metric chart on which is illustrated a typical evaporative cooling problem. Calculations for this problem are given in *Example 1*.

Example 1: An evaporative cooling system is to be installed in the one-story office building shown in Fig. 2. Outdoor design conditions are assumed to be 95 F dry bulb and 65 F wet bulb. *The heat gains which are to be used in the design of the cooling* system are:

All walls, roof and doors	78,500 Btuh
Glass area	5,960
Occupants	17,000
Lighting	62,700
Total sensible heat load	164,160 Btuh
Total latent load (occupants)	21,250
Total heat load	185,421 Btuh

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 10F deg in the cooling air is assumed. The air volume required to be supplied by the evaporative cooler may be found from Equation 1.

$$Q_m = \frac{q_s}{1.08(t_1 - t_s)} \qquad (1)$$

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

where

Q_m = required air quantity through equipment, cubic feet per minute.
q_s = *instantaneous sensible heat load, Btu per hour.*
t_1 = indoor air dry-bulb temperature, Fahrenheit.
t_s = room supply air dry-bulb temperature, Fahrenheit.

This air volume represents a 2.6 min air change for a building of this size. The evaporative air cooler is assumed to have a saturation effectiveness of 80 percent. This is the ratio of the reduction of the dry-bulb temperature to the wet-bulb depression of the entering air. The dry-bulb temperature of the air leaving the evaporative cooler is found from Equation 2.

$$t_2 = t_1 - e_h(t_1 - t') \qquad (2)$$

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

$$= 71 \text{ F}$$

where

t_2 = dry-bulb temperature of the leaving air, Fahrenheit.
t_1 = dry-bulb temperature of the entering air, Fahrenheit.
e_h = humidifying or saturating effectiveness, percent.
t' = thermodynamic wet-bulb temperature of the entering air, Fahrenheit.

The humidity ratio of the cooler discharge air, W_2 is found

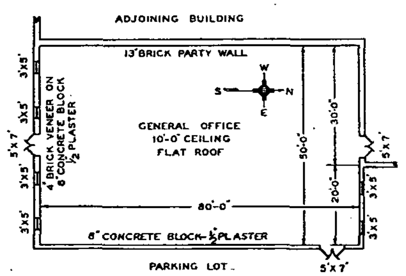

Fig. 2 .... Plan of One-Story Office Building

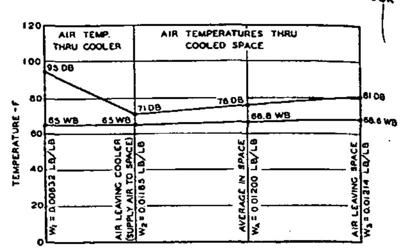

Fig. 3 .... Conditions Within Evaporative Cooler and Cooled Space for *Example 1*

from the psychrometric chart to be 0.01185 lb per pound dry air. The humidity ratio of the air leaving the space being cooled, W_3 is found from Equation 3.

$$W_3 = \frac{q_e}{Q_m \times 4840} + W_2 \qquad (3)$$

$$= \frac{21{,}250}{15{,}200 \times 4840} + 0.01185$$

$$= 0.01214 \text{ lb/lb dry air}$$

where

q_e = latent heat load, Btu per hour.

The remaining values of wet-bulb temperature and relative humidity for the problem may be found from the psychrometric chart (see Fig. 1 for the values in this example). Fig. 3 illustrates the various relationships of the outdoor air, supply air to the space and the discharge air.

RESIDENTIAL COOLING

In many areas of the West and Southwest the natural temperature of evaporation (wet-bulb) is sufficiently low so that air cooled to this temperature by the process of evaporation can be used directly for air conditioning of residences.[4] The first step in designing a house cooling system is the sizing of the cooler. Although the most accurate method of determining cooler capacity requires making a heat gain *calculation*, the time and effort involved in such a calculation cannot in most cases be economically justified in residential cooling. There are a number of rule-of-thumb methods that will give satisfactory results if reasonable judgment is used in applying them.[5]

One method that is commonly used is to divide the difference between the design dry-bulb and wet-bulb temperatures by 10 and consider this to be the number of minutes needed for each air change. If the heat gain is considered high because of unusually large unshaded glass areas or for other reasons, a faster air change should be used.

Packaged air coolers are usually specified for residential work. Since the air flow rating of these coolers is calculated at zero external static pressure, the air delivered by the cooling system will be less than the cooler rating. Many times a house calling for a 3 min air change will require a cooler with a 2 min catalog rating. If performance data is not available from the cooler manufacturer, it is a good rule to assume that the cooler will not deliver more than 70 percent of the free air or catalog rating. In designing residential duct systems, the equal friction method or the velocity reduction method is used. Common velocities in such systems range from 1200 to 1400 fpm for trunk ducts and large branches to 800 through 1000 fpm for small branches and grilles. A consideration that is often overlooked in designing the system is the need for exhaust. If the air is not removed as rapidly as it is introduced, air pressure will build up to a point where there will be an

almost complete stoppage of air flow. There will also be a noticeable increase in relative humidity. While windows and doors located at distant points may be used, a better method is to exhaust the air to the attic, thus forcing out the hot air in the attic. This reduces attic temperature and improves the cooling conditions in the house. An attic fan can be used to secure *optimum exhaust*.

