up to a distributing system from which it runs down through the pads and back into the sump. A fan (usually included within the unit) pulls the air through the evaporative pad and delivers it to the space to be cooled.

The spray-type cooler (see Fig. 7) contains an evaporative pad usually made of glass fiber, a water slinger, a centrifugal vaporizer, or spray nozzles to throw a fine spray into the air stream and the evaporator pads. Eliminators are usually required on the downstream side of the evaporator pads. These devices are supplied with or without the air-handling fan.

The rotary-type cooler (see Fig. 8) is a device which continually wets and washes the evaporator pad by rotating it through a water bath and into the air stream. The evaporator pads are usually of copper wire construction to provide the necessary structural and corrosion resistance.

The air washers previously discussed in this chapter are also used for direct evaporative cooling.

Control of sump water within these evaporative coolers consists of a float valve for level control and a bleed-off device. Overflow stand pipes, automatic valves or recirculating pump bypass connections are used for bleed-off. An evaporative air cooler operating with an efficiency of 80 percent is generally considered optimum. In this case, efficiency is the same as humidifying or saturating effectiveness found from Equation 1.

Design Considerations

Various methods for designing evaporative cooling systems are in common use. Simplified rule of thumb methods use an assumed air change rate as a basis. Good engineering practice requires an evaluation of the building heat gain, internal loads, and the cooling season wet-bulb temperature pattern.

The suitability of evaporative air conditioning for a particular application is, in the first instance, determined by the climatic conditions. The lowest temperature theoretically attainable with the most common systems of the direct or single-stage type is that of the wet-bulb temperature of the entering air. The process is one of adiabatic saturation and in practice is almost always operated with 100 percent outdoor air. Since the lowering of the dry-bulb temperature of the air during the evaporative process is always accompanied by a corresponding increase in moisture content, it follows that the greatest application of evaporative cooling for conditions for human occupancy is in areas in which periods of high temperature are always accompanied by low outdoor relative humidities. The areas in which the climate is suitable for the reliable production of optimum comfort conditions by evaporative cooling are limited. Despite this, evaporative air conditioning is extensively used over areas with less favorable climates as a means of improving conditions for human occupancy. It finds wide application also in industrial applications, particularly in those in which an improvement of dry-bulb temperatures can be used to advantage, and in which high humidities are desirable or at least not objectionable.

Proper analysis of the cooling season climatic data is most important. The most acceptable approach appears to be based on an analysis of the average high wet-bulb temperatures of the area for the periods when cooling is needed. Criteria established on this basis must, of necessity, take into account the extent to which departures from optimum conditions both in degree and duration can be tolerated.

There is no latent heat load on evaporative cooling equipment as with refrigeration cooling, since it operates on a 100 percent outdoor air basis. The air quantity handled by a typical evaporative cooling system is higher than with refrigerated cooling or heating systems. These relationships can be seen by comparison of *Example 1* with the sample air-conditioning cooling load calculation, *Example 11* of Chapter 13.

Example 1: An evaporative cooling system is to be installed in the one-story office building shown in Fig. 6 of Chapter 13. Outdoor design conditions are assumed to be 95 F dry-bulb and 65 F wet-bulb. The heat gains, calculated in *Example 11* of Chapter 13, which are used in the design of this type of system are:

All walls, roof and doors	78,500 Btu/hr
Glass areas	5,970
Occupants	17,000
Lighting	62,700
Total sensible heat load =	164,170 Btu/hr

Find the required air quantity, the temperature and humidity ratio of the air leaving the cooler (entering the office), and the temperature and humidity ratio of the air leaving the office.

Solution: A temperature rise of 10 F deg in the cooling air is assumed. Equation 20 from Chapter 13 may then be used to calculate the air volume required to be supplied by the evaporative cooler:

$$Q_{re} = \frac{q_s}{1.08(t_i - t_s)}$$

$$= \frac{164,230}{1.08 \times 10} = 15,200 \text{ cfm}$$

where

Q_{re} = required air quantity through equipment, cubic feet per minute.
q_s = instantaneous sensible heat load, Btu per hour.
t_i = indoor air dry-bulb temperature, Fahrenheit.
t_s = room supply air dry-bulb temperature, Fahrenheit.

This air volume rate represents a 2.6 minute air change for a building of this size.

The evaporative air cooler is assumed to have a saturating effectiveness of 80 percent. This is the ratio of reduction of the dry-bulb temperature to the wet-bulb. The dry-bulb temperature of the air leaving the evaporative cooler is found from Equation 3:

$$t_2 = t_1 - e_a(t_1 - t') \qquad (3)$$

For the conditions of this problem Equation 3 becomes:

$$t_2 = 95 - 0.8(95 - 65)$$

$$t_2 = 71 \text{ F}$$

The humidity ratio of the cooler discharge W_2 is found from the psychrometric chart $W_2 = 0.01185$ lb per lb dry air.

