are presented in Appendix A.

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. Results of this analysis are shown in Table 10, and in Appendix A.

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, KoolKalk® evaporative cooler analysis software. Appendix-A contains this output and other input. 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.

Comparative Present-Value Costs of Alternatives

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

Alternative	Initial Cost (PV)	Life Cycle Cost (PV)	
DX	$327,178	$796,689	
DX + IEC	$340,530	$876,781	
D EC	$343,918	$571,024	*****
D+I EC	$396,254	$597,417	

Table 10: LCC Comparisons

The results indicate that the ECGM_D EC 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. It is interesting to note that 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 higher 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 on 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 alive”. 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 in the graphical boundaries on a psychrometric chart.

Another 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 used in schools is often greater than 20 years. Many districts have instead invested in resourceful maintenance personnel whose task is to “keep it working”, and many times they do by replacing bad components. HVAC renovation funds could be a budget line item to pay for deferred maintenance and equipment replacement, but some districts have set other priorities. In many instances, renovation funds are related to political and bond elections, and schools have less control over this schedule. 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."[39]

Peak summer hour electricity and water costs were calculated to compare equivalent cooling costs applicable to a 2600 square foot area portable classroom. The table "Peak Hour Energy Use Comparison" is shown in Appendix A. Although water is used at the EAC cooling unit and at the electric generating plant, the power plant water cost is embedded in the cost of electricity, so it was not added here. This estimate includes the total cost of billed electricity and water. The total cooling utility costs for a peak-cooling hour are:

Evaporative Cooler = $0.0973 per hour

Refrigerated Cooler = $0.9237 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 civil penalties up to $25,000 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. … EPA can pay individuals up to $10,000 for turning in a violator that results in a conviction under the Citizen Award Program."[40] 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. In addition, many schools are out of session during the months of the higher humidity levels. See Figure 18: Typical Evaporative Cooling Comfort Zone and Monthly Hours, as an example of this.

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 <u>must</u> maintain comfort or for process applications such as computer rooms. Several schools and commercial buildings have used combination systems throughout their campus 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 also be reduced with high humidity levels. The computer model revealed that the comfort levels for most of the in-session cooling season is similar for all four cases. The EAC's did not meet all of the cooling load hours of the year. It is interesting to note that the refrigerated air model also did not consistently meet the setpoint temperatures. This is expected because it is not economically practical to design a unit that will satisfy the worst-case condition. Design engineers typically use the ASHRAE Fundamentals 2% design conditions. 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 in New Mexico is the 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 a refrigerated air unit 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; a lack of proper maintenance can result 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."[42]

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 by bus to most New Mexico 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.

PART II: MAINTENANCE AND OPERATIONS

Evaporative Air Cooler's (EAC's) are very forgiving (unlike the refrigerated vapor compression cycle), and can provide cooling even without proper maintenance, but 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. EAC's require specific maintenance at regular intervals. The change of seasons is an appropriate time for primary maintenance, but other secondary maintenance and inspection tasks should be performed on a monthly basis between the primary maintenance.

Primary maintenance refers to seasonal requirements for summer use or winter shutdown. It includes:

- Media replacement
- Lubrication
- Water Control
- Inspection and Adjustment
- Weatherization Protection

Secondary maintenance refers to inspection and repair duties on EAC components:

- Media Condition
- Water Sump and Distribution
- Fan and Belts
- Air and Water Leaks

An important note about EAC maintenance: Shut off electrical power and water prior to any work on EAC systems. Safety is important, so disconnect the power to the cooler before attempting any preventative maintenance. Cautions that electricity and water together can make for a shocking experience often go un-heeded because of an individual's experience level. For well-trained personnel, safety is a habit. Unintentional electrical contacting can destroy circuitry, controls and even send electric spikes over the wires, which can adversely affect other sensitive electrical systems in a school. Water systems that were unintentionally left pressurized can potentially cause thousands of dollars of water damage. Here are some safety tips to keep in mind:

- Keep your hands dry when touching electrical wires or receptacles.
- Many buildings are designed with roof-mounted coolers, so be certain your ladder has a firm, level footing, and that the top of the ladder extends 18-24 inches above the roofline.
- Wear nonskid shoes, even on a flat roof.
- It is a good practice to work in pairs when in confined spaces. Roof work can usually be done by one person, but it good practice to carry a cell phone or 2-way radio and advise someone that you will be performing maintenance and where you will be.
- It also helps to have a checklist on a clipboard so that you can track your maintenance tasks should you be interrupted. An Operations and Maintenance (O & M) Checklist is included in Appendix A.

SUMMER START-UP

The summer start-up of an EAC actually occurs in the spring when the outside temperatures are too warm to perform ventilation cooling. The cooler was drained and sealed in the fall and now it is time to get the system ready for cooling season service. Many of these service items apply to direct, indirect and combination EAC systems, those that are specific to a certain type are noted. A typical direct EAC "aspen pad cooler" and its components are shown in Figure M1: Direct EAC, below.

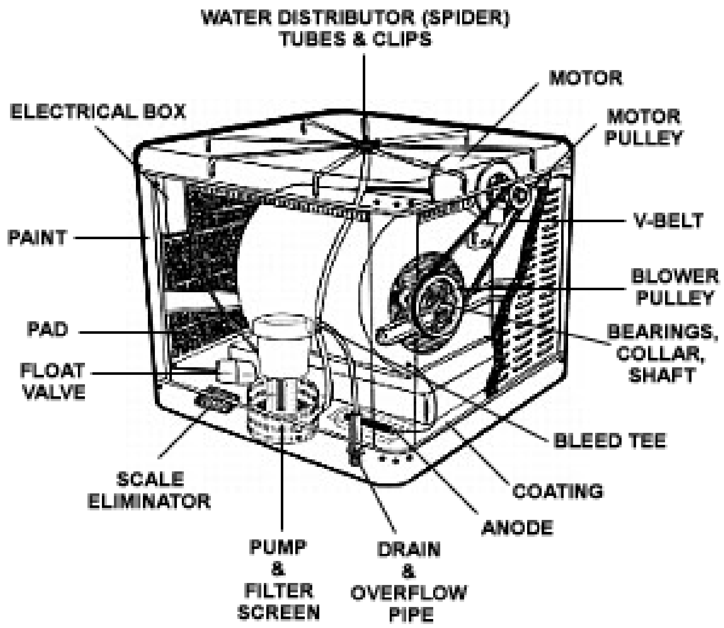


Figure M1: Direct EAC

Cooler maintenance is not a difficult task, and can be completed with a minimum of mechanical knowledge and a little assistance. Use this guide and ask for help at your local home improvement center or hardware store where evap coolers are sold. :[1]

