maintain the vapor pressure deficit at a zero level, but it should be maintained as low as possible. A maximum of about 0.46 is recommended, which corresponds to 90 percent RH at 32 F. Some compromise is possible for short storage periods. In many instances, the cold storage operator may find it desirable to add accessory equipment such as atomizing nozzles for water, or in special cases the owner of the fruit may find it desirable to use moisture barriers such as film liners.

In addition to temperature control, the rate of deterioration of many fruits may be retarded by changing the composition of the atmosphere in the storage rooms. The oxygen level which is almost 21 percent in air is allowed to drop to 2 to 3 percent by respiration processes. Carbon dioxide, which is present in very small quantities in air, is permitted to increase to as much as 8 percent depending upon the commodity. This is possible only in specially designed and constructed rooms, which must be gas tight, with provision for removing excess carbon dioxide (CO_2) and ventilation controlled to maintain oxygen in the proper range. This is known as *controlled atmosphere storage*, and is being used successfully with certain apple varieties. Research studies have shown promising results with pears. Intensive studies are now underway with bananas, and there is some interest in its use with grapes.

APPLES

Not only are apples the most important fruit stored on a tonnage basis but the average length of storage period is considerably greater than for any other fruit. There are many important apple varieties varying in relative importance in different parts of the country. The Delicious variety is predominant nationally because of heavy production, in all important areas, particularly in Washington. The approximate order of national importance of the leading varieties is: (1) Delicious (including red strains); (2) McIntosh; (3) Winesap; (4) Rome Beauty; (5) Jonathan; (6) Golden Delicious; (7) York Imperial and (8) Stayman. On a regional basis, McIntosh, Delicious, Rhode Island Greening, Rome Beauty and Cortland are most important in the northeastern states; Delicious, York Imperial, Stayman, Rome Beauty and Golden Delicious in the Central Atlantic states; Jonathan, Delicious, McIntosh and Golden Delicious in the North Central states; Delicious, Winesap, Golden Delicious, Rome Beauty and Jonathan in Washington, and Yellow Newtown, Delicious and Gravenstein in California. The length of storage may be short for fall varieties and those going into processing, but cold storage is critical to proper handling and marketing.

Storage Temperature

For most varieties, 30 to 31 F is the recommended storage temperature. This is 1.5 to 2.5 F deg above the average freezing point (28 to 28.5 F) of most apples and should be safe for modern storage rooms. In older rooms with limited air distribution, a 30 F temperature is unsafe, because of variability of temperature at different locations within the room.

Some apple varieties if held at the above temperatures develop physiological disorders that impair storage life and marketability. However, if storage temperatures are elevated to 38 to 40 F, such storage disorders may not be an economic factor. Unfortunately, such an elevation in temperature results in an accelerated rate of deterioration that also greatly restricts the length of storage life and the period of marketability. Because the remedy may have almost as serious consequences in relation to marketability as does the physiological disorder, a storage temperature of approximately 36 F is often used.

Chilling injury is the term commonly applied to disorders associated with low storage temperatures where freezing is not a factor. There are many types of chilling injury, but the actual relationship of these to each other is not known with certainty. The principal disorders classed as chilling injury in apples are: (1) soft scald, (2) soggy breakdown, (3) brown core, and (4) internal browning. Important varieties susceptible to one or more of these disorders are Rome Beauty, Jonathan, Golden Delicious, Grimes Golden, McIntosh, Rhode Island Greening and Yellow Newtown. In addition to variations of susceptibility by variety, there are also variations from year to year which may be related to climate, fruit size and cultural factors.

Where specific problems exist that may be expressions of chilling injury, the cold storage operator should consult with authorities in his locality.

The most effective means of prolonging storage and market life of apple varieties susceptible to chilling injury has been storage in *controlled atmospheres* at elevated storage temperatures, which is discussed in a later section.

