Table 7 .... Air Travel with Ejector Nozzles

Approx. Nozzle Outlet Velocity, Fpm	Static Pressure, In. of Water	Approx. Effective Air Travel from Nozzle, Ft
400	0.01	12
500	0.016	15
600	0.023	17
700	0.031	20
800	0.04	23
900	0.051	26
1,000	0.063	28
1,100	0.076	31
1,200	0.09	34
1,300	0.106	37
1,400	0.123	39
1,500	0.141	42
1,600	0.16	45

metal and must be insulated with about one inch cork to prevent sweating if the combination system is used. Nozzles made of insulating board in the shape of a truncated pyramid with square inlet and outlet areas have also been used successfully. Table 7 gives nozzle pressures, velocities, and air travel for *ejector nozzles in storage rooms of 10 to 13 ft ceiling height.* The air travel or throw from the air nozzles should not exceed 35 to 40 ft for best results.

The air velocity in the duct branches or headers for the ejector nozzles should not exceed 1200 fpm for sheet metal ducts or 1000 fpm for wood or cane fiber ducts. If a combination system is used, the usual design is to provide two ejector *nozzles and one humidifying spray nozzle per 20 ft bay.* The humidifying nozzle is placed above and between the two ejector nozzles, which are spaced about 18 in. apart. Compressed air and water lines are required for each spray nozzle.

Return ducts are sized in the same manner as supply ducts, except that velocities are generally somewhat lower. For sheet metal ducts, the return velocity at the apparatus should not exceed 1500 fpm; for wood or cane fiber ducts this velocity should not exceed 1300 fpm. Return ducts are often omitted with the combination system, and one central return used with the apparatus located centrally with respect to the storage room.

Outdoor air connection and all damper areas should be based on a velocity of about 1000 fpm. Intake louvers and screen should be based on 750 fpm velocity. Relief dampers with a total area about 25 percent greater than the outdoor air dampers should be provided. These are needed for exhaust when large quantities of outdoor air are introduced. They should be uniformly distributed and located as far away from the supply outlets as possible. Aluminum vaned dampers, which open on a slight increase in air pressure in the storage room, are used for this purpose. The air thus discarded may often be used to advantage to help cool adjacent spaces in the warehouse. If some shrinkage is not permitted to occur in storage, it will happen rapidly in transit anyway. A five percent loss of weight in 60 days of storage is a reasonable allowance to add to the latent load. In addition, the respiration and outdoor air will contribute to the latent load.

System Design

The engineering problem of designing a suitable storage for preserving the quality of lemons and grapefruit for a considerable holding period requires an understanding of the biological as well as the engineering aspects. All citrus fruits suffer from similar diseases and require similar treatment in storage except as to temperatures maintained. Lemons and grapefruit should be held at 58 to 60 F, whereas oranges are immediately precooled and stored at 34 to 36 F. An exception is grapefruit from regions where stem-end rot is prevalent, which can only be stored for short periods and at temperatures from 32 to 34 F—about the same as for oranges. Uniformly high relative humidities, not less than 80 percent in any case, are required for all citrus fruit. Usually relative humidities are maintained between 84 and 88 percent.

A uniformly low carbon dioxide concentration must be maintained in the storage room by means of adequate ventilation. This concentration should be not higher than 0.2 percent and preferably about 0.1 percent. The latter condition requires from 70 to 75 cfm of outdoor air per carload of fruit.

Two types of air distribution systems have been outlined herein. One is the conventional system using a supply air quantity of 650 cfm per car (1 cfm per storage box). The other is the combination system using direct humidification in the storage rooms and much less supply air (250 to 350 cfm per car). The latter system is considerably cheaper in first cost but is not recommended by some large growers for best results. With either type of system, the refrigeration requirements are about 0.6 to 0.7 tons refrigeration per car, considerably less than for oranges.