1. **Replace pads:** Remove side panels and install new evaporative aspen (or other type) media pads twice during the season (per manufacturers recommendations). Cooler pads become clogged with dust, pollen, mildew and minerals from evaporated water. Dirty media pads reduce cooling efficiency and overwork the motor. Clean debris out of the louvered side panels and water troughs. Call your cooler manufacturer for pad size, or write down the cooler make and model and visit your home improvement center for assistance. New pads will provide the best cooling effect, but depending on what the pad is made from, and the amount of debris and mineral deposits trapped in the fibers, pads can sometimes be cleaned and used for another season. (The rigid media pads used in newer single-inlet coolers are designed to last 4-6 seasons. Replacing them generally costs $50-$400, so it's worth the time and effort to clean these.)
2. **Clean water reservoir:** Remove the cooler overflow/drain tube in the reservoir pan and rinse out standing water, dissolved salts, silt, old pad fibers, etc., with a solution of water and vinegar. If necessary, use a sturdy nylon brush or plastic scraper to loosen deposits. Do not scratch through the protective coating of a metal cooler. A wire brush or metal scraper should only be used on rust spots, and then reseal the pan with spray patch or mastic. Allow to dry,

[1] http://www.newstream.com/us/story_pub.shtml?story_id=5518&user_ip=63.20.94.80. Adapted from Essick's Service Tips for Optimum Cooler Performance .

and spray with Rustoleum. If you have an easy-care polypropylene cooler, there's no need to patch and reseal, just rinse out debris. See the following section for more information on this.

3. **Check Water Supply Tubing:** Check the entire length of the supply line between the indoor valve and the float valve in the EAC for leaks. Leaky sections will have to be cut out and a new piece of tube spliced into the line. In extreme cases, the entire line may need to be replaced. (Consider using copper. It's not as fragile as plastic, and it lasts longer under New Mexico's summer heat and ultraviolet rays.) Check that the pressure-reducing valve located indoors is set for 30 psi.
4. **Check water pump:** Clean the pump screen of debris and make sure the water pump impellor turns freely. If the pump shaft is stuck, water will not be distributed to pad surfaces, so replace the pump. Call the cooler manufacturer or visit a retailer for an inexpensive replacement. Replace with a thermally protected pump.
5. **Check V-belt and oil bearings:** Check to see that your V-belt is not cracked or frayed. If so, replace it. Allow about ½ to 1-inch play in belt tension to reduce strain on the motor and blower bearings. To set belt tension, loosen the bolts at the motor cradle, move the motor, and then retighten the bolts. Oil the blower wheel bearings on both sides of the rotating shaft using a 20-weight non-detergent oil. Lift the oil caps and oil slowly until it fills the stem. Don't overfill! Cooler oil is available in small zoom spout plastic containers to make this easy. Most motors are permanently lubricated, but look for oil caps on both ends of the motor, just to be sure.
6. **Rotate motor and blower wheel:** Turn the blower wheel by hand a few revolutions to spread a thin coat of oil on dry bearing surfaces. If the motor or blower wheel won't turn freely, you may have to replace the motor or call for service.
7. **Open dampers:** If you have manual slide-in dampers, they are usually located where the cooler is attached to the ductwork and/or at the furnace air handler, or both! Remove any slide-in dampers. Open and closed damper positions should be clearly marked on the duct. Remove or open the damper at the cooler, and insert or close the damper at the furnace. If you cannot locate a damper, your cooler may have a barometric damper that opens automatically, or requires open windows. If no air enters the home when the cooler is turned on, call for service, or ask for assistance.
8. **Fill cooler, adjust float:** Turn on water supply and make sure the float shuts water off about 3/4-inch below the top of the overflow/drain tube, but an inch above the pump inlet. If the float valve is not working, replace it by purchasing an inexpensive repair kit. If the overflow tube leaks around the gasket, tighten the nut or replace the tube gaskets. If water runs over the tube, bend the float arm or other float valve adjustment. Check to make sure cooler is level and there are no leaks.
9. **Control corrosion:** The easiest way to minimize corrosion is to install an inexpensive "bleed-off kit" that continually flushes minerals out of the cooler as it operates. To conserve water, add a mineralizing agent neutralizer, or replace the water manually periodically by draining and refilling the reservoir. Other options such as a periodic sump dump (preferred method), zinc anode systems and polypropylene cooler construction can also be used.
10. **Turn on cooler:** Plug in or turn on the blower motor, checking to see that all motor speeds respond appropriately, and that the belt, pulleys and squirrel cage are all turning freely. Replace side panels, turn cooler on and examine water distribution to make sure water fills the troughs and flows down all pads evenly. If water flow is restricted, remove the panel(s) and clear the blockage by snaking a flexible wire into the tube-end orifice. Reattach all side panels, and make one last check for water leaks at the cooler, along the length of supply tubing and at all water connections and inside the building at the water valve. Listen, or use soap bubble mix and a paintbrush to check for air leaks at the EAC-to-duct connection; slide damper and all ductwork joints.

11. **Controls:** Some types of setback thermostats require batteries for the microprocessor power. Determine the battery life and add battery replacement to the maintenance checklist.
12. **Heating Shutdown:** When the heating season is over, turn the gas setting at the furnace to pilot only, or shut it off completely. (Some plumbers recommend keeping the pilot burning during the summer to prevent moisture from collecting in the gas line, others say there's not enough moisture to worry about so you might as well shut off the gas completely to save on utility bills). Follow seasonal shutdown procedures recommended by the boiler or furnace manufacturer.

Cleaning the Sump and Water Distribution System

When water evaporates, only pure water is absorbed by the air. 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. Periodic cleaning and flushing of the pads will increase their service life.

