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COLD STORAGE
for
APPLES and PEARS

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Bureau of Plant Industry, Soils, and Agricultural Engineering
Agricultural Research Administration

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Cold Storage for Apples and Pears

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USE OF COLD STORAGE FOR FRUIT

Holding apples and pears in cold storage in producing areas rather than at market terminals or at points in transit has become a common practice in recent years. In the Pacific Northwest this change has been more or less coincident with the decline of speculative buying of the fruit by eastern interests and with the growth of cooperative marketing enterprises owned and controlled by the growers. As a result the available cold-storage space in the fruit-growing districts in Washington and Oregon has been materially increased, but even yet it is inadequate for the needs of the industry. Many of the existing cold-storage plants are inadequately equipped to handle satisfactorily the tonnage stored. Year by year there is remodeling and expansion of existing plants, as well as new construction to provide additional refrigerated storage space. Some of the storages are well designed and carefully and efficiently operated; others are not. It is the purpose of this circular to present in concise language, as nontechnically as possible, the essential features in the design and operation of cold-storage plants and in the handling of the stored fruit in the Pacific Northwest, although the same principles will be found equally useful in other parts of the country.

The principal fruits requiring refrigeration for storage are apples and pears. Grapes also are stored extensively in some places, particularly in California. Refrigeration is used also for the precooling or short-time storage of other fruits.

As rural electrification and automatic refrigeration equipment have become more available, individual fruit growers or small groups of growers have been building cold-storage plants at or near their orchards instead of relying on large plants that serve a whole community or a large number of growers. This has been coincident with the development of better handling and packing methods. The time, labor, and facilities required for sorting and packing have demanded refrigeration near the orchard, so that packing and shipping will not be under the pressure of getting the job done in a matter of a few days after picking. Having refrigeration facilities at hand has permitted the orchardist to give his fruit optimum protection while it is awaiting packing and to employ a comparatively small crew of skilled sorters and packers instead of having to mobilize large crews, oftentimes of persons who know little or nothing about fruit handling or packing. This has been especially important under war conditions, when the utilization of efficient cold-storage facilities near the orchards has been imperative to take the fullest advantage of a short labor supply as well as to prevent wastage of fruit that is a vital part of the Nation's food supply.

Many of the cold-storage plants designed and operated along lines found satisfactory for general cold storage have been neither efficient nor economical for fruit, owing to specialized requirements for the rapid cooling of the fruit and the maintenance of its temperature within narrow limits. For best possible returns on investments, emphasis must be placed upon both the design and the efficient operation of a fruit cold-storage plant.

Many cold-storage operators, including foremen and plant engineers, will desire more detailed information on many subjects that necessarily are greatly condensed in a publication of this kind. For this reason, attention is called to other publications on refrigeration engineering and fruit storage (*3, 4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 23, 24, 25.*)[1]

RESPONSE OF FRUIT TO STORAGE CONDITIONS

Before undertaking to design and operate a cold-storage plant, the nature of the product to be stored must be understood. Apples and pears are alive at the time of harvest; the length of time they may be held for consumption in the fresh state depends upon how long the end of their life can be delayed. Their storage life dates from the day they are picked, even though they may remain temporarily in the orchard or packing house. The length of storage life varies with the variety, orchard, district, and conditions of growth, the stage of maturity at which the fruit is picked, and the temperature at which it is held.

Respiration and Ripening Processes

When an apple or pear is harvested at a desirable stage of maturity its tissue consists largely of water and such carbohydrates as sugars, fruit acids, and, in and between the cell walls, celluloselike substances from which pectins are produced. These carbohydrates cement the cells together, and the degree of adhesion or disintegration of the cells determines whether the flesh of a fruit is firm, tough, crisp, and juicy, or soft and mealy. The chemical changes that take place in fruit during ripening are very complex. Starch changes to sugar; sugars change form; acids decrease; and soluble pectins increase in the cell walls. These changes go on until the fruit becomes overripe and unpalatable, with subsequent collapse. As these carbohydrate constituents of the cell undergo ripening changes, oxygen is consumed from the air, water and carbon dioxide are produced, volatile constituents are given off, and heat is generated. All these activities are embodied in what is spoken of as respiration.

The chemical changes taking place in ripening fruit, and consequently the rate of respiration, are retarded as the temperature is lowered. The quicker heat is removed from fruit after picking to bring it to an optimum storage temperature, the earlier the ripening processes will be arrested and the longer the fruit can be kept.

The generation of heat during the respiration and ripening processes, referred to in more detail on page 31, is greater than is commonly realized and is a factor deserving important consideration in the design and operation of fruit cold-storage houses. The faster a fruit ripens the greater the quantity of heat generated. A Bartlett pear ripens faster than an apple at a given temperature, and, therefore, its greater heat of respiration results in larger refrigeration demands, even when it is taken into storage at the same temperature as the apple. Data on the generation of heat in apples and pears have been discussed in an earlier publication (*20*).

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[1] Italic numbers in parentheses refer to Literature Cited, p. 60.

STORAGE TEMPERATURES

Research by Magness and others (*14*) has shown that when apples are stored at 40° F., the rate of ripening is about double that at 32°, and at 60° the rate is about three times that at 40°. At 85° the softening and respiration rates have been found to be about double those at 60°. At 30° about 25 percent longer time is required for apples to ripen than at 32°. This emphasizes the importance of having the cold storage designed to establish quickly and to maintain uniform low temperatures.

UNIFORMITY OF TEMPERATURE

Uniformity of temperature relates both to its range on the thermometer scale and to the maintenance of a like temperature throughout a storage room. In some plants, cycles of compressor operation cause a fluctuation of 2° to 4° F. in air temperatures. Slight fluctuation does not injure fruit unless it is downward to a point resulting in freezing or in low-temperature injury. Apples or pears exposed to a temperature fluctuating from 30° to 34° will keep as long as if stored at a constant temperature of 32°. If the fruit is stored at a uniform temperature of 30°, however, its life may be lengthened by 25 percent (*14*).

Maintaining uniformity of temperature in all parts of a storage room is more important than avoiding small fluctuations at a given point. Fruit ripens faster when stored in a part of the room where the temperature is continuously higher than in another part. This frequently results in the mixing of overripe and prime fruit in shipment, or it may result in undetected deterioration and decay of fruit in inaccessible locations.

The influence of the temperature of fruit on the rate of ripening has special significance in cold-storage management. Apples at 70° F. ripen as much in 1 day as they would at 30° in 10 days; a delay of 3 days in an orchard or in a warm packing shed may shorten their storage life as much as 30 days even if they are then stored at 30°. Storage temperatures recommended for various fruits are discussed in Circular 278 (*20*).

EFFECTS OF RAPID COOLING

Apples and pears are not injured by too rapid cooling unless freezing takes place or the fruit is susceptible to injury by low temperature occurring above the freezing point. Some low-temperature injuries of apples are discussed on pages 9 to 12.

FREEZING IN STORAGE

Because of the dissolved constituents in fruits and vegetables (chiefly sugars and acids) the freezing points of these products are appreciably below that of water. The average freezing point of apples is 28.4° F. It ranges from as high as 29.7° to as low as 27.3° in some of the summer varieties, but is between 28.0° and 29.0° for the principal winter varieties that are stored. The freezing temperatures of pears are slightly below those of apples. Average freezing temperatures of some fruits are given in table 1; for more detailed information on this subject see Circular 447 (*26*).

TABLE 1.—*Average freezing temperature of various fruits*

Fruit and variety	Freezing temperature	Fruit and variety	Freezing temperature
Apples:	° *F.*	Peaches:	° *F.*
Baldwin	29.0	Elberta	29.7
Delicious	28.4	J. H. Hale	29.6
Jonathan	28.3	Grapes:	
Winesap	28.2	American, or labrusca, type:	
Yellow Newtown	28.0	Moore Early	28.3
Pears:		Catawba	26.7
Bartlett:		Concord	27.2
Hard ripe	28.5	Delaware	24.6
Soft ripe	27.8	European, or vinifera, type:	
Anjou:		Ohanez (Almeria)	25.6
Hard ripe	26.9	Alphonse Lavallee (Ribier)	24.8
Soft ripe	27.2	Emperor	24.6
Cherries:		Sultanina (Thompson Seedless)	23.6
Bing:			
Mature (black)	24.1		
Immature (bright red)	25.3		
Sour	28.0		

HUMIDITY

The loss of moisture from apples and pears in storage, resulting in shriveling or wilting, is directly related to moisture in the form of water vapor in the storage atmosphere. When the humidity is maintained at above 90 percent, the development of fruit rots is encouraged as well as surface-mold growth on the fruit, on the walls, ceilings, and floors of the storage room, and on the packages. Under ideal conditions of humidity, with active air movement, apples and pears may be kept in cold-storage rooms without risk of excessive moisture loss, but when the relative humidity is low, shriveling is aggravated by moving air, particularly when the fruit is stored without wraps. A relative humidity of 85 percent is considered ideal for most fruits.

AIR CIRCULATION AND VENTILATION

Apples and pears should be stored in an atmosphere free from pronounced odors. They acquire off-flavors when stored with potatoes, onions, cabbage, and certain other products. If stored by themselves, most fruits do not require a change of the air other than that occasioned by the opening of doors or ports under normal operation, provided the fruit is not overripe when received and is quickly cooled to an optimum storage temperature.

In most parts of the United States it has not proved practical to substitute natural cold air for mechanical refrigeration during winter months, so that it is seldom advisable to make any special provisions in the storage designs for bringing in outside air.

In the storage of apples there is an advantage in having active air movement about the packages, particularly with varieties susceptible to apple scald. Less scald develops when they are stored in moving air. A heavy odor in an apple storage means that some of the fruit is reaching an advanced stage of ripeness and is a signal to remove the apples that are approaching the end of their storage life.

Ethylene, a gas given off by ripe apples, pears, and some other fruits, hastens the ripening of fruit stored at high temperatures, but has very little effect at low temperatures. Even a very small quantity of the gas will cause accelerated ripening at favorable temperatures. This is an added reason for designing the cold storage for the rapid cooling of fruit in all parts of the rooms rather than attempting to provide for removal of the ethylene by ventilation.

CONTROLLED-ATMOSPHERE, OR GAS, STORAGE

Reducing the oxygen content and regulating the concentration of carbon dioxide in the atmosphere of a storage room generally slows up the rate at which fruits ripen. This principle has been applied as an auxiliary to refrigeration in the storage of some varieties of apples and pears. Gas storage has come into considerable use in England and to a limited extent in the northeastern part of the United States, where certain varieties of apples are susceptible to low-temperature disorders when stored in air at 32° F.

The common practice is to seal the storage rooms until they are essentially gasproof and permit the fruit to consume oxygen until it reaches the desired level, thereafter controlling the concentration of the gas by ventilation. The concentration of carbon dioxide is built up to the desired percentage by the respiration of the fruit and thereafter is controlled, when necessary, by circulating the air through an atmospheric washer containing a dilute solution of caustic soda to absorb the excess carbon dioxide. Refrigeration equipment also is necessary, since a temperature of about 40° is desired.

The application of the principle of controlled-atmosphere to the storage of fruits has been limited because of the varying tolerance to carbon dioxide gas of different kinds of fruit. Likewise, different varieties of apples respond differently to a given atmosphere of the gases used. For detailed information on the use of controlled-atmosphere storage, see references to studies made in different localities in the United States (*1*, *9*, *22*).

STORAGE SANITATION

A storage interior free from decayed fruit, dirt, and mold is a criterion of good management. The growth of surface molds within a storage, however, may indicate favorable conditions of relative humidity and does not particularly menace stored apples and pears packed in closed containers. The use of fungicidal paints or the annual whitewashing of walls, ceilings, posts, and air ducts and the oiling of the floors will largely prevent the growth of surface molds, which make them unsightly. Mold growth and spores may be killed by spraying the empty storage with a sodium hypochlorite solution having 0.8 percent available chlorine. The rooms should be closed for a few days following the application.

Chlorine vapor from a spray of sodium hypochlorite is an irritant to the mucous membrane. Workmen should therefore be protected from injury while spraying. This may be done by use either of fans to produce an air movement to carry away the fumes or of an all-service gas mask in nonventilated rooms.

Fumigating the storage rooms is another method of killing molds and one that will reach areas not accessible to sprays. Sulfur dioxide is commonly used for this purpose. It is produced by burning sulfur at the rate of 5 pounds per 10,000 cubic feet of space. As soon as the sulfur has been ignited, the rooms should be closed for 24 hours. Sulfur furnaces should not be placed near motors or delicate machinery, as the fumes are corrosive and prolonged heavy concentrations are destructive to machinery parts. Removal of such equipment or protection by covering is a recommended precaution.

In burning sulfur, precautions against fire should be taken by placing the furnace over a 3-inch layer of sand or in a receptacle of water with a surface of 2 feet greater radius than the furnace.

Sulfur dioxide is injurious to apples and pears, and no fruit should be placed in the rooms until all traces of gas have disappeared. It is likewise a strong irritant to eyes and mucous membranes, and care must be exercised to avoid contact with the fumes during and after fumigation. Doors should be opened to air the rooms thoroughly after fumigation and before they are entered by workmen. For this reason it is feasible to fumigate only during the season when the storage space is not in use.

STORAGE BEHAVIOR OF APPLES AND PEARS

Success in the storage of apples and pears is dependent upon giving due consideration to their inherent characteristics and to their normal cold-storage life, as well as to the handling of the fruit before storage (*8, 20*).

Apples

A temperature of 30° to 32° F. and a relative humidity of 85 to 88 percent give best results in the storage of most varieties of apples in most parts of the United States. Certain varieties, however, sometimes will not tolerate continuous low-temperature storage. Yellow Newtown apples from the Pajaro Valley of California and McIntosh and Rhode Island Greening apples from New York and New England should be held at 35° to 38° to prevent the development of internal browning and brown core. Grimes Golden should be held at 34° to 36° to prevent soggy break-down. Under conditions described below, certain other varieties should be stored at temperatures higher than 32° to avoid storage disorders.

The higher the storage temperature the faster the apples will ripen and the sooner the end of their storage period will be reached. Apples stored close to the place where they are to be consumed may be held until they are ripe, and if in the hands of the consumer the day following removal from storage they will still be acceptable. Apples stored at more distant points must have sufficient life left when withdrawn from storage to withstand the higher temperatures of transportation and distribution. The longer apples are stored the shorter their life after removal to higher temperatures. Thus, apples that leave cold storage in apparently good condition may reach the consumer in an overripe and mealy condition with many decayed fruits when distribution requires 10 days to 2 weeks. Some forms of deterioration of apples in storage are discussed here.

