Residential evaporative air cooling systems

This month’s skills workshop focuses on evaporative air cooling systems, with specific reference to residential applications.

All evaporative cooling systems use the principle of evaporating water with air to provide cooling. Some systems use the air to cool the water (e.g. cooling towers) but evaporative air coolers use the water to cool the air.

Depending on the evaporative air cooler selected, the climate conditions and the system cooling requirements, the application of evaporative air cooling can be utilised to provide a range of cooling functions.

Residential applications are generally used for comfort cooling, with relief cooling provided during periods of peak or extreme external wet bulb temperatures. Residential evaporative air coolers are generally smaller than commercial units.

Selection of evaporative air cooler

Evaporative air coolers are best selected in conjunction with the designer or installer of the system. Evaporative air coolers should:

• Be correctly sized for the cooling load.
• Be correctly sized for the application comfort cooling, relief cooling, spot cooling or humidification.
• Be of the correct configuration for the required application – direct, indirect or two-stage.
• Have the appropriate sound rating – lowest possible internal and external for residential applications.
• Have the appropriate energy efficiency – low energy use.
• Have the appropriate water usage features – high evaporation efficiency and a reliable automatic water quality management system.
• Have the appropriate controls – automatic and programmable.

A residential system, including ductwork and relief path arrangements, can usually be designed by the evaporative air cooler supplier, system installer or a consultant designer.

Selection of system type

The type of system required will depend on the end use and the specified operational performance requirements. Residential evaporative coolers are almost exclusively of the direct type, although some indirect systems are used.

Direct evaporative air coolers are the simplest, oldest and most widespread type of evaporative air cooler applied. The system uses a fan to draw air over wetted pads and delivers the cooled air into the conditioned space either directly or via an air distribution system. Warm dry air is converted to cool moist air as the heat in the air evaporates the water.

Indirect evaporative air coolers are similar to direct units but use a heat exchanger of some form to separate the supply air from the cooling water or moist air streams. The primary cooled moist air from the evaporative process does not come in contact with the indoor environment; rather it is used to cool secondary air that then enters the space.

Climate

The successful application of evaporative air cooling will depend on the geographic location of the site, the local climate, and the owner’s performance expectations for the cooling system i.e. comfort cooling or relief cooling.

Generally evaporative air cooling is effective for comfort cooling at wet bulb temperatures up to 23°C and effective for relief cooling at wet bulb temperatures up to 25°C.

Comfort

Human comfort depends on a range of factors including temperature, humidity, air movement, clothing and the type of activity as well as cultural factors and personal preferences.

Comfort zones have been developed for refrigerative and evaporative cooling applications. The evaporative air cooling comfort zone differs from the refrigerative air conditioning comfort zone because of the different air velocities used and because of the differences in how indoor humidity is considered.

Comfort provided by evaporative air coolers is a function of both temperature and air velocity. Humans can be comfortable over a range of conditions; for example you can be comfortable at 25°C with air velocity of 0.05 m/s, and you can be equally comfortable at 26°C with air velocity of 0.1 m/s.

Sizing an evaporative air cooler

The sizing process

The process for sizing an evaporative air cooler should include the following steps:

• Determine the outdoor design conditions for the location.
• Determine the required indoor design temperature, maximum air change rate and required minimum indoor and outdoor noise levels.
• Determine the cooling load on the space.
• Select the evaporative air cooler(s) to match the cooling load.
• Ensure evaporative air cooler rated cooling performance and airflow are both suitable for the application.
• Ensure an effective air relief path can be achieved.
• Determine noise level at site boundary or other critical outdoor locations. Ensure that there is enough area to install noise reduction measures if required.

The design of an evaporative air cooling system is a balance between:

1. The indoor temperature that can be achieved with the outdoor design conditions at the time of the peak room sensible cooling load, and;
2. The air change rate required to achieve the supply air temperature to handle the room cooling load. A correctly designed evaporative air cooling system will hold the room set point temperature except in extreme (above design) conditions. It is important to select the correct outdoor and indoor design conditions as the first sizing step.

Outdoor design conditions

In order to properly apply and size an evaporative air cooler, the external wet and dry bulb design conditions first need to be established for the location.

External design conditions depend on the region and location of the building. AIRAH manual DA09 Load Estimation and Psychrometrics provides design outdoor air temperatures for comfort cooling applications in a range of Australian and regional locations. The temperatures from DA09 are sourced from the Bureau of Meteorology temperature/weather monitoring stations at the locations shown. Any significant microclimate effects or regional variations that are applicable to the installation should be allowed for in the load calculations.

Dry bulb temperatures for your location are also available from the Bureau of Meteorology which also records coincident humidity levels and a range of other climate data. Wet bulb temperatures can be calculated from the dry bulb and humidity data.

Indoor design conditions

In order for a cooling load to be calculated, a desired or target indoor temperature must be selected. Target internal design temperatures should be agreed with the system owner.

When considering target indoor design temperatures, the following should be noted:
• AIRAH specifies 24°C as a design indoor temperature for refrigerative air conditioning systems.
• AS 2913 Evaporative air conditioning equipment specifies 27.4°C as the target indoor temperature for nominal evaporative air cooler capacity rating.
• HB 276 also specifies design criteria for evaporative air cooling systems.
• Owners often wish to specify their own target indoor air temperatures.

In reality, internal temperatures and humidity levels will vary in response to external conditions, internal loads and evaporative air cooler settings. Evaporative air cooling systems will cool the outdoor air no matter how high the outdoor temperature rises. However, the resultant supply air temperature and the maximum air change rate will determine whether the desired indoor design temperature can be maintained.

