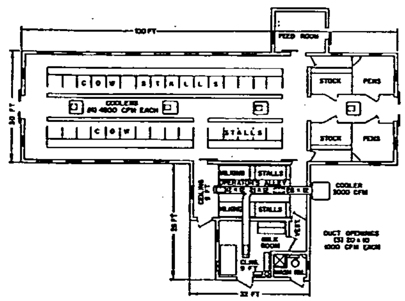

Fig. 11 .... Evaporative Cooling System for Conventional Stall-Type Barn

the roof with vertical ducts dropped down to the ceiling. In the case of high ceiling barns, the ducts should terminate approximately 10 ft above the floor as there is no advantage in cooling the upper air space of the barn.

Evaporative cooling may also be applied to the other types of farm animal buildings and to poultry houses. A recent development is the blackout poultry house to improve egg production of layers by delaying their age of sexual maturity. These houses are tightly closed to exclude all light from entering. Packaged air coolers are used to keep temperature below 90 F and to provide ventilation. The evaporative cooling system also keeps the birds calm and less flighty. The pullets are maintained on 8 hr of artificial light per 24 hr period until they are 12 weeks of age. From 12 to 20 weeks, the birds are maintained on 6 hr of artificial light per 24 hr period. After 20 weeks they are placed on the usual 14 hr daylight.[20] Another new use for evaporative cooling is the cooling of farrowing houses. It is now possible to farrow sows throughout the year. In the past, pig production declined during the summer because it was not possible to keep the sows cool. If a sow becomes over-heated she becomes nervous, restless and, in turn, tramples her litter.[21]

PRODUCE COOLING[22]

Farm storages for fruits and vegetables may be classified as common storage and refrigerated storage. Common storages can be improved considerably through the use of evaporative cooling. High humidity, lower temperature and fresh air to provide adequate oxygen for respiration and for carrying away the waste products of the living processes can be achieved.

Potato Storage

Evaporative cooling systems for potato storage houses should be designed for through-cooling with the air passing directly through and in contact with the potato pile. Capacity of the cooling system should be based on a 3 min air change to give quick and even cooling.[23] The total volume of the storage should be considered in calculating the size of the system so as to provide sufficient cooling if the depth of storage is increased at a future time. Above floor ducts can be used but under floor ducts are to be preferred as they can also be used for the handling of the potatoes with bin unloaders. The ducts should be 20 in. wide and at least 14 in. deep to allow room for the insertion of the bin unloader conveyors. Duct tops must be removable and should be 3 × 8 in. lumber to support a loaded truck. Boards should be spaced to provide ½ in. slots. Distributing and delivery ducts act as extended plenums so it is not necessary to reduce duct depth as the far end of the ducts is approached. Delivery ducts should extend to within 6 ft of the walls to provide uniform air flow through the storage. Since friction loss in the duct system is negligible the resistance of the potato pile is the principal load on the fan in the evaporative cooler. The resistance is approximately 0.25 in. static pressure (potato storage should not exceed 12 ft in depth). The additional resistance of the ducts, inlets, dampers and evaporative cooler will add another 0.25 in. for a total of 0.50 in. that the fan must overcome. In large storages it may be advisable to divide the house into two sections to keep the cooling system within practical limits. A single system should not handle over 12,000 cfm of air if main and distributing ducts are to be of reasonable size.

Fig. 12 shows the floor plan of a typical potato storage house. Ducts have been sized by the velocity reduction method using 1000 fpm for trunk duct, 750 fpm for distributing ducts, and 500 fpm for delivery ducts. Duct system is laid out so that all delivery ducts are of equal length and spaced on 12 ft centers. All outdoor air is normally used during the cooling period. As an example, assume that the desired temperature within the storage is to be 40 F. The system should operate on 100 percent outdoor air if the temperature of the air discharged from the evaporative cooler is as cool or cooler than the inside of the storage and the storage temperature is not lower than 40 F. Should the temperature of the air discharged from the cooler become warmer than the inside of the storage, the air within the house should be recirculated. If the outdoor air drops below 40 F, some outdoor air and some storage air should be circulated. During the winter months the air should be recirculated. Continuous recirculation is not necessary, and the evaporative cooler may be put on time switch operation to run intermittently 10 to 15 min out of every hour.