Air conditioning principles are involved in the proper handling of lemons and grapefruit in storage. Careful consideration must be given to air volumes, air temperatures, humidity, ventilation, and air distribution. Systems must also be designed with suitable automatic controls in order to be flexible and responsive to varying load demands. Therefore all the basic factors of air conditioning design are involved.

Load Calculations

Refrigeration load consists of heat gain through room surfaces, internal load, and outdoor air load. Heat gain through the exposed walls, floor, and ceiling is sensible load and is calculated in the usual manner from the product of the transmissivity area, and the temperature difference. The transmissivity for one inch of wood or cane fiber is usually taken as 0.33 Btu per (hr) (sq ft) (F deg per in.).

Internal load consists of fruit cooling and respiration, fruit box cooling, fan and pump motor heat, and heat from lights and people (usually insignificant and often omitted). Part of this internal load is latent heat and about 10 percent of the cooling-down load may be considered as such. In these calculations the fruit and the boxes should be considered separately due to the difference in specific heats. Lemons have a specific heat of 0.94, grapefruit 0.87, and wooden boxes about 0.40.

Outdoor air load will consist of the heat and moisture gain from infiltration of air into the conditioned space, and from outdoor air taken in at the air washer. If the outdoor air drawn in through the washer is equivalent to, or greater than, a one hour air change in the conditioned space, no additional outdoor air need be figured for infiltration.

Sensible and latent heat loads should be calculated separately because the supply air quantity is a function of the former only. A certain amount of shrinkage and moisture loss occurs normally in the storage room. If humidities are carried so high as to prevent all shrinkage, molds will appear on the fruit and boxes.

Example 2 illustrates typical load calculations for a lemon storage basement. *Example 3* continues the calculations as applied to a conventional system using high air volumes. *Example 4* gives calculations for a combination system using low air quantities and auxiliary humidification.

Example 2: A lemon storage basement is 152 ft long × 114 ft wide × 13 ft ceiling height. The long wall of the building faces

south. The lower 9 ft of the walls is 8 in. of concrete below ground, and the floor is 6 in. of concrete on the ground. Above ground the walls and ceiling are of frame construction insulated with 1 in. of cane fiber board. The packing floor is located above the storage basement.

Conditions to be maintained in the storage space are 58 F dry-bulb temperature and 88 percent rh. The floor area of the storage is 17,328 sq ft, and the volume is 225,264 cu ft. The maximum storage capacity is 70 cars, entering at the rate of two carloads per day.

Outdoor	Conditions	Indoor
80 F avg max	Dry-bulb temp, F	58 F
65 F	Wet-bulb temp, F	56 F
45%	Relative humidity	88%
56.5 F	Dew-point temp, F	54.5 F
68	Grains per lb	63
30	Btu per lb	23.9
13.81	Cu ft per lb	13.23

Sensible Heat Load

(1) Heat Transmitted Through Surfaces	Btuh
Walls below ground (4,788)(0.10)(70 − 58) =	5,745
Walls above ground (2,128)(0.18)(80 − 58) =	8,420
Sun effect on S. wall (608)(0.18)(120 − 80) =	4,380
Floor = (17,328 sq ft)(0.10)(65 − 58) =	12,130
Ceiling = (17,328 sq ft)(0.18)(80 − 58) =	68,700
Total Transmitted Heat =	99,375

Cooling 2 cars of lemons per day, 650 boxes (50 lb each)
(90% of load assumed to be sensible)

(2) Fruit load

$$= \frac{(2)(650)(50)(0.94)(80 - 58)(0.90)}{24} = \quad 50{,}500$$

(3) Box load

$$= (2)(650)(6)(0.40)(80 - 58) = \quad 2{,}860$$

(4) Respiration load of 68 cars maximum in storage (Refer to Table 5).

$$\frac{(68 \text{ cars})(32{,}500 \text{ lb})(2{,}754 \text{ Btu})}{(24 \text{ hr})(2000 \text{ lb})} = \quad 127{,}000$$