1. Turn off the fans. Open the ends of the water distribution pipes of rigid media coolers to flush out debris that could clog the water flow paths. Replace the covers when done. When a using silt collection leg below the riser pipe, remove plug and completely drain the system.
2. Gently hose stubborn deposits from the face of rigid media pads and distribution troughs.
3. Completely empty the sump to remove the old algae and dirt that was just rinsed off the pads.
4. Completely empty the sump of water and silt. Hose down the sump to completely clean corners and components.
5. Refill the sump with clean water.
6. Disinfect the system by adding the proper amount of chemicals approved for EAC’s, or inspect/replace zinc anode.
7. Manually turn on the pump to run fresh water through the distribution system. Inspect for even flow from all orifices over the distribution trough(s). Repair blockages in the distribution “spider” or replace tubing.
8. Check to make sure the bleed-off is adjusted correctly and that the pump is still delivering water over the pads for about 30 minutes. Adjust float and bleed valve until pads stay completely wetted under the driest conditions. An easy and inexpensive way to accurately measure the bleed rate is to use an empty gallon milk container and a watch to measure gallons per minute. Bleed rates will vary with local water conditions. A guideline for setting the bleed rate is shown in Appendix A.

WINTER SHUTDOWN

Heating season changeover usually occurs when the outside air is too cold to maintain ventilation heating, in the fall. Only EAC winterizations are addressed here, but consult the manufacturers information for the heating system start-up procedure. Maintenance requirements for seasonal shutdown are for energy conservation, freeze protection and extending the service life of the unit. The following maintenance procedures are important step toward maintaining consistent comfort conditions while minimizing energy costs.

1. Drain all water from the EAC's sump tank, header and internal tubes or pipes. Leave the drain plug out of the hole, but where it can be found in the spring.
2. Turn off the indoor water valve in the line to the EAC. Disconnect the line downstream of this valve and attach a hose routed to a drain or large bucket. At the unit, disconnect the other end of this water line, and allow the line to gravity drain. Then blow out the remaining water in this line between the unit and the indoor hose-to-drain. Reconnect the two connections, but leave the water valve off.
3. Clean the tank and pump filter with a cloth soaked with a diluted chlorine-based household bleach and flush immediately with clean water.
4. If you use washable media pads, remove pads, hose clean and allow them to dry; then reinstall. For rigid media units, run the supply fan for about an hour without water to completely dry it out. Inspect the leading face of the rigid media for solids buildup. If the buildup is significant, you can clean the media per the manufacturer's recommendations. See the Appendix B. Also, make a maintenance note to properly adjust the water flow over the media in the spring.
5. Dry the internal components, and use a rag to sop water from sump corners.
6. Remove the fan belt and lay it on top of the blower assembly to extend belt life.
7. Re-attach all panels securely on rigid media units. For aspen pad coolers, fit flexible covers to exposed units to protect the unit and minimize air leaks in and out of the building.
8. Reinstall seasonal slide dampers near the EAC, or in the conditioned space, or sometimes both. Duct dampers will often be marked with a summer and winter position.
9. EAC ducts which discharge air through one main duct into the room can often be fitted with a piece of tight fitting foam type pad of sufficient thickness for rigidity, just behind the single air diffuser. A tight seal here will prevent drafts and heat loss in the winter.
10. Disconnect electricity to the EAC. This is usually at an electrical disconnect switch at the EAC, but can be inside, or at the breaker switch.

CONTROLS

The types of control systems usually found on EAC's are

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

EAC control type #1, Fan and pump switches, has no periodic maintenance other than confirm that a sign posting "User Instructions for EAC Switch and Window Operation" are 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 (monthly) 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 stand-alone controllers. Maintenance consists of a periodic (monthly) 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.

PERIODIC MAINTENANCE REQUIREMENTS

EAC's require periodic maintenance to maintain reliable comfort conditions and to extend the service life of the unit. An O&M Schedule Checklist and Service Log is a valuable tool to remind even the experienced maintenance person of the small but significant ways to keep their equipment running at peak efficiencies. See Appendix A for sample forms. Inspect and repair/replace the following components periodically:

1. Change filters every two months or as needed depending on local conditions. Filters are usually found on EAC systems that are combined with heating and/or refrigeration cooling.
2. Inspect the water sump, supply lines and media distribution header for blockages. Ensure that ALL the face area of the media is wetted after 5 minutes of pump operation on a hot and dry day. Adjust water supply, clean the water distribution system and maintain adequate water levels to prevent blockages.
3. Check the water level in the reservoir. Adjust float valve so that water is at least one inch above the pump inlet.
4. Inspect aspen pad cooler media for holes or sagging, repair or replace as necessary. Manufacturers of aspen media recommend that these pads be replaced twice a cooling season for best performance.
5. Inspect the fan "squirrel cage" for debris or any imbalance. These wheels are dynamically balanced at the factory, but occasionally a balancing weight clip can be removed accidentally.
6. Inspect the fan shaft bearings, lubricate if the oil well is empty.
7. Inspect fan belts for fraying and tension. Adjust or replace as necessary.
8. Listen to the motor for metal contact or arcing, which can be a sign of imminent failure. A short piece of hose can be used to listen to motor and bearings, but keep it clear of rotating parts.
9. Inspect ductwork for air leaks. Many times aluminum duct tape or silicone rubber can be used to seal small leaks. If the duct is insulated, inspect for loose or fallen sections and moisture. Repair as necessary.
10. Check the inventory of replacement parts. Keep adequate stock of frequently used parts based on the number of units requiring maintenance.

EAC TUNING FOR PEAK PERFORMANCE

Certain aspects of EAC performance such as adequate airflow are fixed by the initial design or are dependent upon the local humidity conditions. These include the fan and duct size and cooling loads. However, there are other components that can be modified or replaced to improve the performance, reduce the supply air temperature, save energy and water, and extend the life of the unit. These modifications usually do not require special tools or certifications, but will require a determined approach to regular and consistent maintenance. These EAC tune-up tips are presented below.

At the EAC unit

1. Check that the entire face of the media is wetted during normal operation. If it is not, verify that the water distribution piping and header over the media is not clogged.

2. Check the pump for proper operation. Use a manufacturer approved strainer at the pump inlet to prevent internal fouling.