Apple Storages

Evaporative cooling systems for apple storages should be designed to distribute the cool air to all parts of the storage. The evaporative cooler may be floor mounted or located near the ceiling in a fan room. The system should be designed to discharge the air horizontally at the ceiling level. Since the degree of cooling possible is limited by the prevailing wet-bulb temperature, the maximum practicable size system should be installed to bring down the storage temperature rapidly and as close to the wet-bulb temperature as possible. In general a system having a 3 min air change capacity is the largest practicable system that can be installed. (This will actually result in a 1 to 1½ min movement of air when the storage is loaded.) Evaporative cooling improves conditions in apple storages so that the length of time in storage can be increased considerably. Operation of the system is similar to that for potato houses.

For further information on apple storage, see Chapter 47.

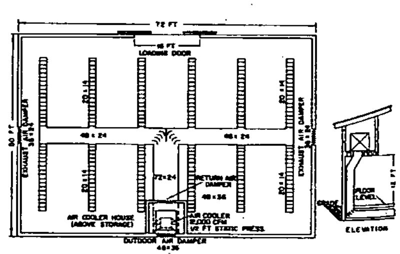

Fig. 12 .... Evaporative Cooling System for Potato Storage House

Table 2 .... Three-year Average Hourly Solar Radiation for Horizontal Surface during Peak Summer Month

City	Btu/ Sq Ft	City	Btu/ Sq Ft
Albuquerque, N. M.	198	Lemont, Ill.	142
Apalachicola, Fla.	170	Lexington, Ky.	170
Astoria, Ore.	132	Lincoln, Neb.	150
Atlanta, Ga.	158	Little Rock, Ark.	148
Bismarck, N. D.	140	Los Angeles, Calif.	162
Blue Hill, Mass.	128	Madison, Wis.	138
Boise, Idaho	155	Medford, Ore.	170
Boston, Mass.	125	Miami, Fla.	153
Brownsville, Texas	175	Midland, Texas	177
Caribou, Maine	115	Nashville, Tenn.	154
Charleston, S. C.	152	Newport, R. I.	138
Cleveland, Ohio	152	New York, N. Y.	140
Columbia, Mo.	153	Oak Ridge, Tenn.	148
Columbus, Ohio	127	Oklahoma City, Okla.	165
Davis, Calif.	184	Phoenix, Ariz.	200
Dodge City, Kan.	184	Portland, Maine	133
East Lansing, Mich.	132	Prosser, Wash.	176
East Wareham, Mass.	132	Rapid City, S. D.	152
El Paso, Texas	195	Richland, Wash.	137
Ely, Nev.	175	Riverside, Calif.	176
Fort Worth, Texas	176	St. Cloud, Minn.	132
Fresno, Calif.	188	San Antonio, Texas	176
Gainesville, Fla.	156	Santa Maria, Calif.	188
Glasgow, Mont.	152	Sault Ste. Marie, Mich.	138
Grandby, Colo.	149	Sayville, N. Y.	148
Grand Junction, Colo.	173	Schenectady, N. Y.	117
Great Falls, Mont.	150	Seabrook, N. J.	135
Greensboro, N. C.	155	Seattle, Wash.	117
Griffin, Ga.	164	Spokane, Wash.	139
Hatteras, N. C.	177	State College, Pa.	141
Indianapolis, Ind.	140	Stillwater, Okla.	167
Inyokern, Calif.	218	Tallahassee, Fla.	134
Ithaca, N. Y.	145	Tampa, Fla.	167
Lake Charles, La.	160	Upton, N. Y.	148
Lander, Wyo.	177	Washington, D. C.	142
Las Vegas, Nev.	195		