AMMONIA INJURY

The appearance of ammonia injury on apples is recognized by a prominence of the lenticels, which become white at the center, with some or many surrounded by bands of black on the red surfaces or of green on the yellow-green areas. Even short exposures to small concentrations of ammonia will produce these color changes. When ammonia concentrations are 2 to 5 percent, an exposure of 5 to 8 minutes results in prominent lenticels with the surrounding discoloration spreading between the black or green rings. After the apples have been exposed to the fumes for a short period, they partially recover when aerated. The residual damage may be only a slight skin blemish around the lenticels or it may be more serious and affect the flesh tissue.

APPLE ROTS

Apple rots are either initially or finally caused by fungi commonly referred to as molds (*6*, *19*) or are associated with them. From the standpoint of the cold-storage operator, a most important characteristic of rot-producing fungi is that their growth and the germination of spores are either entirely stopped or greatly held in check at temperatures of 30° to 32° F. The riper the apples are before being handled the more susceptible they become to injury and rot infection. The growth of such important fungi as blue mold, gray mold, and *Alternaria* progresses slowly at temperatures of 30° to 32° once infection takes place. Gradual cooling over 2 to 4 weeks is a bad practice. It hastens the unseen development of rot fungi and later results in a greater percentage of decay than in fruit cooled quickly.

The cold-storage warehouseman needs to keep a close watch for ripening and decay in all storage lots. Certain "side rots" and the "bull's-eye" rot from perennial canker are of slow growth until apples reach a certain stage of ripeness, whereupon the rots grow rapidly and become apparent in a few weeks, often causing severe loss before being detected. Susceptible lots should be inspected frequently and should be sold before becoming ripe, especially after the first signs of decay are noticed.

The effect of cold storage upon susceptibility to decay of the fruit before it is washed and packed depends upon the character of storage and the degree of ripeness of the fruit when handled. The washing and packing of firm apples that are placed in good cold storage promptly after harvest may take place over a long period without increasing the danger from storage rots. When apples are to be held at temperatures conducive to ripening, it is preferable to pack them before storage unless they are to be consumed promptly after packing.

BITTER PIT

Bitter pit, sometimes called Baldwin spot or stippen and recognized by sunken areas or pits with brown spongy areas in the flesh, cannot be controlled in cold storage. Bitter pit is a disorder related to growing conditions and may become noticeable on the tree or after the fruit has been harvested and stored. Leaving apples on the tree until they are mature often reduces loss from bitter pit or prevents its subsequent development in storage. Crops of susceptible apples intended for storage should be held at 30° to 32° F. for 2 months before being packed so that affected fruits may be sorted out.

INTERNAL BROWNING, OR BROWN CORE

The terms "internal browning" and "brown core" are used, respectively, to designate the effects of low-temperature injury in Yellow Newtown and McIntosh apples. The Yellow Newtown grown in the Pajaro Valley in California is especially susceptible, and in this variety the injury commonly appears as elongated areas of brown discoloration radiating from the core. As it progresses it may spread throughout the tissue and resemble internal break-down. In McIntosh, as well as in Yellow Newtown and some other varieties, it is characterized at first by a slight brown discoloration between the seed cavities that may later progress until the entire core area becomes brown, making the fruit unmarketable. Susceptible apples should not be stored at 30° to 32° F. but at 36° to 40° to prevent or minimize losses during storage. In districts where internal browning and brown core are serious storage hazards, the application of controlled-atmosphere storage should be considered (*22*).

INTERNAL BREAK-DOWN

Internal break-down, recognized by a more or less general brownish discoloration of the flesh, usually outside the core area and at the blossom end of the apple, is essentially death from old age. It manifests itself variously in different varieties. In Jonathan an area on one side or in a zone beneath the skin may become brown and dry while the rest of the flesh is crisp and juicy. This is sometimes spoken of as "Jonathan break-down." It is associated with fruit harvested at an advanced stage of maturity and may occur early in the storage season.

In other varieties internal break-down may appear as brownish streaks in ripe, mealy tissue, later becoming badly discolored, dry, and spongy. This is designated as "mealy break-down" and in some varieties the skin often ruptures. Late in the storage season or after removal from storage this disorder frequently occurs beneath bad bruises, or in tissue near the core in a region affected with severe water core at the time of harvest. The risk of loss from internal break-down is negligible when apples are harvested at the proper stage of maturity and stored promptly at 30° to 32° F. for normal periods for the variety. When found in a storage lot, it should be regarded as a signal for prompt disposal of the fruit.

A somewhat similar type of discoloration occurs in the fruit of some varieties in some districts before harvest. It is caused by a deficiency of boron. This type of break-down does not become worse while the fruit is in storage.

APPLE SCALD

Apple scald is a browning of the skin and is distinguished from soft scald by being superficial and generally diffuse, and from a similar superficial browning following washing injury by being more localized and more pronounced on the green or unblushed surfaces. It is associated with fruit harvested at an immature stage and may be entirely prevented in some varieties, including Delicious, by delaying picking until the fruit is sufficiently mature. It is induced by certain volatile products of respiration, and if apples are not too immature when harvested it can be largely controlled by placing paper containing at least 15 percent of an odorless and tasteless mineral oil in contact with the fruit as soon as possible after harvest. When shredded oiled paper is used, at least half a pound per bushel is necessary and it should be well distributed so as to be in contact with every apple.

Where practical considerations dictate the storage of loose fruit for extended periods, scald prevention calls for (1) fruit adequately mature when picked and (2) active air movement over it. The use of slatted crates or orchard boxes and adequate spacing of containers in storage is beneficial. Apple scald ordinarily does not begin to appear earlier than 60 days after harvest, and the more mature the apples when picked the later its appearance. When it begins to appear, the fruit should be disposed of, as the scald is likely to spread and become more intense, especially after the apples are taken out into living-room temperature. Scalded fruit frequently arrives at the market in bad condition, with rots starting in the scalded tissue.

SOFT SCALD AND SOGGY BREAK-DOWN

Soft scald is frequently confused with apple scald but has a different appearance and is radically different with respect to cause and prevention. Soft scald seldom occurs on fruit picked at the proper stage of maturity and stored immediately at 30° to 32° F. It is usually caused when susceptible varieties of apples are delayed at warm temperatures after harvesting and are then placed in low-temperature storage (below 36°). It cannot be prevented by the use of oiled paper or by picking at an advanced stage of maturity.

In its early stages soft scald may resemble apple scald, as faint patches of brown become apparent, but soft scald develops rather rapidly into slightly depressed areas of discolored skin. The margins of the affected areas are sharp, and the pattern is generally irregular. The apple may have the appearance of having been rolled over a hot stove. Another distinguishing feature is the brown spongy tissue beneath affected areas. In certain varieties the disorder may be confined to the small points of contact where apples press against each other. When limited to this type of manifestation, soft scald is sometimes referred to as "contact scald" and when found in midwinter it rarely develops to greater proportions.

Jonathan and Rome Beauty are the varieties most susceptible to soft scald. At the expense of a shortened storage life these varieties should be stored at 36° to 38° F. if they cannot be given 30° to 32° within 24 hours after picking. The same applies to Golden Delicious if not stored within 4 days after picking. McIntosh, Delicious, and other varieties are sometimes affected. In the Winesap, soft scald is largely confined to fruit that has been held in common storage for a period and then moved into cold-storage temperatures of 30° to 32°. Soft scald can be prevented by holding the fruit in 25-percent carbon dioxide gas for 24 hours before storage at 30° to 32°.

Soggy break-down is a disease of the tissue of certain varieties of apples that has similar causes. It is largely avoided by using storage temperatures of 36° F. or above. It most commonly appears in Grimes Golden and Golden Delicious and is characterized by internal regions of brown spongy tissue, frequently with no outward signs until deterioration has reached advanced stages. The dead tissue appears as sharply defined islands or bands between core and skin or may extend to the skin and there coalesce with the surface manifestations of typical soft scald.

SCALDLIKE DISORDERS

Apples subjected unduly long to heated washing solutions, as when the washer is stopped with unrinsed fruit in the washing section, sometimes get the appearance of scald without the distinguishing evidence of heat cracks. This is caused by a bleaching of the pigment and subsequent browning of affected areas, and becomes evident within a few days after washing. Usually the discolored areas are more intense where the wax has been removed at scratches or abrasions, although in severe cases the entire apple takes on a cooked appearance. In less severe cases a diffuse discoloration appears over the entire surface, whereas in apple scald such discoloration is first observed in patches or on the unblushed side of the fruit. Apples so injured are subject to shriveling and are unsuitable for prolonged storage.

Golden Delicious and Yellow Newtown apples that hang on the tree with the cheek freely exposed to the sun may have sunburn that is not very noticeable at the time of packing, but after a period in storage the areas take on an appearance that is difficult to distinguish from apple scald. This should be diagnosed as delayed sunburn. It does not materially shorten the storage life of the fruit and when found on occasional specimens does not require the early disposal necessary when occasional specimens are found with apple scald. The only prevention is a more careful sorting of sunburned apples at the time of packing.

Small sunken scalded spots result from the contact of apples with Douglas-fir wood. They may result from contact with fir-tree props or from packing in fir boxes. The toxic effect of this wood will penetrate paper wraps and box liners.

FREEZING INJURY

Injury from freezing ranges from no visible evidence following incipient ice formation in the flesh to a brown discoloration of the entire apple following "freezing to death" at prolonged low temperatures. Intermediate stages of injury may be only a slight softening of the flesh, which, however, should be interpreted as indicating a shortened storage life; a flaky or corky character in a flesh lacking normal crispness; brown discoloration of tissue around the 10 fibrovascular bundles and extending as threadlike fibers throughout the flesh; and the appearance of sunken spots where the apples were bruised while frozen. After apples have been badly frozen, the skin becomes shriveled, the surface is discolored in irregularly shaped areas, and the tissue beneath may be translucent and water-soaked or have some shade of brown. Badly frozen tissue becomes dry and corky after prolonged storage.

When slight freezing occurs near refrigeration coils or cold-air ducts, the frost can be removed by raising the temperature at those points to 32° F., but when the apples are frozen deep in the piles, a storage-room temperature of 40° or above and an active circulation of air between the packages will be necessary to thaw them out. The fruit should not be moved while frozen, as this will result in severe injury. The thawing of frozen apples at a temperature of 70° does not result in greater injury than thawing at 32° to 40°, but a high temperature is not recommended, because of its accelerated ripening influence. To prevent shriveling, the relative humidity should be kept as high as possible during the thawing process, preferably above 80 percent.

JONATHAN SPOT

Jonathan spot is a skin disease giving the apple a freckled appearance from small black or brown spots that appear usually on the deep-colored areas. Although it sometimes develops on other varieties, especially Rome Beauty, from a commercial standpoint it is of importance only on the Jonathan. It may be confused with the black spots around the lenticels caused by arsenic burn or with the brown freckled appearance of Jonathans caused by other spray or washing injuries, but these are distinguished by their appearing earlier in storage, regardless of temperatures. The disease is prevented almost entirely by picking before overmature and storing promptly at 30° to 32° F. Jonathan spot is an indication of "old age," and its appearance is a warning that the fruit is being kept beyond its commercial storage period. It may develop on fruit still on the tree.

WATER CORE

Water core occurs in the fruit before it is removed from the tree. As it is usually associated with advanced picking maturity, crops severely affected are ordinarily not considered well suited for prolonged storage. The water-soaked areas gradually become smaller during storage and, if they are not severe, may completely disappear. Apples affected with water core never completely recover, however, because the affected tissue has been weakened and is disposed to internal break-down. In the Delicious, Rome Beauty, Stayman, and other softer varieties, internal break-down may follow slight water core at the fibrovascular bundles. Apples that have apparently made a complete recovery while in cold storage frequently become worthless from internal break-down within 5 or 6 days after removal to living-room conditions.

The disappearance of water core is not hastened by storing the apples in atmospheres of low relative humidity but rather by holding them at temperatures that produce rapid ripening. As such ripening is not desirable, however, the only recommendation that can be made is to limit the storage season as much as possible and keep the fruit under refrigeration.

PEARS

Pears have a slightly lower freezing point than apples and, not being subject to such low-temperature diseases as soft scald and brown core, can be stored at slightly lower temperatures, 29° to 31° being recommended.

As pears are rather susceptible to shriveling, it is important to keep the relative humidity of the storage room above 85 percent, preferably about 90 percent.

Pears are more responsive to high temperature than most varieties of apples, so that it is very important that heat be removed as rapidly as possible immediately after harvesting. They have a high rate of respiration, and the heat of respiration is an important consideration in storage, especially during the cooling period. For successful storage, therefore, the fruit at the center of packages must be cooled approximately to the storage temperature within a period of 48 hours before the packages are stacked in the permanent storage piles. This is usually done by circulating air at temperatures of 26° to 31° F. through widely spaced stacks of packages immediately after they are packed. After this initial cooling, packages should be stacked so as to provide air channels for the continuous removal of the heat of respiration and for uniform refrigeration throughout the piles. Stacking away from the walls and on strips or floor racks is necessary to prevent the conduction of heat to the fruit.

Pears may be held in cold storage and subsequently washed and packed without serious injury or disfigurement, provided ripening has progressed only slightly. The prevalence of scratches and other friction marks often found on fruit thus held depends on the stage of ripeness rather than being due to the influence of refrigeration. Holding the fruit for 2 or 3 weeks prior to washing and packing is safe if the fruit is kept at 30° to 31° F. from the time it is harvested.

LOSS OF RIPENING CAPACITY

Following prolonged storage, certain varieties of pears may seem to be in excellent condition but when taken to high temperatures they fail to ripen. Although the color of the fruit may become yellow in the ripening temperatures, the flesh does not soften or become juicy. Bosc, Comice, and Flemish Beauty exhibit this characteristic and do so earlier in the season when stored at 36° F. rather than at 30° to 31°. It is important that these varieties be stored at optimum low temperatures and for periods not longer than the varietal storage season. Following storage, ripening must proceed promptly at optimum ripening temperatures.

OPTIMUM RIPENING TEMPERATURES

Commercial varieties of pears grown in the United States do not ripen satisfactorily for eating while held at 29° to 31° F. Some varieties gradually become softer at these temperatures, while others may turn slightly more yellow but soften scarcely at all. All unripened pears need to be withdrawn from cold storage and held at higher temperatures to ripen for eating.

The optimum ripening temperature for most varieties is between 65° and 70° F. Bartlett has much better quality when ripened in this range than at higher temperatures. Bosc fails to ripen normally at lower temperatures. Kieffer has optimum quality when ripened at temperatures between 60° and 65°.

PEAR ROTS

Blue mold rot and gray mold rot are the most important storage rots in pears. Blue mold rot usually results from skin punctures. Gray mold rot may start at ruptures of the skin or at broken stems and spreads from fruit to fruit by contact. Once established, gray mold grows slowly in cold storage, but having the capacity to enter the unbroken skin of adjacent fruits, it often produces the so-called "nest rot" when a whole group of pears is affected. The spreading from one pear to another can be prevented by packing in wrappers impregnated with copper. Sanitary measures in harvesting and packing, together with prompt cooling to temperatures of 29° to 31° F. are important factors in preventing losses from decay. Lining the orchard boxes with old newspapers is an important precaution to take to reduce mechanical injuries and resulting infection.