3. Verify that the pump is correctly sized for the unit. Consult the manufacturers literature and compare it to the pump nameplate data.

4. If the local electrical system is unstable for any reason, consider adding surge protectors to the 120-volt components, especially control systems that use microprocessors.

5. Check that float valve controlling the water level in the sump is set correctly. If it is set too low, it could starve the pump. If the level is set too high, the water in the media will overflow to drain when the pump is turned off and the media water drains back into the sump, wasting water.

6. Check that the bleed rate is set correctly for your water conditions. Refer to the section on water quality and the manufacturers recommendations to determine the proper flowrate. Testing your supply water for hardness level will set a basis for making adjustments. Consider using EAC chemical treatment to minimize bleed rate and conserve water.

7. Add a 4 inch “dead leg” on the internal water supply riser. Use a “Tee” connection under the supply riser pipe leading to the top distribution header on rigid media EAC’s to collect silt and debris by gravity. Periodically remove the end cap and flush debris.

8. Use a sump dump rather than a continuous bleed to save water, have cleaner sumps and extend media life. Media that is caked with mineral deposits is not as effective as clean media.

9. Check the water pressure on the roof. If it is over 50 psi; consider adding a pressure-reducing valve on the branch water line upstream of the water sump float valve, set at 30 - 35 psi. This will increase the reliability and extend the life of the float valve.

10. Check fan belts for frays, cracks and proper tension. Belts should not be forced over the pulleys, and should have approximately ½ inch of slack when measured halfway between the pulleys. Also, check for proper pulley alignment. Check the fan and motor bearings for proper lubrication, but do not over-lubricate these. Rumble or chatter noises from the EAC should be investigated immediately.

11. Consider insulating the EAC cabinet. Products are available commercially that fit over a aspen pad cooler to help minimize the supply air temperature. See Appendix B.

Air Distribution System

12. Check for duct leakage, especially at connections to the EAC flex-connector, duct joints, diffusers and the seasonal slide damper. Seal all air leaks to maximize the volume of cool air flowing into the room.

13. Insulate all rooftop ductwork with rigid or wrapped fiberglass that is rated for exterior applications. Ensure that all insulation joints are sealed weather tight.

14. Replace the seasonal slide damper with an operable multi-blade damper. A good location for the new damper is in the main duct in the attic or ceiling cavity. Add this seasonal adjustment to the EAC maintenance list, and note the exact locations of all EAC dampers.

15. Get a copy of the T&B or "Test and Balance" and/or "Commissioning" report which was likely prepared when the building or system remodel was constructed. Compare the airflow rates to those specified on the "blueprint" plans especially for any problem rooms. A T&B technician will often adjust balancing dampers at the spin-in duct damper or at the room air diffusers so that the diffusers nearest and farthest from the fan get their share of air. Have the system rebalanced if tampering is evident or airflow problems persist.

16. Do a complete inspection of the relief air path between the room and the relief air openings to the exterior. Look in ceiling plenums to see if the air has a free path to the exhaust fan or the dampered opening. Inspect fire dampers usually located in the ceiling plenum near corridor walls, as these can sometimes accidentally spring close and block airflow. If the supply fan has insufficient pressure to move the air out of the building, consider adding an appropriately sized exhaust fan, and electrically interlock it with the supply fan operation. Relieve "used" EAC air through the attic space if possible.

17. Inspect all relief air dampers and adjust if necessary so the dampers go to full open when the supply fan is on high speed. Replace spring or weight operated barometric dampers with motor operated dampers, which are electrically interlocked to open when the supply fan is on. The use of insulated blade dampers will help prevent heat loss in the heating season. Many EAC problems can be traced to insufficient relief air area.

Other Tips

18. Add twist timers or microprocessor based thermostats to reduce EAC operation to occupied hours only. If you have setback thermostats, review the programming to ensure that the unit is scheduled to operate only during occupied hours.

19. Evaluate the benefits of commissioning or recommissioning your HVAC and related controls systems. Look at he results of previous “Test and Balance” reports to reveal inconsistencies and problem areas.

20. Use an automatic “pre-wet” cycle (which can be a feature of a microprocessor controller, see above) to start the sump pump around two minutes before the fan is energized. This will send only cool air into the conditioned space. Manual pre-wet instructions can be added to an EAC instructions note posted below the control switches.

21. If the supply fan motor has only one speed, consider replacing it with a two-speed motor and controls so that energy use and windage noise are reduced during periods of low cooling load. If the motor is greater than five horsepower, consider adding a variable frequency drive and controls to track the fan speed to the cooling load.

22. Evaluate a nighttime or morning “cold soaking” plan, especially if your EAC units were undersized. Cold soaking runs the coolers during the unoccupied hours when the wet-bulb temperature is low, to decrease the temperature of the mass within the building. Massive concrete buildings usually hold the cold longer than frame construction. The relief air control system must work automatically, as this will not work with closed windows. Also, ensure that the heating system will not automatically energize during cold soaking periods.

23. Be sure the cooler inlet is 10 feet away from, or 3 feet below, plumbing vents; gas flues; clothes dryer vents; or bathroom, kitchen, or laundry exhaust fan vents.

24. Consider evaluating new products to enhance your EAC performance, many can be found on the Internet. Some examples are:
    a. Ventilated or insulated evaporative cooler top covers that shade the cooler from the sun.
    b. Canvas, plastic, Mylar and other materials for winter EAC wraps.
    c. Freeze protection devices (if necessary).
    d. Water saving devices, storage tanks, zinc anode systems, etc..

TROUBLESHOOTING

Comfort complaints come from various sources for various reasons. Some involve an individual's particular metabolic rate, state of health, activity, age, gender, etc. The general rule: "You can't please all the people all of the time" applies to HVAC systems. Nevertheless, there are complaints that can be clues to impending failures or deficiencies in the cooling, air distribution or building systems. Comments about insufficient cooling, high humidity, noise, vibration, smells or indoor air quality should be given immediate attention because they can save you time and money if repaired sooner rather than later. Some comfort issues can be addressed by educating the occupant how to operate the controls and the windows. Many complaints can be prevented by regular EAC system maintenance.