For long storage life, prompt cooling after harvest is essential. Table 1 indicates that the rate of deterioration is 4 to 5 times as fast at 50 F as at 30 F. Therefore, variety with a storage life of 6 months at 30 F might store only 40 to 45 days at 50 F. In this case, a delay of one week at 50 F would reduce the storage life at 30 F by about one month. At higher outdoor temperatures, the effect would be even greater.

Rapid cooling in refrigerated spaces requires: (1) adequate refrigeration capacity, (2) rapid air circulation, and (3) proper stacking to permit good exposure of the fruit to cold moving air. Refrigeration load calculations are discussed in Chapter 27 of the 1961 Guide And Data Book. It should be noted that vital heat resulting from respiration is very low in apples and is a relatively small part of the load as compared to sensible heat in the fruit and containers, heat leakage from surroundings and heat production by fans and lights. Heat exchange capacity is important in relation to the effect this may have on the moisture content of the air, but during a cooling period it is more desirable to compromise on relative humidity than on cooling rate. Water loss from the fruit during rapid cooling may be less than in slower cooling because of the relation between vapor pressure deficit and temperature.

In recent years, the problems of cooling in relation to stacking arrangement have been made more complex by the use of pallets, paperboard containers, and pallet bins. Special precautions should be taken in stacking containers on pallets, so that as much container surface as possible is exposed to moving air. Otherwise, the rate of cooling may be reduced sufficiently to result in over-ripeness and the eventual loss of slow cooling fruits. Paperboard containers aggravate the problem because having no bulge, as do wood containers, they can be stacked tightly. Pallet bins with solid sides and slatted bottoms are now coming into extensive use as field containers for apples and no doubt will become an increasingly important storage container. They have the important advantage of increasing storage capacity of a room by at least one-third. Precise information is not available on cooling rates of fruits in bins under different stacking arrangements. However, experience to date indicates no serious cooling problem. Fruits in the center of the container are the slowest to cool, but with proper stacking and air flow, the problem seems no more serious than with boxes. Most rapid cooling occurs when all sides of the bin are exposed to air movement, and the channels of the two-way entrance pallet for the forks of a fork-lift truck are all open in the direction of the air flow. The space between bins in any direction need be only approximately 3 to 4 in. to permit a free flow of air.

Where storage rooms do not have sufficient refrigeration capacity to maintain suitable temperatures of stored fruits at the same time that warm fruits are being cooled, consideration should be given to precooling before placing the apples in the storage rooms. The different methods of precooling are discussed in Chapter 54.

It is unsafe to generalize on the storage life of apple varieties because much depends on harvest maturity, elapsed time and temperature between harvest and storage, rate of cooling in storage and sometimes cultural factors. The best storage potential is usually found when the apples are mature, but have not attained their peak of respiration when harvested. However, the grower is usually inclined to sacrifice storage quality for the better color often gained in red varieties by longer holding on the tree. Furthermore, even if harvest of a variety is begun at the proper time, the fruit which is picked last may be at an advanced stage of maturity. Such late picked apples do not have good storage characteristics. Neither do those harvested on the immature side, but this is seldom a problem with apples intended for storage before marketing. Harvest at the proper maturity, careful handling, and prompt storage after harvest are conducive to long storage life in relation to the potential for the variety.

Table 2 lists the range in storage life at 30 to 31 F of several apple varieties. Several varieties listed in the table are susceptible to chilling injury at 30 to 31 F when grown under certain climatic or cultural conditions and may be more properly stored at temperatures of 34 to 36 F or even higher. Much depends on the expected length of storage period before marketing and the availability of storage space at different temperatures. Where such a problem exists, consultation with regional authorities is suggested. Where possible, lots should be segregated by grower and harvest date so that periodic inspections can be more easily made.

Air Purification

During ripening, whether in cold storage or not, fruits produce organic substances that are volatile and therefore escape into the atmosphere of the storage room. Common volatiles are the pleasant odors characteristic of varietal aromas. Others such as those from containers or decay may be unpleasant and and will contribute to undesirable flavors if absorbed by fruit. Ethylene, an odorless volatile, may under certain conditions accelerate ripening, thus shortening market life. Other volatiles may contribute to storage disorders such as scald.