Evaporative cooling is often combined with forced air heating.[6] Fig. 4 illustrates a typical combination system. Since the cooler usually handles at least five times as much air as is required on the heating cycle, the ducts and registers must be sized to fit the cooling requirements. This results in low register velocities on the heating cycle. However, the areas where residential evaporative cooling is widely used are characterized by mild weather, and register velocities are not as critical as in cold winter areas. If it should be necessary or advisable to have higher register velocities and a better air distribution balance than would normally prevail on the heat cycle in a combination system, registers are available with blades so arranged that all of the register may be used for cooling, while only ½ or ⅓ of the register is used for heating.[7] Registers for evaporative cooling systems should have the blades set on at least ½-in. centers and preferably on 1-in. centers to minimize resistance to air flow. The use of combination systems may cause problems of furnace corrosion unless the heat exchange element of the furnace is made of stainless steel or coated with porcelain enamel. This problem can be overcome by locating the cooler and the furnace in the system so that they may be isolated from each other. Manual slide dampers or motor operated dampers should be installed in the trunk duct at the cooler outlet and at the furnace plenum. In summer, the furnace damper is closed and the cooler damper is opened, with damper positions reversed in the winter.

Most residential cooling systems are operated with manual controls. Evaporative cooling systems differ from other types of heating and cooling systems in that they are largely self-regulating. Since the lowest possible temperature that can result is several degrees above the prevailing wet-bulb temperature, it is impossible to undercool to the extent that can occur with other types of equipment. Furthermore, the cost of operation is so nominal that there is no particular cost incentive to regulate the system automatically. A simple means of providing better regulation is to install the cooler with a two-speed motor that can be operated on high speed during the heat of the day and on low speed during the evening and night when the cooling load is low and quiet operation is especially desirable. In general there is no need for a humidistat in residential cooling as the effective temperature will always be lower regardless of the outdoor relative humidity, if the saturation media is wet.

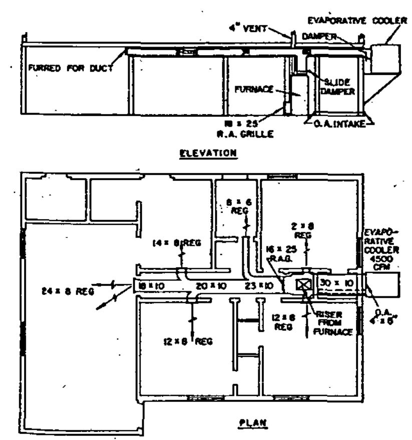

Fig. 4 .... Layout of Combination Heating and Evaporative Cooling System for Residence

COMMERCIAL COOLING

Evaporative cooling systems for commercial applications are divided into two categories: (1) those in which the cooling load is primarily external, and (2) those that must handle heavy internal loads. The design of the former is similar to the residential systems covered in the preceding section. If they are large and complex it is advisable to make a heat gain calculation and to have precise knowledge of local wet- and dry-bulb temperatures. Coincident values of these temperatures and the number of hours that any given wet-bulb temperature will be exceeded in a statistically normal summer are essential. These will permit a rational analysis of the conditions that can be maintained by evaporative cooling. Two books[8,9] that have appeared in the literature provide much useful data on climatic conditions for the design of evaporative cooling systems. Frequency of occurrence of wet-bulb temperatures are given for a large number of cities as well as coincident wet- and dry-bulb temperatures for representative localities.

Two-Stage Cooling

The effectiveness of evaporative cooling in producing comfortable conditions depends on the weather, and the general limitations are related to the prevailing outdoor dry-bulb and wet-bulb temperatures. The use of two-stage systems for commercial applications can extend the range of atmospheric conditions under which comfort requirements can be met. (For the same design conditions, two-stage cooling will provide lower cool air temperatures and thereby reduce the required air flow rate.) The simplest arrangement is a combination of precooling coils using cooling tower water and evaporative cooling. Fig. 5 is a schematic arrangement of such a system.[10]

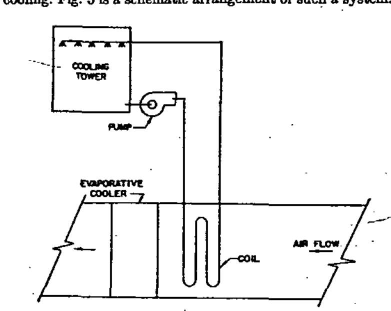

Fig. 5 .... Two-State Evaporative Cooling with Precooling Coil and Cooling Tower