Table 1 .... Average Respiration Rates of Storage Lemons

Temp, F	Mg CO_2[a] per Kg per Hr	Sensible Heat,[b] Btu per Ton per 24 Hr
32	2.65	580
40	3.70	810
50	10.50	2,310
60	13.5	2,970
70	18.6	4,090
80	28.2	6,200

[a] Haller, et al. Respiration of Some Fruits in Relation to Temperature. Proceedings Amer. Society of Horticultural Scientists, 1931.
[b] Calculated from Mg CO_2 per kg of material per hour × factor 220.

equipped with both preheating and reheating devices to maintain uniform conditions in storage, regardless of the conditions outside.

Air Cleaning and Ventilation

Lemons give off carbon dioxide and other products and take up oxygen during storage. The oxygen used must be replaced in the storage rooms and the respiration products removed. Besides carbon dioxide, the respiration products, under certain conditions, may contain acetaldehyde. Certain molds growing on lemons produce a gas believed to be ethylene. Since ethylene has a marked tendency to stimulate respiration of the fruit, it too must be removed from storage atmosphere. Until other dependable methods are developed, this must be done by ventilation. In order to determine ventilation requirements, the carbon dioxide content of the storage atmosphere can be taken as an index of the harmful respiration gases. While this test is only fairly accurate for determining the accumulation of ethylene or other harmful products, it is the simplest and most reliable method now known. The carbon dioxide content should not be allowed to exceed 0.1 percent.

The outdoor air requirements may vary. Fruit which has been injured by cold weather or extreme heat has a higher respiration rate than normal. Fruit of different degrees of maturity and vitality may also have different respiration rates.

Table 1 shows the respiration rate of lemons and the production of sensible heat.

For normal fruit it is good practice to design for 75 cfm of fresh air per carload (650 storage boxes).

Air Distribution

Without an adequate volume of air uniformly distributed it is not possible to maintain favorable conditions in lemon storage rooms. Air distribution should be accomplished by means of well designed supply and return ducts and the air should be delivered as close to the fruit as is possible. The volume of primary air circulated should not be less than 1 cfm per storage box, and it should not be forced to travel more than 35 ft from the nozzle. No attempt should be made to substitute secondary air circulation and auxiliary atomizing spray nozzles for an adequate supply of primary air in lemon storage rooms. The velocity of air through the ducts and air nozzles should not exceed 1200 fpm. Higher velocity air ejector nozzles complicate the control of storage conditions.

Air conditioning equipment must be automatically controlled. The design and flexibility of the control system must be such that varying conditions may be easily obtained.

Table 2 .... Average Respiration Rate of Grapefruit and Production of Heat

Temp, F	Mg CO_2[a] per Kg per Hr	Sensible Heat,[b] Btu per Ton per 24 Hr
40	4.86	1,070
50	6.92	1,522
60	12.60	2,770
70	16.0	3,520
80	19.0	4,180

[a] Haller et al.: Respiration of Some Fruits in Relation to Temperature. Proceedings Amer. Society of Horticultural Scientists, 1931.
[b] Calculated from Mg CO_2 per kg of material × factor 220.

Pneumatic or electrical controls are desirable for all citrus storage because of their operating efficiency.

In all building construction and especially in storage rooms with refrigeration and air conditioning, good engineering is the least expensive service that can be purchased. Design of a satisfactory system of air conditioning for lemons, requires a knowledge of the fruit itself, a fact not always recognized by the air conditioning industry.

Storage of lemons after shipment to market is entailed with considerable risk because most of their storage life may have been exhausted before shipment. Knowledge of the field and packing-house history of fruit that is intended for storage would be essential for good results. Data and calculations are given in examples in later text.

GRAPEFRUIT STORAGE

Florida grapefruit is frequently placed in storage for short periods of time—four to six weeks. The incidence of decay and rind pitting are deterrents to long time storage and may develop in the fruit during storage or during shelf life following storage. Decay is controlled by storage at 32 F. On the other hand, pitting of rind is prevented by storage at 50 F. Practical benefits are reported in keeping quality of Marsh grapefruit by a storage program in which fruit is placed for one or two weeks at 50 F before it is transferred to 32 F for either four, six, or eight weeks, plus seven days at 70 F.

The respiration rate of grapefruit varies considerably, the average rate being near the rate of a tree-ripe lemon. Table 2 gives rate of respiration and production of heat for Florida grapefruit per ton per 24 hr.

Recommended storage conditions for California lemons and grapefruit are as follows:

	Lemons	Grapefruit
Temperature, F	58	60
Relative humidity, percent	84–88	86–88

REFRIGERATION OF CALIFORNIA NAVEL AND VALENCIA ORANGES

Decay, aging, pitting, and other rind defects in oranges are accelerated at warm temperatures and are reduced by precooling and refrigerated transportation. Temperature, however, is not the only factor; condition and variety of fruit, type of package, humidity, and ventilation are also of great importance. Often maladjustment of one or more of these factors can nullify the otherwise beneficial results of refrigeration.