The following Table M1: EAC Problems and Solutions, presents typical complaints, possible causes and suggested solutions to some common EAC deficiencies. The more information you can get from the occupants, the more clues you have to identify the trouble and fix it. Other information sources such as from the manufacturer, hardware store sales, installers and the Internet exist, and should be consulted when additional resources are needed.

Table M1: EAC Problems and Solutions

EAC Problems and Solutions

Problem	Possible Cause	Solution
Insufficient Comfort	Insufficient airflow	Good design should compensate for both internal and external building heat gains. A two speed fan can be an acceptable solution to this problem, where the high speed has sufficient airflow to provide both evaporative and skin velocity cooling (this is similar to the wind chill factor). Low speed can be used during the mild months and in the mornings, and high speed during peak periods.
Insufficient Comfort	Insufficient airflow	Verify that relief air dampers open when fan is on. Operable windows may need to be opened in the room which needs cooling, for an air relief path.
Insufficient Comfort	Insufficient water flow	Check water distribution sump, pump, bleed line, water distribution header and spray header or drip tray to ensure that there is no blockage preventing water flow. Make sure that enough water is flowing to completely wet the evaporative media.
Insufficient Comfort	Water pump is not the correct size	Inspect sump pump and compare the flowrate to that recommended by the manufacturer. Replace if necessary.
Insufficient Comfort	Clogged media	Factors such as local dust and water conditions, insufficient bleed rate and poor maintenance can lead to a buildup of dust or mineral deposits on the media which will block the air flow. Consult the manufacturer for cleaning instructions or install new rigid media. Replace aspen media annually.
Insufficient Comfort	No Airflow	This can be caused by a broken fan belt, blown fuse or tripped circuit breaker, motor failure or faulty electrical wiring. Inspect and repair. Parts are often readily available from a hardware store.
Insufficient Comfort	Air leakage from ductwork	Check duct for air leakage at seasonal slide damper covers; flex connections (between the EAC air outlet and the duct); in the attic or ceiling space; and at all duct connections. Time, dirt and air pressure will cause duct taped connections to leak.
Insufficient Comfort	Sagging media	This can often be the fault of sagging aspen or other media used on direct EAC aspen pad coolers, which allows air to pass by without getting cooled. Replace the media.
Inconsistent Cooling	Supply air not cool enough	This condition may be caused by a high local humidity level. EAC's don't work well under these conditions. Consider adding an indirect EAC section, or a refrigeration air system if cooling is for a critical process such as a computer room.

EAC Problems and Solutions (continued)

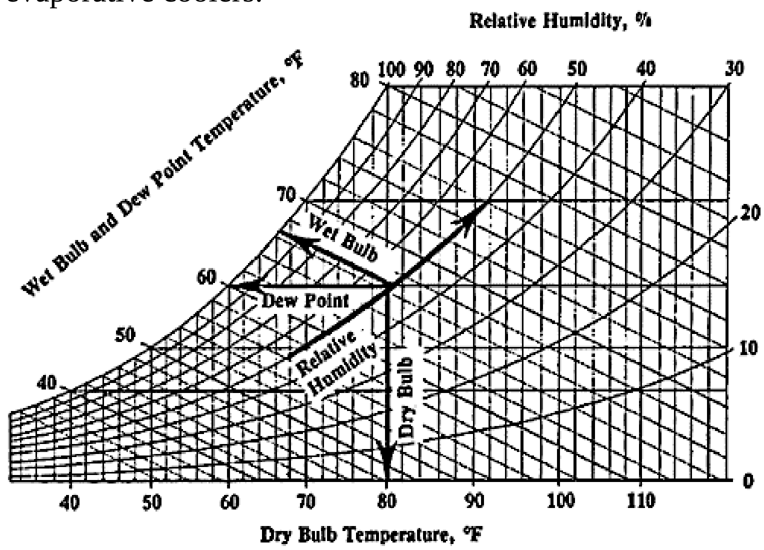
Problem	Possible Cause	Solution
Inconsistent Cooling	Float valve stuck	Check the sump water level. If it is set too high water will be spilling out of the overflow line, too low and the media may be starved for water. Adjust float valve so that it shuts the water when the sump level is approximately 1.5" below the overflow level. This will vary with the media type so consult manufacturers' recommendations.
Inconsistent Cooling	Supply air not cool enough	Heat gained while air travels through long roof mounted uninsulated ductwork. Consider adding external insulation to exterior long exposed ducts. Flexible duct connections and slide dampers should also be inspected for leakage.
High Indoor Humidity	Insufficient Air Relief	EAC's MUST have sufficient relief air for proper operation. Many comfort complaints can be traced to insufficient building relief air. Even if the free area of these openings was designed correctly, often the dampers can be stuck closed from blowing sand or obstructions.
Frequent Comfort Complaints	Untrained Operators	The building occupants and EAC operators need to made aware of how to properly use the fan and pump switches, and if necessary to open the windows for an air relief path. Another solution is to use automatic thermostats with building air relief through the attic or ceiling cavity. Also, consider posting signs at all setback thermostats stating the pre-programmed temperature settings, with instructions on how to temporarily override these settings.
Frequent Comfort Complaints	Insufficient Maintenance	EAC's do require consistent periodic maintenance. A monthly inspection can reveal problems such as sagging media, improper water float valve setting or a loose fan belt which will impair performance. Most EAC repairs do not require highly skilled technicians, and most parts are readily available from a hardware store. Recommended maintenance tasks and intervals are shown below in the Maintenance section.
Water from EAC visible	Leak or float valve out of adjustment	Inspect water supply and bleed lines for leaks, and repair as necessary. Inspect water sump level and adjust float valve as necessary. Water will drain from the media when the pump is turned off creating an unintentional overflow situation. Rigid media can be installed backwards, causing some water carryover into the fan section. Consult manufacturers installation instructions for the correct media orientation. Winterizing EAC covers, slide dampers and draining of water lines will help minimize heat losses and prevent winter water freeze problems.