Equation 8, Chapter 13, may be adapted to solve for the remaining unknown, the humidity ratio of the air leaving the space being cooled W_3, from Equation 4:

$$q_e = Q_{re} \times 4840(W_3 - W_2) \qquad (4)$$

where

q_e = latent load, Btu per hour.
Q_{re} = rate of entry of air to the space from the cooler, cubic feet per minute.

The humidity ratio of the air leaving the space, W_3, from Equation 4, is therefore:

$$W_3 = \frac{q_e}{Q_{re} \times 4840} + W_2$$

The only latent load of the space for this design is the occupancy load, 21,250 Btu/hr as calculated in *Example 11* of Chapter 13. Substituting this and the other known quantities in Equation 4:

$$W_3 = \frac{21,250}{15,200 \times 4840} + 0.01185 = 0.01214 \text{ lb/lb dry air.}$$

The remaining values of wet-bulb and relative humidity for the problem may be found from the psychrometric chart. Fig. 9 illustrates the various relationships of the outdoor air, supply air to the space, and the discharge air.

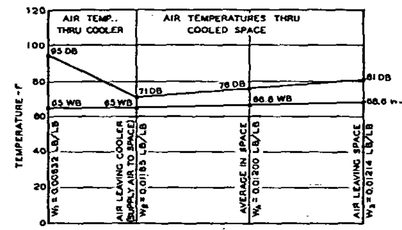

Fig. 9 . . . . Conditions Within Evaporative Cooler and Cooled Space for Example 1

The design of evaporative air-cooling systems is similar to other heating or cooling systems. It should be kept in mind that considerably more air will be handled as no recirculation is used and, therefore, duct, fan, and grille sizes will be larger. This problem has been solved in a number of ways. Large, open buildings such as supermarkets have been successfully cooled and heated by the use of four evaporative air coolers for cooling, two of which are fitted with duct heaters for space heating. In this way a balance between the summer cooling and winter heating air quantity is obtained. In climates which are not particularly suited to direct evaporative air cooling, a combination of refrigeration and evaporative cooling may be economical.

There are many industrial demands for cooling where direct evaporative cooling is economical. Successful application of this type has been made for electric-motor cooling, turbine cooling, and spot cooling in the factories such as textile mills, steel mills, and foundries. Laundries, with their large exhaust air loads, may also take advantage of evaporative cooling. In cattle and poultry barns evaporative cooling has been used with excellent results even in climates which give poor results with human occupancy. This is possible because the blood temperature of these animals is higher than human.[7] Greenhouses use evaporative cooling to reduce temperature and raise humidity.

Two Stage Evaporation Air Cooling

On industrial or commercial installations two stage evaporative cooling will sometimes be found to be effective and economical. Such a system uses a cooling tower and a blast coil ahead of the evaporative air cooler. Using a 6 or 8 row coil and a well designed cooling tower, the air discharged from the blast coil can be within 15 F of outdoor wet bulb. This part of the cooling takes place at constant humidity ratio. Passing the cooled air through an evaporative air cooler further reduces the dry-bulb temperature, the process following the thermodynamic wet-bulb temperature line on the psychrometric chart. Use of this two stage system will result in smaller required air quantities and consequent low duct costs. Careful design can frequently allow the same duct and grille system to be used for heating and maintain proper duct and register velocities.

Control of Evaporative Air Coolers

Control of evaporative air-cooling systems may be accomplished by ordinary dry-bulb thermostats or a combination of a dry-bulb thermostat and a humidistat. These controls are set to turn on at a dry-bulb temperature and off at a pre-set high humidity. When two-speed fans are used, automatic control of fan speed may be employed to provide better control results.

Evaporative air-cooling systems can also be used for ventilation on mild days and at night when air temperatures are relatively low and straight ventilation produces comfortable results. A valve on the water supply to the evaporative air cooler may be operated by a thermostat in the outdoor air to accomplish this automatically. See Chapter 43 for general information on controls.

Maintenance

Much of the discussion of maintenance and operation problems at the end of Chapter 40, Evaporative Apparatus for Heat Rejection, is pertinent to evaporative air cooling and humidification equipment as all these devices use the evaporation of water as the cooling mechanism.

Some air washers and all evaporative air coolers contain extended surface, evaporator pads of one sort or another. Because of these pads, control of the scale-forming mineral content of the water is required or the extended surface pads will soon plug up with scale and the air flow will be reduced. Another effect of scale deposit is to cause channeling of the water and air and so give local high velocities and consequent entrainment. Some scale will be deposited on these pads during drying after shut-down. If replacement or cleaning is required more frequently than once a year the scale control method is usually at fault. Chemical water treatment with polyphosphates is helpful to prevent hard scale. Regular blowdown or bleed-off of sump water is usually the best control to prevent corrosion and hard scale deposit.

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