PEAR SCALD

In pear scald the skin of the fruit becomes dark brown and soft and sloughs off easily under pressure. The affected skin may become almost black and affords entrance for the decay fungi that usually follow. The disease does not appear until the fruit is aged in storage from being held too long or at too high a temperature. Pear scald, other than the type on the Anjou variety, cannot be prevented by packing in oiled wrappers, but susceptibility may be lessened by picking before the fruit becomes too advanced in maturity and by storing at temperatures of 29° to 31° F.

ANJOU SCALD

The Anjou variety is subject to a mottled surface browning or blackening in storage. Unlike pear scald, this does not cause a skin disintegration that is deep-seated, nor does the skin slough off. Anjou scald can be largely avoided by picking fruit at the proper maturity and packing it in oiled wrappers such as are used for apple scald.

CORK SPOT

Cork, or cork spot, is characterized by small regions of dark-brown corky tissue appearing in the flesh of pears. When the affected tissue is near the surface a small depression frequently appears, and the skin at this spot may be slightly dark. The sunken areas on the surface sometimes fail to appear until after storage. Anjou is the variety frequently affected by cork spot. The disease is related to growth conditions in the orchard and is not caused by storage conditions. Affected fruit can be stored approximately as long as normal fruit, but its market value may be greatly depreciated if cork spot is very prevalent.

CORE BREAK-DOWN

Core break-down is characterized by an extremely soft watery condition about the core, followed by rapid disintegration and discoloration in the tissue of this region, sometimes leaving only a shell of the outer tissue unaffected. It frequently occurs during the ripening of fruit that has been left on the tree too long before harvesting and also may occur in fruit that has been held too long in storage at low temperatures. In Bartlett pears it is aggravated by ripening at too high temperatures, in which case it is not confined to the core region.

COLD-STORAGE PLANTS AND EQUIPMENT

Refrigeration

The best way to become familiar with refrigeration is to work with it and use it. Each cold-storage plant has characteristics of is own, and to take advantage of its good points and to avoid difficulties that may not be common to other plants one must be familiar with that particular plant. General principles of refrigeration apply to all plants, however, and knowing these principles will enable an operator to profit by his experience. They are covered in textbooks (*12*, *15*, *16*, *24*), and more specific information is given in handbooks (*2*, *3*, *23*, *25*) on characteristics of refrigerants, condenser, compressor, and evaporator, insulation values, fan and duct data, requirements of stored products, cooling surface, power requirements, and other matters.

PUMPING HEAT

The process of refrigeration might be likened to pumping air out of a tank until the pressure is lower than that of the atmosphere. Once the desired low pressure inside the tank is reached, the only additional pumping necessary is to remove any air that enters the tank by leakage, and then the pumping needed will depend entirely upon the leakage. In a refrigerated space, it is desirable to maintain a certain temperature below that of the surroundings. Heat is pumped out until the desired low temperature is reached, whereupon further pumping is necessary only to remove the heat that enters the chamber by leakage through walls and open doors or heat that is generated within the space.

When pumping air from a vacuum tank, if only a slight approach to vacuum is required, less power and a smaller pump are needed than for a high vacuum. The size of the pump required and the horsepower of the motor depend upon two factors: (1) The quantity of air to be removed and (2) the pressure inside the tank. If too much air is allowed to enter the tank, the pump cannot remove it and the desired vacuum cannot be maintained. Similarly in a refrigerating system, if only a moderately low temperature is required, less power and a smaller compressor are needed than where a very low temperature is desired. Furthermore, if the refrigeration machinery does not have the capacity to pump out heat as fast as it enters the chamber, the desired low temperature cannot be maintained.

In extending the comparison, the factors determining the size of the pumps are, in the case of the vacuum, (1) pressures, usually expressed in pounds per square inch; and (2) quantity of air, expressed as pounds per minute. In the refrigerating system the factors are (1) temperature, expressed in degrees; and (2) heat, commonly expressed as British thermal units (B. t. u.). The term "B. t. u." (the heat required to raise the temperature of 1 pound of water 1° F.) corresponds to the term "pound" (in pumping air), inasmuch as they both express definite quantities of the thing to be handled.

QUANTITY OF HEAT

In dealing with refrigeration problems it is just as necessary to consider the quantity of heat to be handled as to speak of pounds of air or gallons of water when computing the necessary sizes of air or water pumps for given jobs. Just as 1 pound represents a very definite and measurable quantity of air, and it is still the same regardless of the pressure under which it is placed, so 1 B. t. u. represents a definite and measurable quantity of heat, and it too remains the same regardless of existing temperatures.

The refrigeration demand upon the machinery is frequently spoken of in terms of "tons." This usage had its origin in a comparison of refrigerating capacity, or demand, with the refrigeration obtained from melting 1 ton of ice. As 144 B. t. u. of heat are required to change 1 pound of ice to water at the melting point, 288,000 B. t. u. are required to melt 1 ton of ice. Where it is necessary to remove 288,000 B. t. u. of heat in 24 hours, 1 ton of refrigeration is required.

If, for example, a temperature of 32° F. is to be maintained in a storage building, the refrigeration system will have to remove a quantity of heat just equal to that which enters the building. The heat entering may come from a number of sources. In the first place, if the outside temperature is above 32°, some heat will come in through the walls. This can be reduced by insulation, but not even the best of insulation will exclude all heat leakage. If there are cracks in the building, or if doors or windows are open and permit warm air to enter, an increased quantity of heat will be introduced, depending upon the outside temperature and the quantity of air. Materials having temperatures above 32° placed in the cooled space, will introduce still another quantity of heat, depending upon the temperature, weight, and nature of the material. If the materials are living, as for example, apples, they will produce heat continually; and this heat is in addition to that which they contained when first put into storage.

The heat from all these sources and from other incidental sources combines into the total quantity of heat the refrigerating system is expected to remove. If the system has sufficient capacity the heat can all be pumped out. If the heat introduced into or produced within the building exceeds the capacity of the refrigeration system, some of it will remain in the fruit and cannot be taken out until the rate of heat intake drops below the rate at which it can be removed.

The quantity of heat that a refrigeration system can remove may be increased or decreased by the conditions under which it operates, but no manipulation of air movement or special stacking of boxes or other adjustment can prevent the accumulation of heat if it is being introduced or produced faster than it is being removed.

THREE STEPS IN THE REFRIGERATING PROCESS

Heat, like air, is handled in definite quantities, but unlike air it cannot be moved bodily from one point to another. By its nature heat moves from a place of high temperature to one of low temperature. A refrigerating system, or heat pump, takes advantage of this tendency.

Heat from the storage room moves through the walls of the evaporator cooling coils to the ammonia or other refrigerant inside, which is at a lower temperature. The compressor then takes the vaporized ammonia with the heat it has picked up in the evaporator and, by compressing the gas, raises its temperature. The heat from the hot ammonia finally moves into the condenser water because the water is at a lower temperature. Thus the heat from the storage is now in the condenser cooling water, which may either be wasted or cooled by aeration for recirculation. These three steps in heat removal are accomplished by the three essential parts of the refrigerating system—the evaporator, the compressor, and the condenser (fig. 1).[2]

In the evaporator, or cooling coils, the quantity of heat picked up depends upon (1) the temperature difference between the refrigerant (ammonia) in the coils and the air outside, (2) the area of coil surface exposed, and (3) the resistance to heat flow through the walls of the pipes. The resistance to passage of heat into the coil in turn depends not only upon the cleanness of the coil but also upon the velocity of air (or brine if a brine cooling system is used) passing the coil and the velocity of the refrigerant (whether liquid or vapor). The resistance is increased by an accumulation of frost, or if not enough piping surface is exposed a large temperature difference will be necessary between the inside and outside of the coil to permit suffi-

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[2] Bowen (*4, pp. 2–3*) describes the operation of the refrigerator shown in figure 1 as follows:

To utilize its latent heat of vaporization for refrigeration and to conserve the refrigerant, application is made of the physical law that the temperature at which a fluid boils or condenses is raised or lowered, respectively, by increasing or reducing the pressure. To cause the refrigerant to boil at a low temperature in the evaporating coils and hence absorb heat on a low-temperature plane, the pressure in the coils is lowered by the suction of the compressor. . . . To free the fluid of the heat absorbed in the refrigerator and return it to liquid form, the cold refrigerating gas coming from the evaporating coils is compressed until its temperature is raised above that of the water flowing through the condenser so that the contained heat can pass from the gas to the water. (In very small machines, air may be used instead of water.)

The essential parts of a compression-refrigerating system are an evaporator, a compressor, and a condenser.

In the evaporator (the coils in the refrigerator) the liquid boils and in the process absorbs heat from the surrounding medium. The compressor is a specially designed pump that takes the gas from the evaporator coils and compresses it into the condenser coils, reducing its volume and increasing its temperature. The condenser consists of coils of pipe over or through which water or air flows to absorb the heat from the gas, which is thereby liquefied. In some systems the cooling water passes through an inner tube, and the gas from the compressor through the annular space between the inner and the outer pipes. From the condenser the refrigerant passes first to a liquid receiver, and then through a throttling or expansion valve into the evaporator coils, to repeat the process of transferring heat from the refrigerator to the water flowing through the condenser. The temperature of the liquid ammonia is reduced from the temperature of the receiver to that of the refrigerator by vaporizing a part of the liquid.

The expansion valve is of a special design and is capable of very fine adjustment. Its function is to so regulate the flow of the liquid refrigerant that suitable pressure and temperature conditions will be maintained. It is largely responsible for the control of temperature in the evaporating or cooling coils.

cient heat to pass into the coils. This requires a low ammonia temperature. If, because of resistance or insufficient surface in the cooling coils, it is necessary to maintain a low ammonia temperature (which means low suction pressure), the compressor is forced to boost the temperature from a low point, and it cannot handle as much heat as when the suction temperature is higher.

The compressor must also discharge the ammonia at such temperature that heat will flow from it to the cooling water in the condenser. In general, a compressor can handle more heat if the temperature in the cooling coils is kept as high as possible and the temperature in the condenser as low as possible. The same conditions also reduce the power necessary to remove a given quantity of heat.

When the ammonia enters the condenser, heat passes from it into the cooling water. As in the evaporating coils, the heat passing from the ammonia to the cooling water depends upon (1) the temperature difference between the ammonia and the water, (2) the surface area exposed, and (3) the resistance to heat flow through the condenser pipes. Here also, the resistance to the passage of heat depends upon the water and the ammonia velocities and the cleanness of the coil. Scale, which tends to collect on the pipes from the cooling water, may increase the resistance markedly. If this scale is permitted to build up or if there is not sufficient cooling surface, the required quantity of heat can be transferred to the water only by having a large temperature difference between ammonia and water. As pointed out before, the high ammonia temperature in the condenser means reduced compressor capacity and high power consumption. An adequate supply of water as cold as possible will contribute toward a low ammonia temperature in the condenser and therefore to low power consumption.

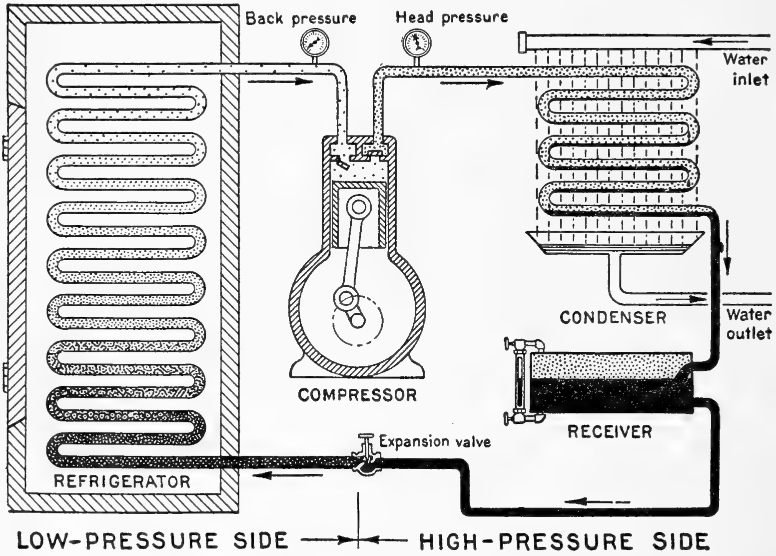

FIGURE 1.—Essential parts of a compression refrigeration system.

CONDENSER

The condenser has one purpose. It must permit the passage of heat from the compressed ammonia to the cooling water (or air in an atmospheric condenser) and do so at as low an ammonia temperature as possible. It must transfer all the heat that has been taken up in the evaporator as well as that added by the work of the compressor. The passage of heat into the cooling water is facilitated by a large area of cooling surface, by a large quantity of cooling water, by a low water temperature, and by high velocity of the water and ammonia passing the surface. A high ammonia temperature also increases the quantity of heat transferred to the cooling water, but it is the function of the condenser to receive and discharge the ammonia at as low a temperature as possible. The design of the condenser and its operation should be such as to remove the required quantity of heat without excessive ammonia temperatures.

In operation the effectiveness of the condenser may be judged by the head pressure indicated on the gage. If the head pressure goes too high, the effects on the system are that less heat is removed from the cold rooms and more power is required to operate the compressor. The effect of various high head pressures on power requirements at various suction pressures may be seen in the accompanying chart (fig. 2). For example, when operating at a 25-pound suction pressure, and a head pressure of 120 pounds, about 1.0 horsepower is required to remove 288,000 B. t. u. per day (1 ton of refrigeration); whereas, at a head pressure of 195 pounds, about 1.5 horsepower is required for removing heat at the same rate. That is, the power cost is about 50 percent higher at a 195- than at a 120-pound pressure. At the same time, a high head pressure results in reducing the heat that the system can handle. This is illustrated in figure 3.

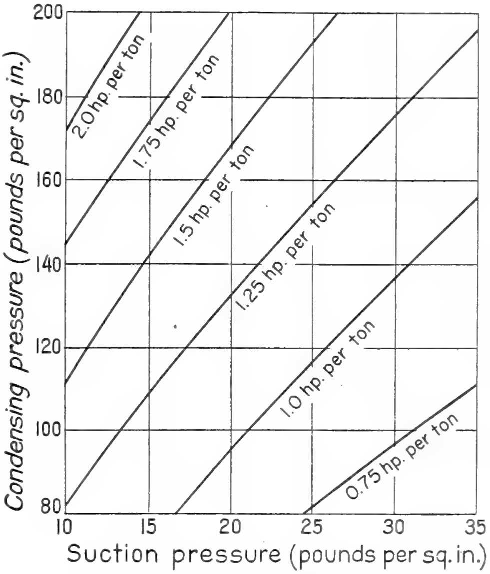

FIGURE 2.—Effect of condensing and suction pressures upon power requirements of a typical ammonia compressor.