Citrus Storages

The chief purpose of evaporative air cooling as it is applied to fruits and vegetables is to provide an effective yet inexpensive means of improving common storages. However, it also serves a special and important function in the case of oranges, grapefruit, and lemons. It is not uncommon for citrus fruit, although mature and ready for harvest, not to have undergone the natural change in color from green. The consumer, however, expects fruit of characteristic color. The color change is achieved through coloring or *sweating* process.[24] Special rooms equipped with evaporative cooling are used to degreen the fruit. Air with a high relative humidity and at a moderate temperature is circulated continuously during the sweating operation. Ethylene gas, the concentration depending upon the variety and the intensity of green pigment in the rind, is discharged into the sweat rooms. The effect of ethylene is mainly to destroy the chlorophyll in the rind, and allow the yellow or orange color to become evident. A temperature of 70 F is maintained in the sweat room during the degreening operation with a relative humidity of 88 to 90 percent. (In the Gulf states 82 to 85 F with 90 to 92 percent relative humidity is recommended.) The evaporative cooling system is designed to deliver 4 cfm per field box of fruit.

Another use for evaporative cooling is as a supplement to refrigeration in the storage of citrus fruit. Although oranges have a long harvesting season and are considered a fresh fruit crop, marketing conditions and other factors may make it advisable to hold them in temporary storage at the packing house for as long as 1 month, and in the case of lemons and grapefruit these crops are usually stored for some time. A large portion of the former crop is picked during the period of least consumption. While citrus storage requires refrigeration in the summer, conditions can often be met with evaporative cooling during the fall, winter and spring when the outdoor wet-bulb temperature is low.

For further information, see Chapter 48.

GREENHOUSE COOLING[25,26]

Proper regulation of greenhouse temperatures during the summer is essential for developing high quality crops. Temperature affects plant growth because it influences the processes which occur within the plant. Temperature and relative humidity can be controlled in the presence of strong radiation with evaporative cooling. The most important problem to be solved in the design of evaporative cooling systems for greenhouses is the calculation of solar heat which is the principal load on a greenhouse. At the edge of the earth's atmosphere there are about 430 Btu per (hr) (sq ft) of sun energy, and when it reaches sea level at about noon in the temperate zone this will be roughly 200 Btu per (hr) (sq ft). In places where much smoke, dust, or heavy clouds exist, the actual incidence of solar radiation will differ from what might otherwise be expected. Table 2 gives solar radiation loads for representative cities. The values cited are average solar heat gains and not peak loads. Temporary rises in temperature inside a greenhouse can be tolerated. An occasional rise above design conditions is not likely to cause damage.

Not all of the solar radiation which reaches the inside of the greenhouse becomes a cooling load. Solar radiation is transformed into: (1) heat of evaporation, (2) chemical energy, and (3) sensible heat. Process 2 (photosynthesis) does not amount to more than about 2 percent of the total radiation. Process 1 will vary from crop to crop, but might tentatively be set at 48 percent of the radiation.[27] This leaves 50 percent which has to be removed by the cooling system. The specific heat of air is 0.24 Btu per lb or roughly 0.018 Btu per cu ft. Therefore, each cu ft per min of air delivered by the cooling system will handle approximately 1 Btu per hr of heat at a temperature rise of 1 deg. Since 50 percent of the solar radiation is used up in Processes 1 and 2, 1 cfm will handle 2 Btu per hr of solar heat at a temperature rise of 1 deg. Example 2 shows how this information can be used to calculate the size of greenhouse evaporative cooling systems.

Example 2: An evaporative cooling system is to be installed in a 50 × 100 ft greenhouse. Design conditions are assumed to be 92 F dry bulb and 73 F wet bulb, and solar radiation is 138 Btu per sq ft. An indoor temperature of 90 F dry bulb is not to be exceeded at design conditions.

Solution: The evaporative air cooler is assumed to have a saturation effectiveness of 80 percent. For the conditions of this problem Equation 2 becomes:

$$t_2 = 92 - 0.8\,(92-73)$$
$$t_2 = 77 \text{ F}$$