EAC Problems and Solutions (continued)

Problem	Possible Cause	Solution
Noise from EAC	Windage noise from ductwork	A good ductwork design should limit duct air velocities to 700 feet per minute maximum and 500 fpm at the diffuser. Air faster than this may produce windage noise in the ductwork and at the supply air diffuser. Some users accept higher windage when the EAC is on high speed as a trade-off for lower first costs associated with smaller ductwork.
Noise from EAC	Fan belt, pulley and motor adjustment	Regular maintenance will often identify these problems for repair. Inspect for proper belt sheave alignment and proper belt tension, and repair. Parts are often readily available from a hardware store.
Odors from ductwork	Outdoor air contaminants	Check near the outside air intake for other sources of contaminants. Separate the intake from any source of bad smells or contaminants such as plumbing vents, gen-set exhaust, garbage storage, etc.

GLOSSARY

Adiabatic Cooling: No change in the total heat of the air. The air dry bulb temperature is reduced as moisture is absorbed, and the wet bulb temperature stays constant. Commonly pictured as "Up the Wet Bulb Line" on a psychrometric chart, as shown below. Same process as used in direct evaporative coolers.



Air changes per hour: The number of times that a room's volume of air is replaced per hour.

Air conditioning Comfort: The process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet requirements of the conditioned space.

Air conditioning Components: HVAC system components provide, in one or more factory-assembled packages, means for chilling and/or heating water with controlled temperature for delivery to terminal units serving the conditioned spaces of the building. Types of HVAC system components include, but are not limited to, water chiller packages, reciprocating condensing units, evaporative air coolers, and water source (hydronic) heat pumps.

Air Economizer: A duct and damper arrangement and automatic control system that together allows a cooling system to supply outside air to reduce or eliminate the need for mechanical cooling during mild or cold weather.

Air Handler: A unit of components such as dampers, filters, evaporative cooling section, coils, furnace, etc. used for air conditioning.

ASHRAE:	The American Society of Heating Air Conditioning and Refrigeration Engineers.
ASHRAE Comfort:	The physical conditions represented in the area on a psychrometric chart enclosing all those conditions described in the ASHRAE Handbooks as being comfortable. See Comfort Window.
Automatic:	Self-acting, operating by its own mechanism when actuated by some impersonal influence, as, for example, a change in current temperature or humidity of an air conditioning system.
Barometric Damper:	A single or multi-blade air valve in a duct, wall or ceiling that is usually opened with air pressure and closed with the force from springs or weights.
Bleed Rate:	The flowrate of water leaving the evaporative cooler sump, and which is replaced with cleaner inlet water. Used to control the buildup of dust and minerals in the sump water.
Building envelope:	The elements of a building, which enclose conditioned spaces through which thermal energy may be transferred to or from the exterior or to or from unconditioned spaces.
CFM:	Cubic feet per minute. Typical English measurement for the flowrate from a fan.
Comfort Window:	The limits of human comfort as determined by physiological considerations, which when shown graphically on a psychrometric chart resembles a rectangle with rounded sides.
Conditioned space:	Space within a building which is provided with positive heat and/or cool supply, or which has heated and/or cooled air or surfaces, or where required, with humidification or dehumidification means, so as to be capable of maintaining a space condition falling within the comfort zone set forth in the ASHRAE Handbooks.
Direct digital Control (DDC):	A type of control where controlled and monitored analog or binary data (e.g., temperature, contact closures) are converted to digital format for manipulation and calculations by a digital computer or microprocessor, and then converted back to analog or binary form to control physical devices.
Degree-day, Cooling (CDD):	A unit, based upon temperature difference and time, used in estimating cooling energy consumption. For any one day, when the mean temperature is more than 65 ° F., there are as many degree days as degrees Fahrenheit temperature difference between the mean temperature for the day and 65°F. Annual Cooling Degree Days (CDD) are the sum of the degree days over a calendar year.

Design conditions:	Specified environmental conditions, such as temperature and light intensity, required to be produced and maintained by a system and under which the system must operate.
Dew Point	The warmer air is, the more water vapor it can "hold." Dew point is a measure of how much water vapor is actually in the air.
Direct Evaporative Cooling:	Both the wet bulb temperature and the total heat remain constant - an exchange of sensible heat and latent heat. See Adiabatic Cooling.
Dry Bulb Temperature:	The temperature of the air obtained by a conventional thermometer.
Duct:	A main trunk or branch round or rectangular tube, normally installed for air distribution of heating and/or cooling air conditioning systems and which depends on a blower for air circulation.
Economizer, air:	A duct and damper arrangement and automatic control system that together allows a cooling system to supply outside air to reduce or eliminate the need for mechanical cooling during mild or cold weather.
Economizer, water:	A system by which the supply air of a cooling system is cooled indirectly with water that is itself cooled by heat or mass transfer to the environment without the use of mechanical cooling.
Energy Efficiency HVAC system:	The ratio of useful energy output (at the point of use) to the energy input in consistent units for a designated time period, expressed in percent.
Energy efficiency Ratio (EER):	The ratio of net equipment cooling capacity in Btu/h to total rate of electric input in watts (W) under designated operating conditions. If the output capacity in Btu/h is converted to watts (to create consistent units) the result is equal to the cooling COP (EER X 3.41 = COP.)
Energy:	The capacity for doing work taking a number of forms that may be transformed from one into another, such as thermal (heat), mechanical (work), electrical and chemical in customary units, measured in kilowatt-hours (kWh) or British thermal units (Btu).
Enthalpy:	Total heat content of air-water vapor. Not changed by adiabatic saturated (or direct evaporative) cooling.
Evaporative Air-cooling:	Lowering of the dry-bulb temperature as air moves over a water surface.
Exfiltration:	The uncontrolled outward air leakage through cracks and interstices in any building element and around windows and doors of a building caused by the pressure effects of wind and/or the effect of differences in the indoor and outdoor air density.

Fan System Energy (or Fan System Power): The sum of the nominal power demand (nameplate horsepower) of motors of all fans that are required to operate at design conditions to supply air from the heating or cooling source to the conditioned space(s) and return it to the source or exhaust it to the outdoors.

Free Cooling: Any form of cooling that does not require energy intensive mechanical vapor compression cooling, such as vapor compression refrigeration. Free cooling can come from natural or forced ventilation or evaporative cooling.

Global Warming: a reported phenomenon of the 1980s and afterward, according to which the average temperature on earth is gradually increasing over its level in recent history; attributed to the increased concentration in the atmosphere of gases such as carbon dioxide that trap heat radiating upward and reradiate it toward earth.