Total Room Sensible Load = 279,735

(5) Outdoor air load, 70 cars, 72 cfm per car for 0.1% CO_2

$$\frac{(70)(72)(80 - 58)(0.24)(60)}{13.23} = \quad 120{,}700$$

(6) Fan motor heat (20 hp)
(20 × 2545) = 50,900

442,335

Total Sensible Heat Load =
442,335/12,000 = 36.6 Tons refrigeration

Latent Heat Load

Cooling 2 cars of lemons per day (fruit only)
(10% of load assumed to be latent)

$$\frac{(2)(650)(50)(0.94)(80 - 58)(0.10)}{24} = \quad 5{,}610$$

Respiration load of 68 cars max in storage

$$\frac{(68)(32{,}500)(192)}{(24)(2000)} = \quad 8{,}850$$

Moisture loss from lemons
(assume 5% of weight in 60 days)

$$\frac{(68)(32{,}500)(0.05)(1060)}{(60)(24)} = \quad 81{,}200$$

Total Room Latent Heat Load = 95,660

Outdoor air load for *5040* cfm; *outdoor* dew point, 56.5 F, 68 gr per lb; indoor dew point 54.5F, 63 gr per lb; moisture gain, 5 grains per lb.

$$\text{Load} = \frac{(5040)(60)(5)(1060)}{(13.23)(7000)} = \quad 17{,}340$$

Total Latent Heat Load = 113,000

Example 3: For the 70 car storage basement of *Example 2* calculate the requirements for a conventional system supplying 1 cfm air per box or 650 cfm per carload.

Solution:

Air Quantities

For the 70 car storage basement of *Example 2*, provide 650 cfm of supply air per car = (70) (650) = 45,500 cfm or 45,500 /13.23 = 3,440 lb per min.

To maintain not more than 0.1% CO_2 concentration, provide not less than 72 cfm outdoor air per car = (70)(72) = 5040 cfm or 5040/13.23 = 380 lb per min.

$$\text{Time for 1 air change} = \frac{\text{Storage volume}}{\text{Outdoor air cfm}}$$

$$= \frac{225{,}264 \ cu\ ft}{5040 \text{ cfm}} = 44.7 \text{ min}$$

Since this outdoor air quantity is greater than one air change per hour in the conditioned space, no additional outdoor air need be considered as infiltration in the heat load calculations.

Return (or recirculated) air
= supply air − outdoor air
= 3440 − 380 = 3060 lb per min
= 45,500 − 5040 = 40,460 cfm

Apparatus Selection

Supply fans required for 45,500 cfm. Assuming an arrangement requiring two systems with the resistance of the apparatus and duct system equal to 1¾ in. water the fan motors needed will be 10 hp each for 22,750 cfm fans.

Air washers required for 22,750 cfm at 500 fpm face velocity = 22,750/500 = 45.5 sq ft.

Make each washer 8 ft wide × 6 ft high above the pan. Assuming an 18 in. deep pan, the air washers will be 7.5 ft high × 8 ft wide × 8 ft long. With two spray banks, a water circulating pump of about 250 gpm capacity at 65 ft head will be required. A 5 hp pump motor is necessary for each washer.

Air Temperatures

Total room sensible load (from *Example 2*) = 279,735 Btu

Add for 20 hp fan motor (from *Example 2*) = (20)(2545) = 50,900 Btu

Gross sensible heat load = 330,635 Btu

$$\text{Lb supply air per min} = \frac{\text{Gross sensible heat load, Btu}}{(60 \text{ min})(\text{sp ht})(\text{temp range})}$$

$$= \frac{330{,}635}{(60)(0.24)(\text{temp range})} = 3440 \text{ lb}$$

$$\text{Temp range} = \frac{330{,}635}{(60)(0.24)(3440)}$$

$$= 6.68 \text{ F deg, say 7 F deg}$$

58 F room temp − 7 deg range
= 51 F indicated supply air temp