If the head pressure is too high when the plant is running to capacity, it may be because the condenser is too small, there is not enough cooling water, the cooling water is too warm, noncondensable gases are present, or the condenser tubes are dirty. The water used in the condenser usually contains impurities that corrode the pipes and form deposits on them. If such deposits are allowed to accumulate over long periods they interfere seriously with the exchange of heat.

TYPES OF CONDENSERS

While all condensers have as their purpose the cooling of the hot ammonia gas, thereby changing it to a liquid, there are several different general types. In each the hot gas is circulated through or around pipes that are exposed to a cooling fluid, usually water. In a double-pipe condenser the ammonia is passed through a bank of pipes. A smaller pipe carrying cooling water extends full length inside each section of ammonia pipe. Several banks of double-pipe condensers are usually mounted together to give the required capacity. In a vertical shell-and-tube condenser the ammonia gas enters the top of a large vertical cylinder and the condensed liquid drains off at the lower end. Numerous vertical pipes inside the cylinder are mounted so that a film of cooling water runs down the inside of each pipe. As the ammonia condenses on the outside of the pipes it flows to the bottom of the cylinder, where it is drained off to the receiver.

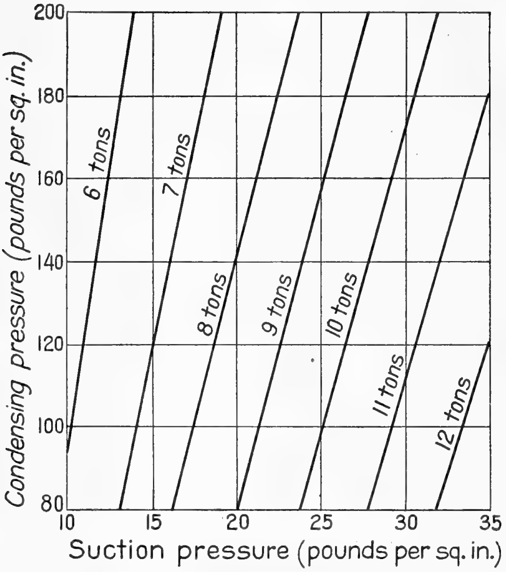

FIGURE 3.—Effect of condensing and suction pressures upon the capacity of a typical ammonia compressor.

The horizontal shell-and-tube condenser is similar to the vertical, except that the shell is in a horizontal position and the water pipes carry cooling water under pressure. The water is usually passed back and forth through several tubes in series before being discharged. In this way its velocity is increased to give more rapid cooling without having to discharge large quantities.

An evaporating condenser has the ammonia gas pass through coils that are exposed to a spray or drip of water. At the same time air is blown through the water spray past the pipes and causes some of the water to evaporate. This evaporation keeps the water cool, so that it can be recirculated, and the only waste is the water that is evaporated or carried away in the air blast. This is particularly suited to conditions where cooling water is limited or expensive and where the atmosphere is relatively dry during the time large loads are expected on the refrigeration machinery.

Where a dry climate or limited supply of cooling water makes it desirable, the effect of evaporative cooling may also be obtained with shell-and-tube or double-pipe condensers by using a cooling tower or a cooling pond. In this type, the water from the condenser, instead of being wasted, is pumped to a tower (frequently on top of the building) or to a cooling pond adjacent to the building where it is forced through nozzles to form a spray. After falling through the atmosphere, where it is cooled by the evaporation of a small portion, the water is recirculated through the condenser.

Another type, the atmospheric condenser, as frequently used with small cooling or freezing cabinets, usually is not practical for larger installations.

COMPRESSOR

The compressor, by pumping ammonia from the evaporator to the condenser, takes the heat that has been absorbed in the coils and, by raising the temperature, allows the heat to be carried away by the condenser cooling water. The rate of heat removal by an ammonia compressor running at a given speed depends only upon the head pressure and the suction pressure at which it operates; the higher the suction pressure and the lower the head pressure the more heat will be removed. If the speed is increased, the rate of heat removal will increase proportionately, assuming a given set of pressure conditions. It is good practice, therefore, to operate a compressor at as high a speed as its design will permit, especially during the season when warm fruit is being received.

In fruit storage the demand on the refrigerating equipment is at a maximum for only a short period in fall. Much of the capacity of this equipment is unnecessary during the rest of the year. To get the most out of it for this critical period, while keeping the investment in equipment at a minimum, it is sometimes economical to operate at higher speeds than would be advisable for year-round operation. Compressors, however, should be speeded up only after consulting the manufacturer regarding the particular machine. Greater capacity may be obtainable in some slow-speed compressors by changing the valves and lubrication system to permit considerably higher speeds.

It is a mistake to judge the capacity of the refrigerating system by the size either of the compressor or of the motor installed. The capacity will depend upon the whole system and the conditions under which it operates. For comparative purposes the refrigerating capacity of a compressor is normally expressed as standard tons when operating with a head pressure of 155 pounds and a suction pressure of 20 pounds, but the actual capacity will be influenced by conditions in the system as a whole that cause variations in these pressures. The capacity of and power required for typical ammonia compressors of various sizes are given in table 2.

TABLE 2.—*Capacity and power data for typical 2-cylinder ammonia compressors*

Cylinder size (inches)	Displacement per revolution	Speed	Typical refrigerating capacity and power requirements at 155-pound condenser pressure and 20-pound suction pressure	
			Capacity	Power
	Cubic foot	*R. p. m.*	*Tons*	*Hp.*
3 x 3	0.024	400	2.1	3.5
4 x 4	.058	375	4.7	7.1
5 x 5	.113	360	8.9	13.4
6 x 6	.196	360	15.6	21.8
6½ x 6½	.249	360	20.0	28.0
7½ x 7½	.383	360	31.0	43.0
8 x 8	.465	360	39.0	53.0
9 x 9	.662	300	48.0	63.0
10 x 10	.909	300	67.0	87.0

EVAPORATOR

The evaporator, or cooling coil, absorbs the heat from the room. The ammonia, having had its load of heat removed in the condenser, is expanded to a vapor. This expansion, or evaporation, under low pressure, reduces the ammonia temperature to such a point that it is ready to pick up more heat from the cold room. This is done by direct expansion coils in the room or by air circulated from the room to a bank of coils or finned surfaces. Here, as in the condenser, conditions should be such as to permit the heat to flow with as little temperature difference as possible between the ammonia and the air in the room. If there is not sufficient cooling surface, if the surface is covered with frost, or if other factors retard the heat flow, the ammonia would have to be extremely cold. This would mean a low suction pressure, which reduces the capacity of the compressor. At low pressures ammonia gas is less dense, and the smaller quantity of gas drawn into the compressor at each stroke results in lower refrigerating capacity.

That the capacity of a typical compressor is increased markedly as the suction pressure is raised is shown graphically in figure 3. For example, at 140-pound head pressure and at a suction pressure of 24 pounds the compressor delivers 9 tons. An increase of 4 pounds in suction pressure changes the capacity of the same machine to 10 tons. If by increased cooling surface or careful operation the pressure could be increased to 36 pounds, about 12 tons of refrigeration would be obtained, a gain of 33 percent. Similar changes in suction pressure in an ammonia machine of any size would result in approximately the same percentage increase in capacity.

Another disadvantage of operating at low suction pressures is that the coils are extremely cold and a large quantity of moisture is condensed out of the air, resulting in low storage humidity. Ample evaporator coil surface will permit the cooling to be done without excessively cooling the air that touches the coils. The results of cooling the air to low temperatures are shown in table 3.

TABLE 3.—*Relation of coil-room temperatures to relative humidity in storage room*

Degrees (F.) to which air is chilled	Maximum relative humidity when the temperature (° F.) is raised to—								
	24°	26°	28°	30°	32°	34°	36°	38°	40°
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
16	68	62	57	52	47	43	40	37	33
18	75	68	62	57	52	48	44	41	36
20	83	76	69	63	57	53	49	45	39
22	91	83	75	69	63	58	54	49	44
24	100	91	83	76	69	64	59	54	48
26	--------	100	91	83	76	70	64	59	53
28	--------	--------	100	91	83	77	71	66	58
30	--------	--------	--------	100	91	84	78	72	64
32	--------	--------	--------	--------	100	92	85	79	70

COLD-STORAGE ROOMS

Two general methods are used in the distribution of refrigeration units in cold-storage rooms for apples and pears: (1) Placing refrigeration pipes on the ceilings and (2) circulating cold air through the rooms. The first is more commonly the direct-expansion system, though cold brine may be pumped through the pipes from a brine cooler. The gradual evolution in the use of refrigeration for fruit from the direct-expansion to the brine-spray system has included the dry-coil bunker system in the intermediate stage. The unit-cooler system is a modification of either the brine-spray or the dry-coil system and is especially convenient for small plants.

Fruit keeps equally well under any of these systems, provided they are installed so that cooling will be equally fast and temperatures will be kept uniform, with atmospheric humidity at about 85 percent. The choice hinges largely upon economy in installation and operation.

DIRECT-EXPANSION SYSTEM

In direct-expansion rooms, that is, where cold ammonia is circulated in exposed pipes near the ceiling, the air in contact with the coils becomes cold and, being denser than warm air, moves downward. As it picks up heat from the fruit it rises to the pipes to be again cooled. This gravity circulation, caused by differences in air temperatures, results in heat movement by convection. Air velocities in such currents are relatively low, but take place in all parts of the room if the pipes are well distributed over the ceiling, and produce fairly fast cooling. To dispose of the accumulated frost or condensed water the pipes are usually put in groups or banks, and gutters for catching the drip are hung under them, as illustrated in figure 4.

In rooms where large areas of the ceiling are without coils, direct expansion alone cannot cool the fruit very promptly, and there may be fairly large temperature differences between various parts of the room, even after the fruit has cooled to its final temperature. In such cases, use of either portable or permanent fans operating in the room to stimulate air movement will tend to make the temperatures more uniform. Fans installed to give a positive air movement will give even better results. Fans blowing directly over the cooling pipes are effective in reducing both condensation and the danger of localized freezing of the fruit.

BRINE-PIPE SYSTEM

To avoid all possibility of accidental leakage of ammonia from the cooling system into the storage rooms the cooling pipes are sometimes designed for carrying cold brine. The brine is cooled in a separate brine cooler and circulated by pumps to the various rooms. Other advantages of this method are that temperature control is simpler than in a direct-expansion system and a reserve of refrigeration is available in the cold brine to carry over short periods of shutdown. This system however, is more costly than direct expansion and for this reason it is not commonly used in fruit districts. In comparison with an air-circulation system, brine pipes otherwise have the same advantages and disadvantages as a direct-expansion system. A brine of calcium chloride instead of common salt (sodium chloride) may be used for this type of installation. Data on the density and freezing points of sodium chloride and calcium chloride brines are given in table 4.

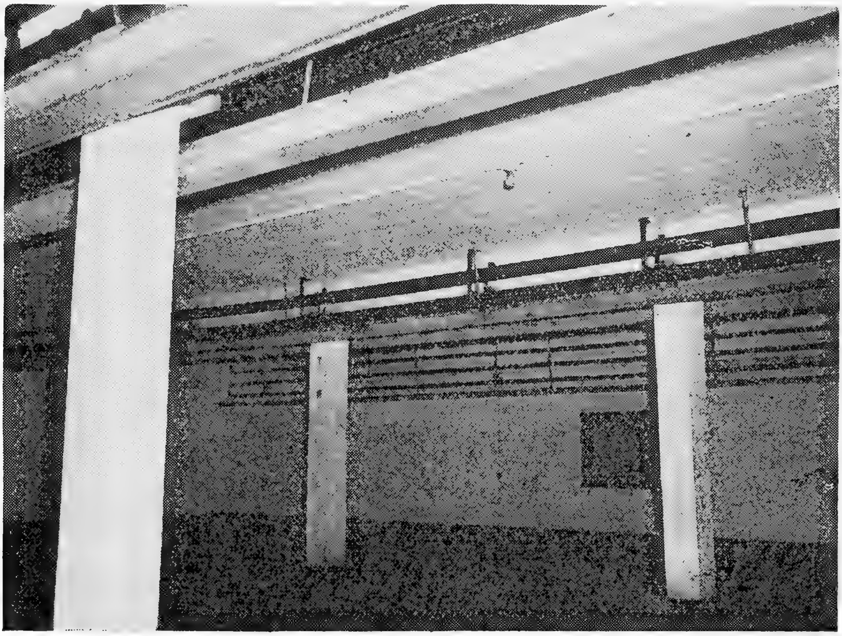

FIGURE 4.—Cold-storage room piped for direct-expansion system, with gutters suspended beneath pipes over the space to be occupied by fruit.

TABLE 4.—*Data on sodium chloride (common salt) and calcium chloride brines*[1]

SODIUM CHLORIDE

Specific gravity	Salt in 100 pounds of brine	Freezing point	Density	Specific gravity	Salt in 100 pounds of brine	Freezing point	Density
	Pounds	°*F.*	*Pounds per gallon*		*Pounds*	°*F.*	*Pounds per gallon*
1.00	0	32.0	8.33	1.10	13.5	14.9	9.17
1.02	2.8	29.1	8.50	1.12	16.1	10.4	9.34
1.04	5.5	26.0	8.67	1.14	18.6	5.4	9.50
1.06	8.2	22.7	8.84	1.16	21.1	−.3	9.67
1.08	10.9	19.0	9.00	1.18	23.5	−3.6	9.84

CALCIUM CHLORIDE

Specific gravity	Salt in 100 pounds of brine	Freezing point	Density	Specific gravity	Salt in 100 pounds of brine	Freezing point	Density
1.00	0	32.0	8.33	1.16	17.6	7.0	9.68
1.04	4.7	29.3	8.67	1.20	21.5	−5.8	10.01
1.08	9.2	23.2	9.01	1.24	25.1	−21.5	10.35
1.12	13.5	16.5	9.35	1.28	28.7	−44.3	10.68

[1] See American Society of Refrigerating Engineers Data Book (3).

DRY-COIL BUNKER SYSTEM

In the dry-coil bunker system of cooling, the ammonia coils are put in a separate room or bunker and air from a large blower is passed over them, then distributed through ducts to the storage room. If large quantities of air are used, prompt cooling and even temperatures may be obtained. The problem of accumulation of frost on the pipes remains, although disposal of the water and frost without damage to the fruit is simpler than under direct expansion. In some installations the pipes are defrosted periodically by spraying with brine or warm unsalted water. The blower is stopped while the defrosting is taking place. In other plants defrosting is done by pumping hot ammonia into the coils. Dry-coil bunkers have largely given way to brine-spray systems in recent installations.