HVAC: Heating, ventilating, and air conditioning.

HVAC Air Distribution system: Conveying means, such as ducts, pipes, and wires, to bring substances or energy from a source to the point of use. The distribution system includes such auxiliary equipment as fans, pumps, and transformers.

HVAC System: The equipment, distribution network, and air terminals that provide either collectively or individually the processes of heating, ventilating, or air conditioning to a building.

HVAC System Equipment: HVAC system equipment provides, in one (single package) or more (split system) factory-assembled packages, means for air circulation, air cleaning, air cooling with controlled temperature, dehumidification, and, optionally humidification. Supplied either alone (unitary) or in combination with a heating and cooling plant. The cooling function may be either evaporatively, electrically or heat operated and the refrigerant condenser may be air, water or evaporatively cooled.

Indoor Air Quality, IAQ: A measure of the amount of pollutants contained in the air within a building. These pollutants can be brought in from outdoors or generated internally from processes, people and outgassing of building materials.

Indirect Evaporative Cooling:	Using the evaporative cooling effect without adding moisture to the conditioned supply air stream or sensible cooling. Instead, moisture is evaporated into a separate air stream, which is discharged outdoors. A heat exchanger used to lower the dry-bulb temperature of the room air stream without adding moisture.
Inertial Mass Separator:	The extraction of particulate in a fluid stream by causing the fluid to change direction. The heavier particles with more inertia will tend to continue in a straight direction and impact on the opposite wall of the enclosure.
Infiltration:	The uncontrolled inward air leakage through cracks and interstices in any building element and around windows and doors of a building caused by the pressure effects of wind and/or the effect of differences in the indoor and outdoor air density.
Latent Heat:	The quantity of heat absorbed or released when a substance changes its physical phase (i.e.: liquid to vapor) at constant temperature.
Legionella:	An acute respiratory infection caused by the bacteria Legionella pneumophilia, which causes a serious pneumonia.
Mean Coincident Wet-Bulb Temperature:	An average value for the wet-bulb temperature during the same time of a specific dry-bulb temperature.
Non-depletable Energy Sources:	Sources of energy (excluding minerals and solid fuels) derived from incoming solar radiation, including natural daylighting and photosynthetic processes; from phenomena resulting there from, including wind, waves and tides, lake or pond thermal differences; and from the internal heat of the earth, including nocturnal thermal exchanges.
Outside Air (OSA):	Outdoor air mixed with an HVAC systems recirculated air to dilute the contaminants which are in the room air.
Plenum:	An enclosure that is part of the air distribution system and is distinguished by having almost uniform air pressure. A plenum often is formed in part or in total by portions of the building such as the volume above a ceiling and below the roof.
Psychrometric Chart:	Graphic representation of the properties of moist air. Gives the readings of DB, WB, and dew point temperatures, enthalpy, specific volume, RH, and water vapor content. Enables one to graphically see cause and effect when the quality of air is changed.

Quality: The point on the psychrometric chart that is established by any two of the following: dry bulb, wet bulb, moisture content, heat content, or relative humidity.

Refrigerant: The working fluid in a vapor compression refrigerated air-conditioner. Sometimes referred to as “freon”.

Relative Humidity: A measure of the amount of water in the air compared with the amount of water the air can hold at the temperature it happens to be when you measure it. The ratio of the vapor pressure of water compared to the vapor pressure at saturation at the same dry bulb temperature.

Rigid Media: A wetted surface used in evaporative coolers composed of wavy sheets of thick paper clued to one another. Can be used in different thickness for greater effectiveness. 123 sf of surface area per cubic foot.

Saturation Effectiveness: A ratio of the change in dry-bulb temperature divided by the difference between the outside air dry-bulb and the wet-bulb temperature. Used to predict the discharge performance of an evaporative air cooler.

Seasonal Energy Efficiency Ratio, SEER: Air conditioners are given a SEER rating by the industry. The higher the SEER rating, the greater the efficiency. An air conditioning unit that has a rating of SEER 10 is 25% more efficient than one with a rating of 8.0.

Sensible Cooling: Cooling that results in lower temperature without increasing moisture content. As in the case of indirect evaporative cooling - no moisture is added to the supply air stream. Constant Humidity Ratio.

Ton of Cooling: Refers to the amount of heat removed from a system by a cooling process. One ton of cooling equals 12,000 Btu/hr.

Vapor Compression: Mechanical refrigeration that uses a refrigerant i.e. chilled water or direct expansion (DX) of the refrigerant working fluid. Referred to as refrigerated cooling in this paper.

Variable Air Volume (VAV) system: HVAC system that controls the dry-bulb temperature within a space by varying the volumetric flow of heated or cooled supply air to the space.

Variable Speed Drive (VSD): A device which when added to a device like a centrifugal fan or a pump, can control the speed and output of the device. Variable speed drives are often referred to as variable frequency drive (VFD) which is a common method of controlling fan speed.

Ventilation Air: That portion of supply air which comes from outside (outdoors) plus any recirculated air that has been treated to maintain the desired quality of air within a designated space.

Ventilation:	The process of supplying or removing air by natural or mechanical means to or from any space. Such air may or may not have been conditioned.
Viscous Impingement Filter:	An air filter which traps particles that have collided into a surface that is coated with a fluid coating.
Wet Bulb Temperature:	The lowest temperature that can be obtained by evaporating water into the air at constant pressure. The name comes from the technique of putting a wet cloth over the bulb of a mercury thermometer and then blowing air over the cloth until the water evaporates. Since evaporation takes up heat, the thermometer will cool to a lower temperature than a thermometer with a dry bulb at the same time and place. Wet bulb temperatures can be used along with the dry bulb temperature to calculate dew point or relative humidity