Various means of air purification have been attempted to reduce volatiles to a level that would not impair storage life. Ozone has been used to break down organic materials by chemical action, and activated carbon for the same purpose by absorption. Both are effective in removing odors. Results in relation to the effect on fruit ripening and storage disorders such as scald are contradictory. Highly variable results have been obtained, also by season and variety. Ethylene is not removed by activated carbon alone, but present thought minimizes its physiological effect on fruit at cold storage temperatures. Furthermore, many apples are harvested at a sufficiently advanced stage of maturity that ethylene would not have a ripening effect.

The value of air purification for reasons other than odor removal has not been established with certainty. For some physiological disorders, such as apple scald, other means of control have been far more effective.

Controlled Atmospheres

As previously mentioned, *controlled atmosphere* storage may offer important gains in extending the market life of certain apple varieties. Those receiving first attention in the United States were varieties susceptible to low temperature disorders, such as Yellow Newtown in California and McIntosh in New York and New England. By elevating the storage temperature of these varieties to approximately 40 F, and altering the composition of the atmosphere, it was found that chilling injury symptoms were eliminated. In more recent years, attention has been given to varieties, such as Delicious, that may be held at low storage temperatures.

Table 2 .... Storage Life of Apples

Variety	Storage Life, Months	
	Normal	Maximum
Jonathan, Grimes, Golden, McIntosh	2–3	4
Golden Delicious, Cortland, Rhode Island Greening	3–4	5–6
Delicious, Stayman Winesap, York Imperial, Northern Spy, Baldwin	4–5	6–7
Winesap, Yellow Newtown	5–7	8

Extensive commercial application of controlled atmosphere storage to the McIntosh variety was made in the northeastern states beginning more than 20 years ago, but only in the last few years has such storage space been available in Washington and California. Commercial applications in Great Britain and in certain members of the Commonwealth were begun at earlier dates and have since extended to the European continent. It is estimated that the CA storage capacity in the United States is approaching 5 million bushels, a significant figure.

The requirements for construction and operation of controlled atmosphere storage areas are so specific that they are usually operated for a single purpose and not associated with multipurpose cold storage warehouses. Construction costs in Washington are reported to be about $2.50 per bushel of storage capacity, which is somewhat higher than for conventional space. Some of the construction requirements in addition to those for conventional storage rooms are: (1) gas tightness (this increases the importance of the vapor seal outside of the insulation), (2) provision for removing excess CO_2 from atmosphere, (3) provision for ventilation to control oxygen level, (4) adjustment to changing atmospheric pressures, and (5) provision for maintenance of very high relative humidity required by longer storage period.

Precautions in the operation of controlled atmosphere rooms are very important. The atmospheres used will not support human life, so if inspection or repair is needed, a source of air must be supplied. Apples varying in storage life either because of varietal characteristics, influences of maturity, or other factors should be stored separately unless construction features permit fruit removal without upsetting atmospheric composition. Atmospheric composition should be determined at least daily. Details of construction and operational requirements can be found in references and by consultation with authorities in the region.

Only apples of good quality and high storage potential should be placed in controlled atmosphere storage. Harvest maturity and handling practices are critical, and only fruits harvested at proper maturity should be considered. In any one district, this limits the harvest of apples for controlled atmosphere storage to a few days only. Immature apples or those retained on the tree to an advanced stage of maturity to gain better color, as is often the case with Delicious and McIntosh, are equally undesirable.

For best results, care in handling practices to avoid bruising and skin breaks is important as a means of reducing deterioration and decay. Prompt cooling after harvest and grading is strongly recommended. Some controlled atmosphere storage operators attempt to have the fruit in storage within one day after harvest. Rapid cooling in the storage room is also recommended to get the core temperatures close to the recom-