BRINE-SPRAY SYSTEM

In the brine-spray system of cooling, air from a large blower is moved over banks of ammonia coils that are continually being sprayed with a solution of salt in water. Sodium chloride (common salt) is generally used in these systems. The salt prevents accumulation of frost, and the fine spray, being in intimate contact with the air, cools it effectively. A far smaller bank of pipes can be used than in a dry bunker, and cooling can be done with a higher ammonia temperature. After cooling, the air is distributed to the storage rooms. When a continuous brine spray is used, it is necessary to use baffles, or eliminators, in the air stream to prevent particles of brine from being carried in the air to the storage rooms. It is also necessary to treat the brine with chemicals, as recommended by equipment manufacturers, to reduce its tendency to become unduly corrosive. Despite the necessity for eliminators, which increase the resistance to air flow, and the tendency of the brine to cause corrosion, brine-spray chambers are generally displacing both direct-expansion and dry-coil bunker systems for fruit refrigeration. The arrangement of blower and enclosed brine-spray compartment in a brine-spray system are illustrated in figure 5.

UNIT-COOLER SYSTEM

A modification of the brine-spray or the dry-coil bunker is the unit cooler, which contains extended surface coils and blowers for moving the air through the coils and discharging it to the room, as shown in figure 6. Some are defrosted by a continuous brine spray, and in some the coils are washed periodically with fresh water to remove the frost. In the latter case warm water from the condenser is generally used.

FIGURE 5.—Arrangement of blower and enclosed brine-spray compartment in a brine-spray system. Motor and brine pump for forcing the brine spray over the enclosed evaporating coils are shown at left foreground. In this plant the return air ducts end in the room containing this equipment. The cold-air delivery ducts extend from the farther end of the brine-spray compartment.

These units usually discharge air at the top, either into ducts or through nozzles, and return it to the coils through openings near the floor. When the return air is picked up in the lower part of the room, it is difficult to get the best distribution of temperatures. A unit cooler installed with air ducts for a better distribution of refrigeration is shown in figure 7.

When defrosting is intermittent, it is important to make the cycle short enough to keep the coils fairly free from frost. A thin layer of frost interferes with heat transfer just as on other types of coils and also reduces the quantity of air circulated on account of the close spacing of the cooling surface.

ATMOSPHERIC MOISTURE

The humidity, or moisture content, of the atmosphere in a storage room depends largely upon the temperature to which the air is cooled in contact with the pipes or the brine.

If doors are left open in warm weather, the warm air entering the storage may be a source of moisture, but the frost on the pipes or the overflow in the brine tank is largely from water vapor transpired by the fruit. It is desirable to keep this transpiration at a minimum by maintaining a relative humidity of approximately 85 percent. This may be done by limiting the quantity of water picked up on the coils or in the spray. Some water in the form of gas or vapor is contained in the atmosphere. The lower the temperature, the less the quantity of vapor that can be held. As the temperature of the air drops, a point is finally reached at which some of the water can no longer exist as vapor and it condenses to form water or frost. The greater the temperature drop, the greater the consequent condensation.

It is important, therefore, to operate without reducing the air temperature lower than necessary. In an air-circulation system, this is done by using large quantities of air and plenty of cooling surface. If too little air is used, its temperature must be reduced greatly and excessive condensation will occur. If there is not enough coil surface in a direct-expansion system the pipes will have to be extremely cold and the air coming in contact with them will lose a large part of its moisture. Contrary to common belief, a brine spray, when used for cooling, does not add humidity to the air. On the other hand, it tends to pick up moisture. For this reason some of the brine must be

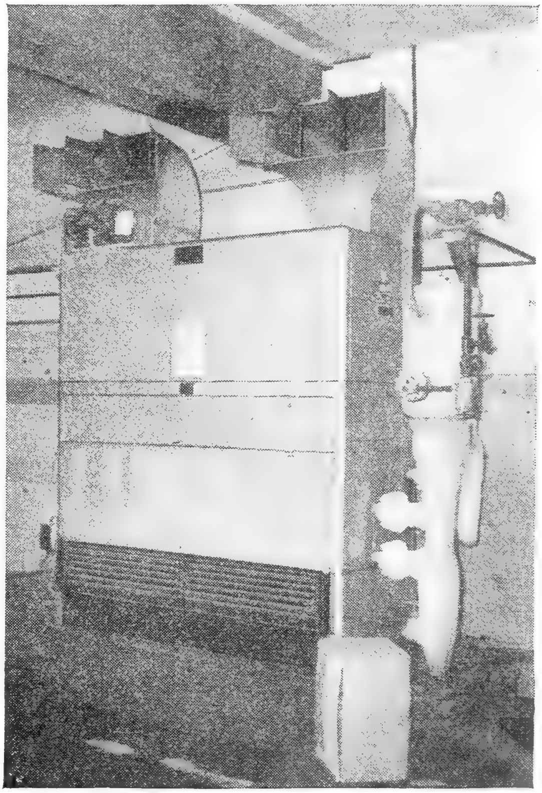

FIGURE 6.—A unit cooler in which the cold air is distributed from nozzles at the top of the room and the warm air is returned from the floor. With such installation, air is not returned from the warmest areas of the room and the best refrigeration efficiency is not obtained. A more efficient installation is shown in figure 7.

drained off occasionally and more salt added. If a brine-spray system results in higher humidity than a direct-expansion or dry-coil bunker system, it is because it removes less moisture. This is because the cooling surfaces with which the air comes in contact are not so cold as when brine coils are used.

In well-designed and well-filled cold-storage plants little difficulty is experienced in maintaining desirable conditions of atmospheric humidity during the greater part of the storage season. If it is found that the relative humidity cannot be maintained above 80 percent by steps directed toward running the compressor with higher back pressures, then a humidifying apparatus should be installed even though the procedure throws moisture into the atmosphere only to be taken out on the evaporating coils. This apparatus is constructed on two principles: one is that of an atomizer; the other is vaporization of water by heating. The use of the latter principle avoids the danger of freezing where air temperatures are below 32° F.

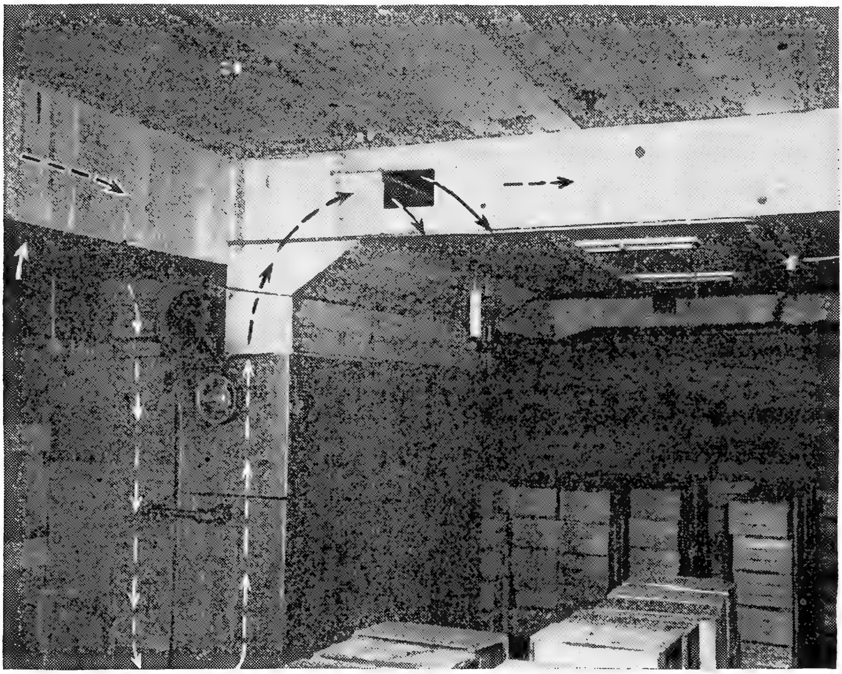

FIGURE 7.—Unit cooler installed with air ducts to deliver the cold air throughout the room and to pick up the return air from the warmest parts, in contrast with the installation in figure 6, where the return air comes from the floor.

CIRCULATION OF AIR

In all plants there is necessarily a variation of temperature in different parts of the room. This variation should be kept at a minimum. The equalization of temperature in all parts depends almost entirely on circulation of air, either by gravity or by forced draft. Gravity cannot be depended upon for adequate circulation unless the whole ceiling area is flooded with cold air or is provided with cooling coils.

As the air circulates in a storage room the heat picked up raises its temperature. If it is not picking up heat it is not doing any good. The air returning to the brine spray or dry-coil bunker is therefore warmer than that entering the room from the delivery ducts. The difference in temperature between delivery and return is often referred to as the "split," and this is directly related to the volume of air circulated and the quantity of heat picked up in the room. If the split is too large, the only way to reduce it without cutting down the heat picked up is to increase the volume of air circulated. It cannot be done by making adjustments of duct openings unless the adjustments result in delivering a greater volume of air.

For each ton of refrigeration used, an air volume of 1,000 c. f. m. (cubic feet per minute) results in a split of about 10° F., although this is modified somewhat when water transpired by the fruit is condensed by the coils. This relation applies to any combination of refrigeration employed, to the volume of air, and to the resulting split. For example, if 1,000 c. f. m. of air is used in picking up the heat equivalent to 2 tons of refrigeration, the split will be about 20°; or if 2,000 c. f. m. gives a split of 5°, about 1 ton of refrigeration is being supplied.

It is customary to design air-circulation systems so as to provide for about 1,000 c. f. m. per ton of refrigeration capacity. For example, a 25-ton plant would circulate about 25,000 c. f. m. This gives a split of about 10° when the machinery is working at full capacity. After the fruit has been cooled and some of the compressors are shut off or slowed down, the same volume of air will result in a lower split. When the refrigeration load is down to 5 tons and 25,000 c. f. m. is still used, a split of about 2° will result. In this case, a variation of at least 2° may be expected in fruit temperatures in different parts of the room. With less air volume the variation will be greater.

THERMOMETERS AND UNIFORM TEMPERATURES

If fruit were not living and generating a small quantity of heat continuously the problem of holding it at a uniform temperature would be much simpler. The heat generated must be given up to the air to prevent a rise in fruit temperature. To pick up this heat, the air must be slightly colder than the fruit, and in picking up the heat the air temperature is raised slightly. For this reason it is not possible to have the same air or fruit temperature in all parts of a storage room. In some rooms the variation may be kept down to a fraction of a degree, while in others it may be difficult to avoid a variation of several degrees even after the fruit has been cooled to its final temperature.

On account of these variations in temperature, readings from a single thermometer in a room may be misleading. To operate a plant to best advantage, it is desirable to know at least the highest and lowest temperature in each room. It is the core temperature of the fruit, however, that is most important and determines how well it will keep. It is sometimes difficult to take fruit temperatures in all parts of a room, but there are times during the season, as fruit is shifted or loaded out, when this is possible. In many cases, if temperature conditions are known, steps can be taken to make them more uniform. When fruit-temperature readings are not taken, it is often assumed that the thermometer in an aisle shows temperatures that prevail throughout the room. This is not true, and wide temperature variations may occur, especially for the first few weeks of storage.

THERMOCOUPLE

In large plants there are often inaccessible parts of the cold-storage rooms where it is not possible to take temperatures with ordinary thermometers. Here thermocouple equipment is useful. The wires of this instrument may be strung from the center of piles where actual fruit temperatures are desired and readings made in aisles or in the compressor room. Thermocouple equipment suitable for cold-storage use is illustrated in figure 8.

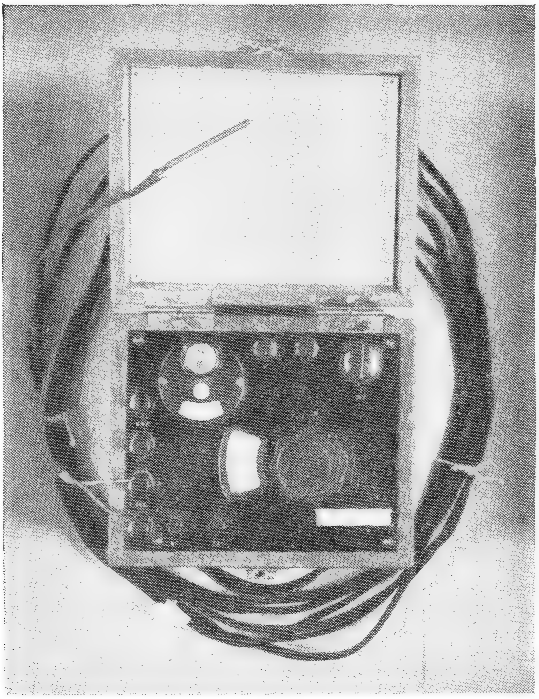

FIGURE 8.—Thermocouple equipment for reading fruit temperatures at remote parts of cold-storage rooms. The wires may be installed for reading temperatures at a central point, or the reading instrument may be carried from room to room.

REQUIRED CAPACITY OF A REFRIGERATION SYSTEM

The storage season may be divided into two distinct periods. The first is during the harvest, when warm fruit is being put into the plant; the principal problem is cooling the fruit, or removing the field heat. The second is the holding period, when the main problem is maintaining low temperatures as uniformly as possible. The heat load during this period is relatively low, consisting of the respiration heat generated by the fruit, the heat entering through the walls, and heat from workmen, power equipment, lights, air entering from outside, and other incidental sources.

NATURE OF HEAT

A discussion of the heat from various sources that has to be removed by a refrigeration system is necessarily more or less technical and includes terms that may not be familiar to all readers. It is not difficult to follow, however, if one keeps in mind that heat is just as real as air or water. It can be moved from one place to another, but it cannot vanish completely. If heat is taken from one place, the same quantity must show up somewhere else. For this reason it is convenient to think of units of heat as quantities that have a definite meaning, just as we think of gallons of water. The important thing to keep in mind is that a B. t. u. is a definite quantity of heat that can be pushed around or divided up but still exists somewhere.

The capacity of the cooling system required for a given job depends upon how much heat must be removed each day. In apple and pear storage this heat comes from several sources, each of which can be considered separately. The total load is the sum of the heat from all sources.

FIELD HEAT

When fruit is placed in storage its temperature is ordinarily higher than that desired. The heat to be removed in cooling it to the storage temperature is called field heat. It takes about 0.9 B. t. u. to change the temperature of 1 pound of apples by 1° F. If the temperature must be reduced from 65° to 32°, for example, the change is 33°, and for every pound of apples 29.7 (0.9×33) B. t. u. must be removed. On the assumption that a box of apples weighs 50 pounds, every box cooled from 65° to 32° requires the removal of 1,485 (29.7×50) B. t. u. If 1,000 boxes are stored under these conditions, 1,485,000 B. t. u. of field heat are introduced into the storage room. If the fruit is cooler or warmer, the heat load will be correspondingly less or greater.