ENGLISH - METRIC CONVERSION FACTORS

	ENGLISH		FACTOR		METRIC		FACTOR		ENGLISH
1	BTU	multiplied by	0.293000	gives	WH	multiplied by	3.412969	gives	BTU
2	BTU/HR	multiplied by	0.293000	gives	WATT	multiplied by	3.412969	gives	BTU/HR
3	BTU/LB-F	multiplied by	4183.830078	gives	J/KG-K	multiplied by	0.000239	gives	BTU/LB-F
4	BTU/HR-SQFT-F	multiplied by	5.674460	gives	W/M2-K	multiplied by	0.176228	gives	BTU/HR-SQFT-F
5	DEGREES	multiplied by	1.000000	gives	DEGREES	multiplied by	1.000000	gives	DEGREES
6	SQFT	multiplied by	0.092903	gives	SQ. METER	multiplied by	10.763915	gives	SQFT
7	CUFT	multiplied by	0.028317	gives	CU. METER	multiplied by	35.314724	gives	CUFT
8	LB/HR	multiplied by	0.453592	gives	KG/HR	multiplied by	2.204624	gives	LB/HR
9	LB/CUFT	multiplied by	16.018459	gives	KG/M3	multiplied by	0.062428	gives	LB/CUFT
10	MPH	multiplied by	0.447040	gives	M/S	multiplied by	2.236936	gives	MPH
11	BTU/HR-F	multiplied by	0.527178	gives	W/K	multiplied by	1.896893	gives	BTU/HR-F
12	FT	multiplied by	0.304800	gives	METER	multiplied by	3.280840	gives	FT
13	BTU/HR-FT-F	multiplied by	1.729600	gives	W/M-K	multiplied by	0.578168	gives	BTU/HR-FT-F
14	BTU/HR- SQFT	multiplied by	3.152480	gives	WATT /SQ.METER	multiplied by	0.317211	gives	BTU/HR- SQFT
15	IN	multiplied by	2.540000	gives	CM	multiplied by	0.393701	gives	IN
16	UNITS/IN	multiplied by	0.393700	gives	UNITS/CM	multiplied by	2.540005	gives	UNITS/IN
17	UNITS	multiplied by	1.000000	gives	UNITS	multiplied by	1.000000	gives	UNITS
18	LB	multiplied by	0.453592	gives	KG	multiplied by	2.204624	gives	LB
19	PERCENT-RH	multiplied by	1.000000	gives	PERCENT-RH	multiplied by	1.000000	gives	PERCENT-RH
20	CFM	multiplied by	1.699010	gives	M3/H	multiplied by	0.588578	gives	CFM
21	IN-WATER	multiplied by	25.400000	gives	MM-WATER	multiplied by	0.039370	gives	IN-WATER
22	LB/SQFT	multiplied by	4.882400	gives	KG/SQ.METER	multiplied by	0.204817	gives	LB/SQFT
23	KW	multiplied by	1.000000	gives	KW	multiplied by	1.000000	gives	KW
24	W/SQFT	multiplied by	10.763920	gives	W/SQ.METER	multiplied by	0.092903	gives	W/SQFT
25	KNOTS	multiplied by	0.514440	gives	METER/SEC	multiplied by	1.943861	gives	KNOTS
26	HR-SQFT-F /BTU	multiplied by	0.176228	gives	SQ.M-K / W	multiplied by	5.674467	gives	HR-SQFT-F /BTU
27	MBTU/HR	multiplied by	0.293000	gives	MWATT	multiplied by	3.412969	gives	MBTU/HR
28	BTU/LB	multiplied by	0.645683	gives	WH/KG	multiplied by	1.548748	gives	BTU/LB
29	LBS/SQ-IN-GAGE	multiplied by	68.947571	gives	MBAR-GAGE	multiplied by	0.014504	gives	LBS/SQ-IN-GAGE
30	BTU/HR/PERSON	multiplied by	0.293000	gives	W/PERSON	multiplied by	3.412969	gives	BTU/HR/PERSON
31	LBS/LB	multiplied by	1.000000	gives	KGS/KG	multiplied by	1.000000	gives	LBS/LB
32	BTU/BTU	multiplied by	1.000000	gives	KWH/KWH	multiplied by	1.000000	gives	BTU/BTU
33	LBS/KW	multiplied by	0.453590	gives	KG/KW	multiplied by	2.204634	gives	LBS/KW
34	MBTU	multiplied by	0.293000	gives	MWH	multiplied by	3.412969	gives	MBTU
35	GALLON	multiplied by	3.785410	gives	LITER	multiplied by	0.264172	gives	GALLON
36	GAL/MIN	multiplied by	3.785410	gives	LITERS/MIN	multiplied by	0.264172	gives	GAL/MIN

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ENGLISH - METRIC CONVERSION FACTORS

		ENGLISH		FACTOR		METRIC		FACTOR		ENGLISH
37		BTU/F	multiplied by	1897.800049	gives	J/K	multiplied by	0.000527	gives	BTU/F
38		KW/CFM	multiplied by	0.588500	gives	KW/M3/HR	multiplied by	1.699235	gives	KW/CFM
39		BTU/SQFT-F	multiplied by	20428.400391	gives	J/M2-K	multiplied by	0.000049	gives	BTU/SQFT-F
40		HR/HR	multiplied by	1.000000	gives	HR/HR	multiplied by	1.000000	gives	HR/HR
41		BTU/FT-F	multiplied by	6226.479980	gives	J/M-K	multiplied by	0.000161	gives	BTU/FT-F
42		Deg. F.	multiplied by	0.555556	gives	Deg. K	multiplied by	1.799999	gives	Deg. F.
43		INCH MERCURY	multiplied by	33.863800	gives	MBAR	multiplied by	0.029530	gives	INCH MERCURY
44		(HR-SQFT-F/BTU)2	multiplied by	0.031056	gives	(M2-K /W)2	multiplied by	32.199585	gives	(HR-SQFT-F/BTU)2
45		KBTU/HR	multiplied by	0.293000	gives	KW	multiplied by	3.412969	gives	KBTU/HR
46		KBTU	multiplied by	0.293000	gives	KWH	multiplied by	3.412969	gives	KBTU
47		CFM	multiplied by	0.471900	gives	L/S	multiplied by	2.119093	gives	CFM
48		CFM/SQFT	multiplied by	18.288000	gives	M3/H-M2	multiplied by	0.054681	gives	CFM/SQFT
49		KBTU/SQFT-YR	multiplied by	3.152480	gives	KWH/M2-YR	multiplied by	0.317211	gives	KBTU/SQFT-YR

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FOOTNOTES

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