The *rate of respiration* of citrus fruit is normally much lower than that of most stone fruits and green vegetables, and somewhat lower than that of apples. Besides temperature the strongest influence on the respiration rate of citrus fruits is the presence of ethylene. Navel oranges have the highest

Table 3 .... Approximate Evolution of Heat by California Oranges Stored at the Temperatures Indicated

Temperature, F	Heat Evolved per Ton of Fruit, Btu per 24 Hr
32	900
40	1,400
60	5,000
80	8,000

Rose, D. H.; Whiteman, T. M.; Wright, R. C.

respiration, followed by Valencias, grapefruit, and lemons. Table 3 shows the heat generated through respiration.

Experience has definitely established that if the carbon dioxide content of storage rooms is held at approximately 0.1 percent or below, a sufficient volume of outdoor air is being supplied.

STORAGE OF PACKED FLORIDA ORANGES

During the last few years the United States Department of Agriculture has been conducting investigations of the storage and keeping quality of Florida Valencia oranges. Some of these studies have been made on the basis of carlot tests, with the Refrigeration Research Foundation and Florida shippers cooperating in the project. The fruit was successfully stored at terminal warehouses at Providence, R. I., and New York, for periods of 8 to 12 weeks at 32 F.

Care should be exercised in the selection of the crop of fruit for storage. It should be in prime condition and should not be picked too early in the season. On the other hand it should not be held on the tree until soft and overripe. Emphasis should be placed on careful grading, with soft, overripe, creased, split, and bruised fruits sorted out. Tests show some beneficial control of decay in storage by the color-added treatment. But frequently, this treatment is too severe and causes high percentages of fruit with burned stems. The color often fades and the appearance of the fruit is spotty and unattractive.

Fairly good control of decay in storage can be accomplished by packing-house chemical treatments such as sodium orthophenylphenate plus hexamine. The treatment was developed by Drs. E. F. Hopkins and K. W. Loucks of the Lake Alfred Citrus Experiment Station through the cooperative efforts of the Florida Citrus Commission. Briefly, the treatment consists in submerging the fruits in a water solution containing 2 percent sodium orthophenylphenate, 1 percent hexamine, 0.05 percent Palmolive soap for two minutes. The effectiveness of this treatment is demonstrated by comparing the results on total decay of Valencia oranges stored for 12 weeks at 32 F and 1 week at 70 F. The figures are averages and based on storage tests at Orlando, Florida and New York City. The unwashed fruit or controls showed 11.9 percent total decay, while the Dowicide-Hexamine treated fruit showed only 3.8 percent total decay.

Further reduction of decay in Florida oranges has resulted from the use of diphenyl treated case liners, or diphenyl treated corrugated paper containers. However, it should be stated that the box liner and the corrugated paper container interferes and slows down the process of cooling and that, therefore, additional precooling and refrigeration should be supplied to compensate for this.

There appear to be no short cuts in preparing fruit for successful long-time storage. The orange does not improve in quality during storage. Total decay can be greatly reduced by careful handling of fruit, good packing-house methods, chemical treatments, diphenyl treated liners or cartons, precooling, refrigerated transit and low temperatures storage at about 32 F.

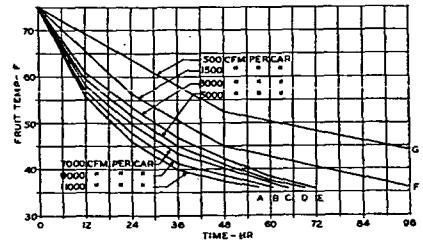

Fig. 2 .... Rate of Precooling with Various Volumes of Air with Air Entering Precooling Room at 34 F

PACKED CALIFORNIA ORANGES

Precooling

The term *precooling* as applied to oranges means the process of removing rapidly the initial heat of the fruit immediately after it has been processed and packed for shipment, so that lower and more uniform temperatures will be maintained in transit without excessive consumption of ice. One advantage of precooling oranges is that some form of modified refrigeration may be used in transit to replace the more expensive standard refrigeration (the re-icing of the refrigerator cars in transit at icing stations).

Precooling plants are usually rated upon the number of cars of fruit that they can precool per day during continuous operation. In addition to precooling the average number of cars of oranges packed per day, a precooling plant should have storage capacity for at least ten days' supply of fruit. There are several types of precoolers in general use, the basic differences being in the number of rooms and the method of cooling and circulating the air. Their efficiency is dependent on meeting the following conditions:

Air volume per car during precooling; not less than 3000 cfm.
Relative humidity of supply air; 95 percent or above.
Temperature of supply air entering room; not more than 2 F. below the selected precooling temperature, which may range from 37 to 38 F.
Ventilation; sufficient outdoor air to keep carbon dioxide content below 0.1 percent (approximately 10 cfm per car).

The rate of precooling is governed by the initial fruit temperature (if adequate refrigeration equipment is provided), and the temperature, volume, and uniform distribution of supply air. Fig. 2 shows the precooling rates with varying air volumes, the temperature of the supply air entering the precooler rooms being the same (34 F) for all air volumes. Naturally the rates of precooling can be equalized by lowering the temperature of the supply air, but not without damaging the fruit. Table 4 shows the weight losses and severe rind defects, including decay, that developed during four days in the precooler under the conditions given in Fig. 2.

Oranges precooled with air volumes above 1500 cfm per car, arrive on the market in better condition than warm fruit loaded directly into pre-iced refrigerator cars and shipped under standard refrigeration. The beneficial results derived by precooling diminish as the air volume is reduced, and ac-