HEAT OF RESPIRATION

Fruit continues to live as long as it is fit for food. It is therefore continually generating heat by breaking down some of its constituent materials. Bartlett pears or peaches starting at 60° F. in a nonrefrigerated, well-ventilated room probably would reach a temperature of 85° to 90° after 4 days and might go even higher. Kieffer pears and grapes produce heat more slowly and probably would not warm up to above 65° or 70° under the same conditions. Storage varieties of apples would very likely be intermediate between these two groups. It is easily seen in the case of Bartlett pears or peaches that if not refrigerated they might become worthless within a week, even if they did not suffer from decay.

The rate at which this heat is generated depends upon the fruit temperature. At 32° F. a box of apples gives off about 20 B. t. u. each day. At 60° the figure is seven or eight times as great. Prompt cooling therefore reduces the total quantity of heat to be removed from a storage room. It is estimated that if a packed box of apples is cooled from 65° to 35° in 1 week, its heat of respiration during this period would amount to about 500 B. t. u.; for 1,000 boxes the heat load would be 500,000 B. t. u., which is about a third as much as the field heat load. If cooling is so slow that it takes 2 weeks to reach 35°, another 500,000 B. t. u. will have been generated. Even after apples are cooled to 32°, they continue to give off heat. Each 1,000 boxes generates about 20,000 B. t. u. per day at this temperature. Thus, 1 ton of refrigeration (removal of 288,000 B. t. u. per day) will take care of the heat from about

14,000 or 15,000 boxes after they are cooled down. The approximate refrigeration required for cooling and storing apples is shown in table 5.

TABLE 5.—*Approximate refrigeration*[1] *required for apples if 1,000 boxes are received daily and the fruit is cooled to 32° F. in 7 days*

Initial temperature (° F.)	Tons of refrigeration	Initial temperature (° F.)	Tons of refrigeration
55	4.9	75	8.8
65	6.9	85	10.8

[1] Allowance for open doors, workmen, motors, and other incidental sources of heat may increase this requirement by 15 or 20 percent.

INCIDENTAL HEAT SOURCES

In addition to the fruit itself, other sources of heat are workmen, motors, and lights. It may be assumed that each workman gives off 1,000 B. t. u. per hour. The heat from motors can be estimated at 3,000 B. t. u. per hour for each horsepower. Each 100-watt light burning adds about 350 B. t. u. per hour.

AIR INFILTRATION

There are always times when it is necessary to leave outside doors or conveyor ports open, and in some rooms the doors are open almost continuously during the harvest season. Outside air entering the cold room may carry in large quantities of heat. It is impossible under ordinary conditions to estimate very accurately the heat load thus added by infiltration of air.

If it is assumed that a draft having a velocity of 200 feet per minute is leaving a cold room at 35° F. through the lower half of a doorway 4 feet wide and 7 feet high and an equal current of dry warm air at 65° is entering the upper half, an estimate of the entering heat can be made; 200 feet per minute is about 2¼ miles per hour and is not a very noticeable velocity. Under these conditions, however, 100,000 B. t. u. per hour would enter through the open door. If the air were not very dry the quantity would be even greater. It would keep an 8-ton machine busy just to remove this heat.

At best, open doors permit a large entrance of heat, or loss of refrigeration, and prevent holding low temperatures in the room. For this reason it is desirable to use small openings covered with canvas flaps for loading cold-storage rooms. Such an opening, installed beside a cold-storage door, is illustrated in figure 9. When it is necessary to use hand trucks and keep full-size doors open, light swinging doors that close after each truck has passed will reduce the loss of refrigeration.

HEAT PASSING THROUGH INSULATION

Even when there is no infiltration of air through doors, windows, or cracks, there is an unavoidable entrance of heat through the walls, floor, and roof when the outside surfaces are warmer than the inside. The quantity of heat entering through the walls may be reduced by insulation, which slows the passage of heat by resisting its flow. The resistance depends upon the character of the insulating material and its thickness. A comparison of the effectiveness of various insulating materials can be made by showing thicknesses that will pass equal quantities of heat under similar conditions.

In many apple and pear cold storages 12 inches of shavings is used for insulating the walls. The thickness of various other materials required to equal the resistance of 12 inches of shavings is shown in table 6. When more than one material appears in the cross section of a wall the total insulating value of the wall is the sum of the values for each of the parts.

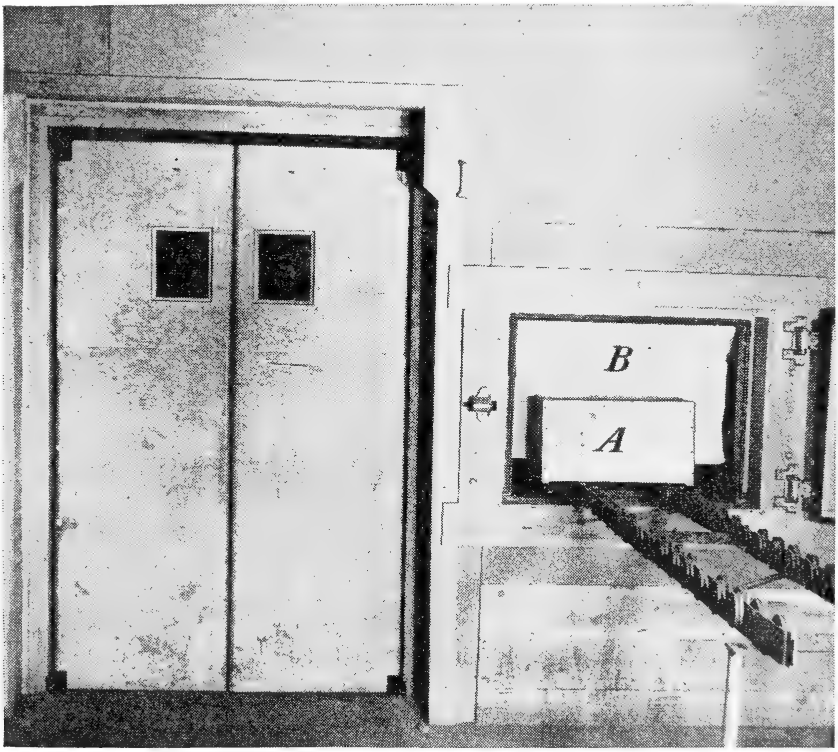

FIGURE 9.—A small opening, or port, for use in receiving or shipping small packages of fruit (*A*) over a conveyor without keeping the larger doors open. The small opening should be covered with a flap of heavy canvas (*B*) to prevent loss of cold air when a package is not passing through the opening. When it is necessary to use a large doorway for trucking, the heavy insulated door (at left, not shown) stands open. The light metal-clad doors shown may be bumped open with the truck and will swing closed after each truck has passed, thus saving much refrigeration that would otherwise be lost through the open doorway.

Frequently in constructing storages air spaces are provided between the various sections of the wall. These tend to hinder the flow of heat. Unless reflecting surfaces are used to line the spaces, however, it would take three to four spaces each at least ¾ inch thick to be equivalent to a 1 inch thickness of shavings. The structural materials in a wall act as insulation, but usually some are not of much value in retarding the heat flow. A 12-inch concrete wall, for example, adds about as much insulation as $\frac{4}{10}$ inch of shavings. Two thicknesses of $\frac{13}{16}$-inch fir boards are almost equivalent to 1 inch of shavings, provided the cracks are closed tight.

TABLE 6.—*Heat-insulation values of various materials in dry condition*

Material	Density	Heat conductivity [1]	Thickness equivalent to 12 inches of mill shavings [2]	Material	Density	Heat conductivity [1]	Thickness equivalent to 12 inches of mill shavings [2]
	Pounds per cubic foot	*B. t. u. per hour*	*Inches*		*Pounds per cubic foot*	*B. t. u. per hour*	*Inches*
Planer shavings	8.7	0.40	12.0	Pumice gravel [3]	18.8	0.61	18.0
Corkboard	8.3	.27	8.0	Fir (across grain)	26.0	.76	23.0
Redwood-bark fiber	5.0	.26	7.5	Concrete	----------	12.0	360.0
Fiber insulation board	13.2	.31	9.25	Cinder concrete	97.0	4.9	147.0
				Cinders	60.0	1.2	36.0

[1] For each degree (F.) of difference through 1 square foot of material, 1 inch thick.

[2] Based on data published in the Refrigerating Data Book, issued by the American Society of Refrigerating Engineers (*3*), except the data for redwood-bark fiber, which are from the Guide of the American Society of Heating and Ventilating Engineers (*2*).

[3] Grain $\frac{1}{32}$ to $\frac{3}{16}$ inch in diameter.

The quantity of heat passing through a wall with 12 inches of dry shavings depends upon the temperature difference between the two sides. When the temperature is 65° F. outside and 32° inside, each 1,000 square feet of such a wall may be expected to permit the passage of about 26,000 B. t. u. per day. That is, 11,000 square feet of such a wall will permit the loss of about 1 ton of refrigeration. Approximately the same quantity would be passed by equal areas of the various materials shown in table 6 if they were of the thickness shown. For walls twice as thick, the heat flow would be only half as great; for a wall only one-third as thick, three times as much heat would pass through.

In fill insulation, such as shavings, sawdust, and redwood-bark fiber, the resistance is influenced by the density of packing. In vertical walls, especially, such material must be packed tight; otherwise settling will occur and leave spaces unfilled after the wall is closed up. In these comparisons of various materials it is assumed that all are dry.

Moisture in any of these materials reduces their effectiveness and will cause some to rot. All should be installed so as not to accumulate moisture. Moisture condenses on surfaces cooler than the air but not on those that are warmer. The insulation material in a wall or roof is usually colder than the outside air. It is important therefore for the insulation to be protected against the outside air by a barrier against water vapor, such as coatings of asphalt or vaporproof paper on the outside of the wall. A barrier is not necessary on the inside, since a wall seldom picks up moisture from the inner, or cold, side. In fact, any moisture that may be present in the insulating material tends to leave the wall and condense on the cooling coils inside the room. For this reason, a vapor barrier on this side of an insulated wall may do more harm than good.

BASEMENT FLOORS

A vulnerable point in the insulation of most fruit cold storages is the basement floor. Beneath a concrete floor, on account of dampness and structural requirements, the insulation, if any, is frequently makeshift. This is expensive, because ground heat prevails during the winter after air temperatures above ground are low, and either excessive refrigeration is used to take care of this leakage or the fruit in the basement is kept at undesirably high temperatures. Usually both conditions exist: even if refrigeration is supplied to maintain low air temperatures in the upper part of the basement room, the temperature of the fruit resting on the concrete floor will be kept somewhat above optimum because of conduction from the ground through the concrete.

Durable insulation equivalent to 4 inches of cork is recommended for basement floors. It is as desirable to provide a space beneath the fruit as between the fruit and the outside walls. For this reason the insulation of bottom floors, whether in the basement or above ground, should be augmented with floor racks or false floors to permit the circulation of cold air beneath the fruit.

CALCULATING REFRIGERATION REQUIREMENTS

In calculating the refrigeration requirements of a cold-storage plant all sources of heat have to be considered. Following is a typical example.

Example.—Calculate the capacity of refrigerating equipment for a cold-storage plant 70×100 feet, having two floors with rooms 9 feet high, one of which is a basement. The walls and roof are insulated with 12 inches of planer shavings and the basement floor with 12 inches of pumice gravel. The average outside wall temperature is estimated to be 65° F., the roof temperature 75°, and the ground temperature 55°. It is desired to refrigerate 50,000 boxes of apples, 30,000 of which are an early variety, like Delicious, to be picked and received over a period of 10 days, the fruit to be cooled from 65° to 32° in not more than 7 days.

FIELD HEAT IN FRUIT

33° (reduction) ×0.9 (specific heat) =29.7 B. t. u per pound.
29.7×50 lb. (box weight) ×3,000 boxes (per day) =4,455,000 B. t. u. per day.

HEAT OF RESPIRATION

While cooling from 65° to 32° in 7 days, apples generate 21,000 B. t. u. per ton (estimated from table by D. H. Rose and others (*20*)).
3,000 boxes daily=75 tons.
75×21,000=1,575,000 B. t. u. per day.

BUILDING-HEAT LEAKAGE

	B. t. u. per day
Basement:	
Floor: 7,000 sq. ft.×1.25 B. t. u.×23°	201, 250
Walls: 2,920 sq. ft.×0.75 B. t. u.×23°	50, 370
Ground floor:	
Walls: 2,920 sq. ft.×0.75 B. t. u.×33°	72, 270
Ceiling: 7,000 sq. ft.×0.75 B. t. u.×43°	235, 750
Total	559, 640

INCIDENTAL HEAT

	B. t. u. per day
Motor:	
Brine pump: 2½ hp.×3,000 B. t. u.×24 hr	180,000
Fan: 10 hp.×3,000 B. t. u.×24 hr	720,000
Conveyor: 1 hp.×3,000 B. t. u.×24 hr	72,000
Infiltration, workmen, etc.: 288,000 B. t. u. per 1,000 boxes received (estimated)×3	864,000
Total	1,836,000

RECAPITULATION

Field heat	4,455,000
Heat of respiration	1,575,000
Building-heat leakage	559,640
Incidental heat	1,836,000
Total heat load	8,425,640

Refrigeration required: 8,425,640÷288,000, or 29.3 tons.

The greatest demands for refrigeration, as will be seen from this example, come from (1) field heat, (2) heat of respiration, and (3) infiltration and workmen, which are directly related to the volume of fruit being received and cooled each day during the peak of the harvesting season. To cool this fruit promptly for late keeping it is essential to have this reserve of refrigeration for a comparatively short time. After the receiving season, when the fruit has been cooled to 32° F., the heat of respiration from 50,000 boxes of apples would require only 3.5 tons of refrigeration, and this added to building-heat leakage and heat of motors for fan and brine pump would demand only 8.7 tons of refrigeration. As the weather becomes cooler the building-heat loss is reduced, resulting in still smaller refrigeration demands. In climates where day temperatures range from 55° to 75° during the harvest season the refrigeration requirements may be roughly estimated at 8 tons for each 1,000 bushels (packed boxes) received into storage daily, in addition to refrigeration needed for building-heat loss and heat from motors. If the quantity of fruit is measured in field boxes, the requirement per 1,000 is about 6.5 tons, instead of 8, since the field boxes contain less fruit.

COLD-STORAGE DESIGN

In laying out a cold-storage plant the first consideration should be efficient refrigeration of the fruit, followed by efficiency and economy in handling it. These requirements do not always permit the lowest cost in construction and operation. An insulated building in the form of a cube—dimensions equal for length, width, and height—represents the minimum requirements for materials in walls and the least outside exposure for heat transfer. Buildings of different dimensions, however, usually are necessary for the practical considerations of receiving, shipping, segregating, and piling the fruit and for the efficient use of labor. Lay-out and design will be influenced also by other factors, such as precooling requirements. Figure 10 illustrates an arrangement of a packing and cold-storage plant for apples and pears.