It is also important to note that as the ambient wet bulb temperature increases above the specified outdoor design temperature, the room temperature that can be maintained with a given air quantity will also increase approximately two degrees for each degree rise in wet bulb.

Determine the cooling load

An essential step in the sizing process is to determine the cooling load to be served. The cooling load of any space is based on:
• The required indoor and specified outdoor design temperatures.
• The location, type, construction, orientation, and characteristics of the building or enclosure.
• The external heat gains to the space due to the external ambient temperature and solar loads.
• The internal heat gains within the space. Cooling loads can be calculated manually (refer to the AIRAH members’ technical handbook) or using appropriate cooling load calculation computer programs. The latent cooling load is the energy required to remove moisture from the air; the sensible cooling load is the energy required to cool the air. Evaporative air coolers should be designed for 100% of the calculated sensible load and it should be remembered that they do not provide any latent cooling.

Determine system supply temperature

It is at this point that system operating temperatures need to be calculated or estimated.

When the outdoor design condition and unit evaporation efficiency is known, the system supply air temperature can be calculated from the following equation (from AS 2913):
\[
t_o = t_i - (e100 (t_i - t_w))
\]  (Equation 3.1)

Where:
- \( t_o \) = System outlet or supply air dry bulb temperature (°C)
- \( t_i \) = Air inlet (ambient) dry bulb temperature (°C)
- \( t_w \) = Air inlet (ambient) wet bulb temperature (°C)
- \( e \) = Evaporation efficiency of the unit determined in accordance with AS 2913 and as declared by the manufacturer (%)

Therefore to can be calculated by inputting the known values of \( t_i \), \( t_w \) and \( e \) into Equation 3.1.

Determine the required airflow capacity

Once the cooling load and system supply air temperature has been determined, the required airflow capacity to meet the room sensible load can be determined using the following equation (from the AIRAH members’ technical handbook):
\[
s = 1.213 \times q_v \times (t_r - t_o)
\]  (Equation 3.2)

Rearranged to \( q_v = S \times 1000 \) (Equation 3.2a)

Where:
- \( s \) = Estimated sensible cooling load (kW) from Clause 3.7.4
- \( 1.213 \) = Specific heat of moist air (1.025kJ/kg K)/Specific volume of moist air (0.845 m3/kg) at standard (sea level) temperature and pressure.
- \( q_v \) = The air flow rate required of the unit to handle the room cooling load (L/s).
- \( t_o \) = System outlet or supply air dry bulb temperature (°C).

Inputting known values for \( s \), \( t_r \) and to into equation 3.2a will determine the minimum air flow rate required by the unit. The air change per hour (ACH) rate is \( q_v \), the unit air flow rate (L/s) \times 3.6 and divided by the space volume (m³).

If the air change rate is too high, then the design room temperature will need to be increased and a new air \( 1.213 \times (t_r - t_o) \times 1000 \) quantity recalculated (using equation 3.2a). This process is repeated until an acceptable air change rate is achieved.

Where a target room air temperature is selected, the unit airflow rate \( q_v \) required to meet that temperature can be calculated.

Where the unit airflow rate is selected, the resulting room air temperature \( t_r \) that can be achieved for those particular conditions can be calculated.

Where the target room air temperature and unit airflow rate are both
known, the sensible cooling load that can be provided by the system can be calculated.

Check comfort conditions
The inlet, outlet and room air conditions should be plotted on a psychrometric chart so that the comfort conditions, and particularly the room humidity or moisture content condition, provided by the evaporative air cooler can be readily assessed.

Check evaporative air cooler cooling capacity
The nominal rated cooling performance of the evaporative air cooler is the sensible cooling capacity at standardised conditions, which are 38°C DB and 21°C WB outdoor air with a 27°C room DB temperature, and is reported as kilowatts (kW) of cooling. A designer can match the evaporative air cooler rating with the sensible cooling load on the space either using the nominal rated conditions or adjusted for the required design ambient conditions and design room dry bulb temperature.

Check evaporative air cooler rated airflow
Due to the effect of airflow on the system efficiency and comfort outcomes, designing for the correct airflow is important. The air change rate through the space to be served should typically be at least 20 air changes per hour (ACH) with a maximum of about 40 ACH, although higher (or lower) airflow rates are acceptable in some non-comfort applications. Manufacturer's instructions should be followed with regard to the correct application ranges of their equipment.

The air change per hour achieved by the system is either:
- The evaporative air cooler airflow (m3/hour) divided by space volume (m3)
- The evaporative air cooler airflow (L/s) x 3.6 divided by space volume (m3).

Relief air path
Airflow and air relief are essential to the correct and effective operation of direct evaporative air cooling systems. The relief air path is the path the warm indoor air will take out of the building. The evaporative air cooler will not be able to supply air if the air has no relief path or route out of the building. The effectiveness of the relief air path will, to a large extent, determine the effectiveness of the overall system.

The following options are available to designers:

Natural relief
Windows and doors can be used to provide a relief air path. Opening and closing windows and doors can direct the cooling capabilities of the system to where it is most needed. The additional considerations that need to be made when considering using windows and doors as a relief air path include security and noise issues and the effects of prevailing winds.

Ducted relief
Where windows, doors and relief grilles are not suitable, natural relief air paths can be created through the floor, ceiling or roof space. It should be noted that relief openings will need to be closable when the system is not in use.

Mechanical exhaust
In some instances, particularly in non-residential applications, the relief air may need to be mechanically exhausted from the space. This takes the pressure off the supply fan and can aid with the correct direction and delivery of cooled air.

This month’s Skills Workshop originates from AIRAH manual DA29 Evaporative Air Cooling Systems.