PRECOOLING

Precooling is usually spoken of as a special process for the rapid removal of heat from a commodity before transportation. The term is used also in some fruit districts to denote rapid heat removal preliminary to stacking in storage or even as a cooling prior to packing. The principles of rapid heat removal are the same regardless of subsequent disposal of the fruit.

Probably the most effective present method of precooling is to stack the fruit in relatively small rooms in which a large volume of cold air is circulated. The advantage of the small room is that cooling need not begin until after all the warm fruit has been brought into it. The additional expense of many small rooms usually demands an adaptation of the principle of dividing the storage into several rooms of moderate size. In large plants it is desirable to have more than one brine-spray chamber, so that temperatures in one part of the storage in which fruit is being held at optimum storage temperatures may not be influenced by the temperatures being used in the precooling rooms. Having air ducts of ample size, with a system of main dampers so that the volume of air to a given room may be governed according to its demands for refrigeration, is an important feature of design. It permits the diversion of refrigeration from well-cooled rooms to a room being filled with warm fruit.

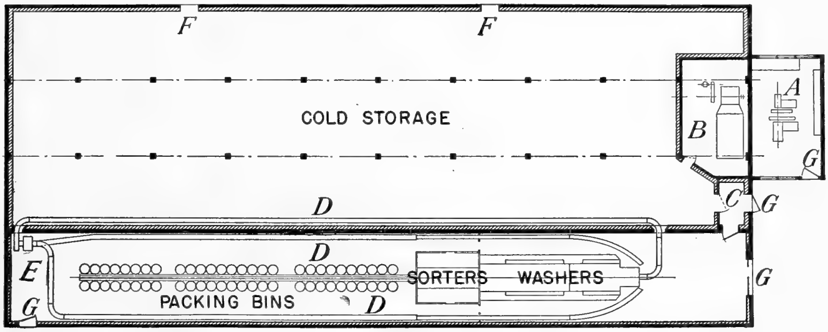

FIGURE 10.—Efficient arrangement of packing house, 20 x 166 feet, and cold storage, 50 x 166 feet, with refrigerated basement, designed for a medium-sized orchard: *A*, Outside compressor room, 16 x 28 feet; *B*, brine-spray and fan room; *C*, air lock to save refrigeration from open outside doors; *D*, fruit conveyor system; *E*, package-lidding press; *F*, ports for receiving or delivering fruit; *G*, outside doors.

For efficient precooling, it is necessary that the rooms be so designed that the cold air will have a positive flow between the stacked packages. The more rapid the circulation and the colder the air, the faster the heat will be removed from the body of each package. For these reasons the circulation system should be planned for the free movement of air in large volume through the fruit packages, rather than having it dispersed about the room from circuitous ducts and from small duct openings that tend greatly to restrict the air flow and to prevent it from having the fullest sweep over the surface of the packages.

Capacity and Height of Rooms

Although numerous small rooms are advantageous for precooling, large rooms may be used to good advantage for the storage period. It is usually expedient for cooperatives and large shippers to have their storage space divided into at least four rooms for flexibility of operation. For instance, for apple and pear storage it may be desirable to hold one room at 36° F. for apples susceptible to soft scald or for fruit intended for early markets, and one room at a constant temperature of 30° to 32° for the long storage of both fruits. The other two rooms can be used for rapid cooling or for storage at different times in the season.

The height of cold-storage rooms for apples has to be adapted to the packages being stored and the cost of labor or availability of machinery for stacking and tearing down piles. Where there is a labor problem, high stacking is not desirable, and the room height must be governed by the height that a man can stack. For example, a workman can stack standard apple boxes 8 high from the floor, and this calls for a 9-foot ceiling in an air-cooled room. If the labor situation permits higher stacking, sufficient head room must be provided for a man to work above the sixth layer, which usually necessitates 12-foot ceilings, with stacks 11 boxes high. Ceilings at intermediate heights have not been found practical for apples in boxes, because they are trucked into position 6 high and the workman stacking above this level requires 6 feet if his movements are not to be hampered through working in a stooped position. Space required by standard apple packages is given in table 7.

Table 7.—*Space required for standard apple packages*[1]

Dimensions (feet)	Northwestern box (1 bushel)	Michigan box (1 bushel)	Virginia box (1⅛ bushels)	Bushel basket (1 bushel)
Height	1.00	1.09	1.13	1.25
Width	1.13	1.13	1.13	[2] 1.50
Net length	1.63	1.48	1.56	[2] 1.50
Gross length [3]	1.88	1.73	1.81	----------
Gross space [4]	2.5–2.7	2.5–2.7	2.7–3.0	3.5–3.8

[1] The data given are for packed boxes having the usual bulge when stacked on their sides. Height and width would be somewhat less where boxes are filled with loose fruit and stacked in an upright position.

[2] Diameter.

[3] Includes a 3-inch spacing between the ends of boxes, recommended for air circulation and convenience in the use of box trucks.

[4] Usually used in calculating capacity of storage rooms and includes allowances for proper spacing of boxes aisle space, conveyors, wall and ceiling clearance, air-duct or piping space, and other space not actually usable. Gross space for baskets is based on stacking in an offset manner.

Lay-Out of Rooms

The plant should be so laid out that an expansion of facilities will be possible. Special attention should be paid to the position and shape of the rooms with respect to receiving and shipping, so as to avoid congestion. Where a packing plant is constructed in conjunction with the cold storage, its position must be such that loose fruit can be brought to it direct either from the orchard or from storage rooms. The packing room should not occupy space that otherwise could be used for cold storage nor obstruct fruit deliveries to the cold-storage plant.

Since the compressor room is a source of heat, placing it at one side of the cold-storage building (see plan, fig. 10) eliminates the cause of a warm spot, especially at the floor of the room above. It also makes machinery more accessible when it has to be replaced and lessens the risk of loss of machinery in case of fire, or of damage to the fruit when ammonia leaks occur in the compressor room. When the room is given space in the basement of the cold-storage building, as is frequently done, there is a tendency to limit it to minimum dimensions, thereby entailing difficulties when later it is desired to expand and to install additional compressors.

Where brine-spray chambers are used, there are several advantages in placing them in an insulated penthouse on top of the building. There is the decided advantage of being able to place the chamber centrally with plenty of room for spacious ducts without infringing upon the most desirable space for fruit storage. Having ample space in the brine-spray room permits the effective elimination of spray before the air enters the cold-storage rooms, allows the use of large fans with slower turning impellers, gives space for reversing the direction of air flow without short turns, and provides good working conditions for adjusting the brine concentration and servicing the equipment. There is less corrosion of the fan when it delivers the air to the brine-spray chamber than when it draws it from the spray.

Fans and Ducts

The efficiency of a refrigeration system depends to a great extent on the effective movement of heat from the fruit to the evaporation coils or the brine spray. The fan and air ducts should move the greatest possible volume of air at the smallest possible cost of power. Two reasons for keeping the fan-power requirements at a minimum are that (1) the fan operates over a long period in the year, so that any reduction in the cost of power to drive it is an important item; and (2) the power used on the fan adds heat to the circulated air, thus adding to the refrigeration load and reducing the useful capacity of the refrigerating machinery. Each horsepower used on the fan puts a load of 0.2 to 0.3 hp. on the compressor motor.

It is false economy to have a fan of lower capacity than necessary to circulate the required volume of air; but it is true economy to have fan and ducts so designed as to move the required volume of air with the least possible power. Many plants are handicapped by having a fan too small or ducts with too much air resistance. Increasing the speed of a fan to get more air circulation is at the cost of more power for every cubic foot of air circulated. For this reason it pays to install an efficient fan having the required capacity at a moderate speed. The fan motor should have more than one pulley, so that the speed of the fan may be reduced after the fruit has been cooled down, provided the split between the delivered and returned air can be kept down to 1.5° F. at the slower speed.

RESISTANCE IN AIR DUCTS

The design of air ducts has an important bearing on the volume of air that can be circulated by a blower, the volume circulated becoming less as the resistance in the ducts increases. The resistance to air flow

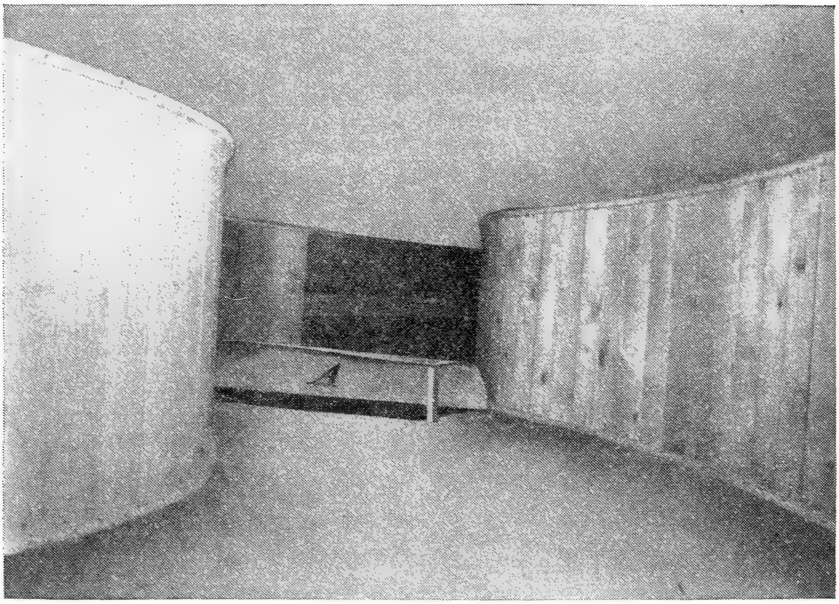

FIGURE 11.—Ducts that are streamlined with easy curves around turns avoid resistance to air flow from eddies and turbulence. *A*, Deflector vane installed to throw part of the flow into a vertical duct.

is greatest in parts where the velocity is high and where the air changes velocity or direction. Air flows like water, and abrupt changes induce turbulence and eddies that increase the resistance (fig. 11). Abrupt changes in the area of ducts and unrounded turns should be avoided. Even in rounded turns the flow of air is accelerated by curved splitters (fig. 12) that aid the air in making the turn with a more equal velocity over the entire face of the duct. Thus dividing the air stream at turns prevents piling up pressure against the outside face of the turn and reduces turbulence.

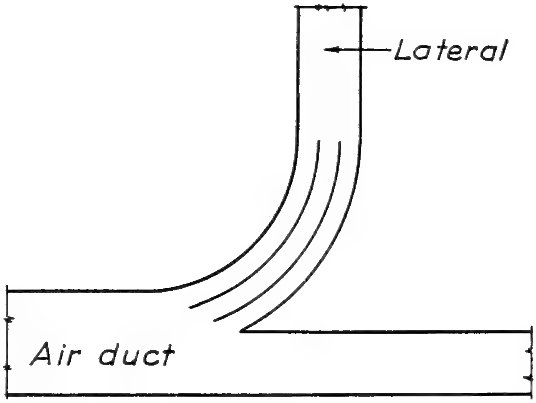

FIGURE 12.—Section of air duct with lateral, showing splitters for preventing excessive air turbulence in the bend. (Not drawn to scale.)

The inside of the ducts should be free of obstructions and as smooth as possible. Where obstructions, such as posts or girders (fig. 13), cannot be avoided, it is worth while to ease the flow around them by installing air splitters to give a streamline effect. This is particularly true at points where the velocity is high. Large ducts are preferable, because they permit delivery of the required volume of air without excessive velocities. Ducts that are too small in cross section or cause abrupt turns in the air streams build up a resistance that results in high power consumption and inefficient circulation.

Increased resistance is also caused by attempting to deliver the air through many small openings in the ceiling of a cold-storage room. This system of delivery has the added disadvantage of short-circuiting the air flow from delivery to return openings. Unless the air passes through the body of the stacked fruit the maximum quantity of heat is not being removed.

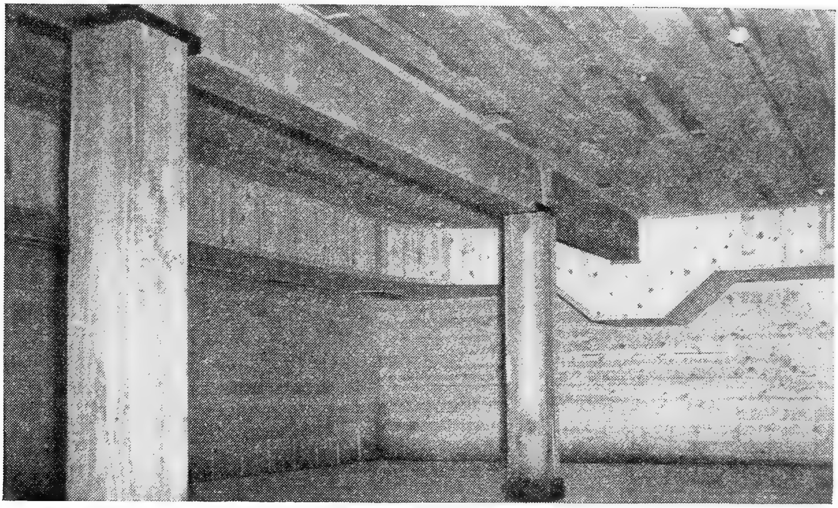

FIGURE 13.—Air duct passing beneath a girder. Unless the interior is streamlined to give smooth walls, rounded curves, and small changes in area, the resistance from turbulence will greatly interfere with air flow.

SPACING AIR DUCTS

The distance between the delivery and the return openings is dependent upon several conditions. The temperature of the air leaving a storage room is necessarily warmer than that entering it from the delivery ducts. The larger the volume of air circulated, the less this temperature difference will be. In fact, in a given room from which a certain quantity of heat is being removed, the temperature difference is determined almost entirely by the rate of air circulation, in cubic feet per minute or in air changes per hour.

The method of distributing the circulation has no direct effect on the temperature rise in the air unless it affects the volume circulated or the quantity of heat picked up. Since the temperature of the air leaving the room is dependent upon the volume circulated, the distribution within the room or the relation between discharge and return openings can be adjusted to the requirements of the specific room, bearing in mind the necessity for having the warmest air in the room enter the returns and the desirability of having relatively high velocities to keep the fruit temperature down as nearly as possible to that of the air.

The greater the distance of air travel between delivery and return openings the greater must be the velocity.[3] One advantage of higher velocities within a room is that locations that might have been high-temperature pockets are swept by moving air and warm air that tends to accumulate in these pockets is carried away to the cooling coils. These higher velocities also take the field heat out of warm fruit faster than relatively still air.

When the distance between delivery and return is great, it is particularly important to leave an unobstructed space over the packages and under the ceiling at all points. Otherwise, the air will tend to move along the aisles or other open spaces instead of over the fruit, and the advantage of high velocities will be lost. As in the case of shorter air travel, it is important to have air flow equalized over the length of the ducts and have it directed for equal distribution throughout the stacks of fruit.

In the design of an air-distribution system for a storage room it is necessary to keep in mind a few points that, if the air volume is adequate, will determine how well a uniform temperature in all parts of the room can be maintained. The air should be both discharged into the room and taken from it at or near the ceiling. The discharge and return openings should be so located that the air is forced to move past all the stored fruit. Installations in which the air is discharged along a center aisle and returned at the floor at one end of the aisle usually do not provide for ample circulation along the sides of the room, and any point in the upper part of the room not directly supplied with cold air from the discharge openings is likely to remain too warm. Complicated duct systems with numerous laterals and small openings are to be avoided. They add to the initial expense, build up high resistance to air flow, and tend to result in local warm spots.

REVERSING DIRECTIONS OF AIR FLOW

Since it is impossible to avoid having the temperature of the air rise as it passes through the room, the fruit near the openings of return ducts is warmer than that near those of the delivery ducts. If all duct openings can act alternately as deliveries and returns, the warmest fruit will not be so warm and the coldest not so cold. This can be done by reversing the direction of air circulation every few hours by means of a simple set of dampers and special duct arrangement near the fan.

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[3] Air velocity and air volume are sometimes considered different expressions of the same thing. They are not. In an extreme case, for example, a long, narrow room, about 10 x 100 feet in plan, consider two arrangements of ducts—in one the ducts are along the side walls, so that the air discharged is returned 10 feet away at the other side; in the other, the air is delivered at one end and picked up 100 feet away in a duct at the other. Now assume that a given volume of air is to be circulated through this room, which is 10 feet high and has a volume of 10,000 cu. ft. If 1,000 c. f. m. of air is to be circulated through this room and it moves from one side to the other, its average velocity will be 1 foot per minute. If, on the other hand, it moves from one end to the other, the same volume will move through the room at 10 feet per minute. In this example, the velocity in one case is 10 times as great as in the other, the volume of air being the same in both cases.

This is an extreme example of a situation in a storage room. The volume of air required depends upon the quantity of heat to be removed and the tolerable difference in temperature between delivery and exhaust air. It is uneconomical to deliver a larger volume than these considerations require. The velocity at which the required volume of air moves through the room depends upon the length of the path it must traverse. Increasing the distance between delivery and return openings requires that the velocity for a given volume be correspondingly increased. For this reason, velocity and volume are not necessarily dependent upon each other. Volume can be adjusted to the heat load, and velocity can be controlled by the distance between openings.

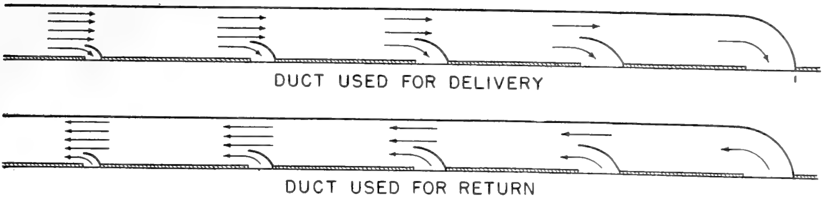

FIGURE 14.—Diagram of delivery and return ducts that may be used interchangeably with a reverse air system. Deflector vanes are used to equalize the quantity of air delivered from the varisized duct openings. These openings are larger as the distance from the fan room increases, to equalize the flow of returning air. Their number is adjusted to the length of the duct.

If the dampers are arranged to operate automatically they require a minimum of attention. To take full advantage of air reversals, ample volume and good distribution are necessary. If such distribution and volume are provided, periodic reversal of the air will result in a minimum difference in fruit temperature throughout the room. The method is particularly adapted to rooms in which air below the freezing point of the fruit is used for the rapid removal of heat in precooling. Reversing the air periodically lessens the danger of freezing the fruit near the discharge openings.

Air traveling along a delivery duct with plain openings along the side or bottom tends to move past the first openings, and the openings farthest from the fan tend to discharge more air than those nearest. In a return duct the reverse is true; more air tends to enter the openings nearer the fan. These effects may be compensated by adjusting the size of the openings. In a delivery duct the openings nearest the fan may be made largest and those at the far end smallest. In a return duct, openings may be small near the fan and larger as the distance from the fan increases. If the same duct is to be used alternately for delivery and return, however, this gradation in size of openings will obviously not be satisfactory. When the duct is used

FIGURE 15.—View from below of a duct opening near the fan room in a reverse air system. The opening is narrow, and an internal deflector vane, or scoop, is used to divert the proper quantity of air to this part of the room.

for delivery the desired equality of volume discharged at various openings may also be had by installing a deflector vane at each to turn the air outward through the opening. These deflectors, or scoops, are illustrated in figure 14 and also in figure 15, which is from a photograph of such a deflector inside a duct.

When the air direction is reversed periodically, the ducts should be laid out somewhat as illustrated in figure 14. The ducts are at the ceiling, one along each side of the room. The figure shows a pair of ducts, either one of which may be used as a delivery while the other acts as a return. The arrangement permits reversing the direction of air movement without throwing the quantity of air entering or leaving such opening out of balance. The openings and deflectors extend the full width of the duct and their size is progressively larger as the distance from the fan end of the duct increases. This provides for uniform air volumes when the duct acts as a return. The scoops are adjusted to distribute the air uniformly when acting as a delivery. The size of openings and adjustment of the deflectors should be fixed for uniform distribution without provision for readjustment from time to time. Openings 10 to 25 feet apart are spaced equally along the duct. It is sometimes convenient to have one opening in each bay.

DESIGN FOR 36° F. ROOMS

Attempts to keep a room at 36° F. by merely choking down the duct openings delivering 30° to 32° air inevitably result in failure, because (1) some fruit adjacent to the delivery ducts will be subjected to low temperature, and (2) choking down the volume of air necessary to remove the field heat, and later the storage heat of respiration, results in a wide range of temperatures in different parts of the room. To avoid these conditions, it is necessary to recirculate sufficient air to raise the temperature of the incoming air and to provide adequate air movement through the stored fruit.

Where it is desirable to refrigerate one room at 30° F. and another at 36° from the same brine-spray chamber, it will be necessary to provide the 36° room with a damper in the main supply duct and to install within the room a recirculating duct with a small fan between delivery and return ducts. This arrangement will choke down the supply of air at 30° and mix it with the warmer air that is recirculated by means of the auxiliary duct and fan. Thus, the air is tempered to 36° before leaving the delivery duct and an adequate volume is circulated.

Girders and Joists

In designing the structural elements of a cold-storage building the layout of the system of air ducts should have preliminary consideration, so that girders extending below the ceiling may be in the direction of air flow from delivery to return ducts. Where this is not feasible, the ceiling should be so constructed that air will flow over the girders between the joists. Where the ceiling is to be insulated, either the insulation should be applied above the joists or the ceiling should be recessed between the joists so as to leave 3 or 4 inches free space between the ceiling and the lower edges of the joists (fig. 16).

SLOTTED FLOORS

To avoid high stacking, rooms with low ceilings and a slotted floor between the first and second levels are occasionally constructed to be refrigerated from a system of ducts at the ceiling of the upper room. This is not a satisfactory arrangement for uniform temperatures. A controlled air movement cannot be directed through all parts of both rooms. Where the less perishable fruits are being stored, this low-cost type of construction may prove satisfactory, if care is taken not to store warm fruit in the lower floor beneath the fruit that has already been cooled. A system of reversed air circulation is recommended for this design, with provision for leaving unoccupied space beneath the air ducts on the upper floor.

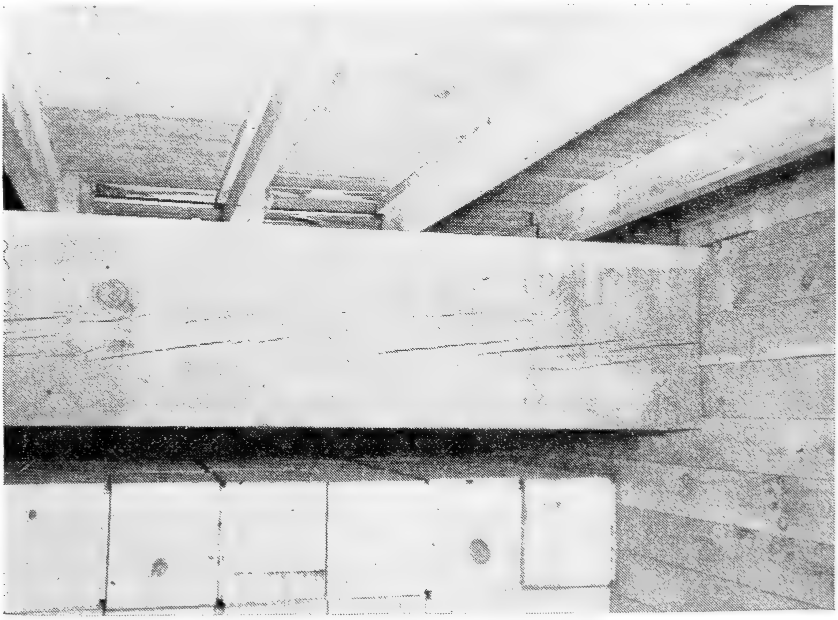

FIGURE 16.—Insulated ceiling raised 4 inches above lower edges of joists, to allow air to circulate over girders. Where the direction of air flow between ducts is transverse to girders, this is important to prevent pockets of stagnant air and higher temperatures in bays near the ceiling.

HANDLING EQUIPMENT

In laying out the building it is important to consider the equipment to be used for handling the fruit. Where fruit is packaged in small containers, the belt system is largely used for receiving it and for transferring it from cold-storage rooms to packing room and return and from the cold-storage rooms to delivery platform or railway car. The belt system of conveyor has proved economical in labor costs and permits the use of receiving and delivery ports such as that illustrated in figure 9 instead of doors. The lay-out of aisles and doors or ports, as well as the shape and arrangement of the rooms, should be designed for the most advantageous use of the conveyor equipment. The installation of belt conveyors in a large cold-storage room is shown in figure 17.

The manufacturer of the equipment should be consulted as to the proposed building plans, so that modifications may be made to meet the requirements of efficient installation and use.

Spacious corridors on the receiving and shipping sides of the building are usually desirable for the conveying equipment, so that packages can be received and shipped at locations other than those immediately opposite the port or door serving a specified cold-storage room. Where two- or four-wheeled trucks are used for conveying fruit packages, the plans should provide for ample receiving and shipping platforms and for elevators in shafts insulated from the storage rooms.

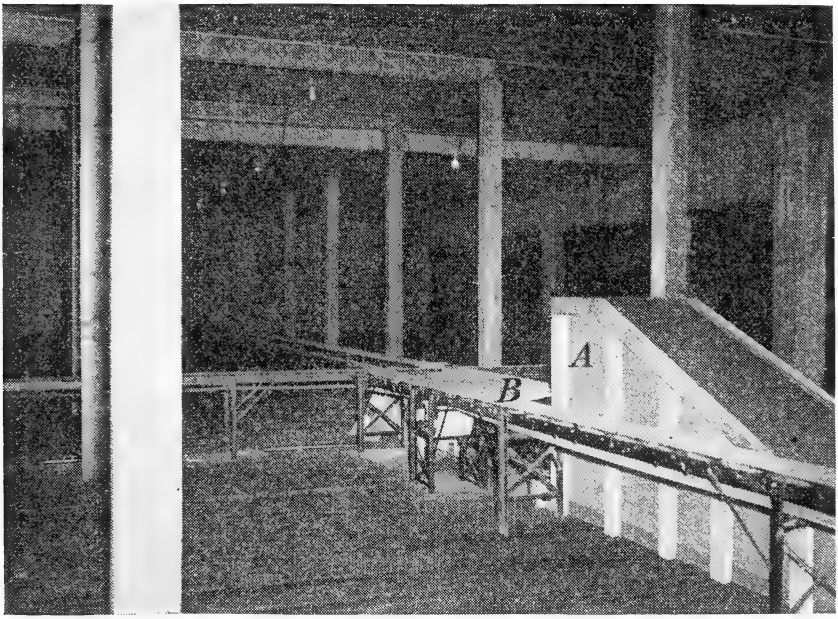

FIGURE 17.—Conveyor belts are used in a large cold-storage room. The belt running from the foreground extends from the receiving to the shipping side of the building. One belt runs in the opposite direction between rooms. *A* is the housing over an inclined belt running to the room below; *B*, the covered take-off for the inclined belt. A curved metal guard guides packages from one belt to another and around turns.

PLANNING FOR ECONOMY

When a new plant is to be installed or additional equipment is considered it is always important to avoid excessive costs. At such times the first cost is frequently a chief consideration in deciding what equipment to purchase. Usually when the cost of a proposed job is learned, it seems excessive and there is a tendency to look for items that can be eliminated or reduced. It is not wise to cut down the first cost by unduly limiting the cooling surface, the condenser capacity, the sizes of fans or ducts, or the efficiency of the insulation. Savings in these items will be small compared with reduced returns from overripe fruit or added power costs projected over many years of operation. When looking for possible economies in cold-storage construction it is important not to lose sight of the following essentials:

1. Sufficient refrigeration must be available to cool the fruit as fast as it comes in. For long-period storage this should be done in the shortest possible time; it is estimated that for each 1,000 boxes of apples received into storage daily at 65° F., approximately 8 tons of refrigeration is required.
2. The air movement must be sufficient to distribute the refrigeration efficiently. In blower-circulating systems there should be at least 1,000 cubic feet of air per minute for each ton of refrigeration. In direct-expansion and brine-coil systems the air movement is most satisfactory if the cooling pipes are well distributed over the ceiling area.
3. The return air must be taken from the room at the points of highest temperature. In general, these are in the upper parts of the room.

SAFETY

Managerial attention should be given to all measures for the safety and health of workmen. Besides safety guards to cover exposed moving parts and openings between floors, all due precautions should be provided against fire hazards and accidents recognized by industrial safety rules, including well-lighted steps, substantial ladders or steps for use in stacking, gas masks for ammonia fumes, and ammonia pressure releases that are exhausted outdoors. Employees should not be required to work in blasts of cold air for long periods without being adequately protected by proper clothing.

The engine room should have doors and windows opening to the outside so that, in case of emergency, ventilation would be possible by opening or breaking them. The outside doors should be kept locked, however, if there is any possibility of children or other persons entering and exposing themselves to danger from the machinery.

A high-pressure release valve should be installed in the refrigerating equipment and connection made to the outside with a vent pipe so that if the pressure release operates, the refrigerant will not be discharged within the building. A gas mask designed for the refrigerant in use should be hung just inside the outside door so that it can be reached without entering the engine room. To be effective this mask must be kept in operating condition, and employees must be familiar with its use.

The fire-insurance inspector should be consulted and the recommendations for avoiding and fighting fire should be followed. The electric installation should be made in accordance with prevailing codes. If no legal code applies in the locality the insurance inspector should be consulted about the appropriate provisions of the National Electric Code that should be followed in making the installation.

In order to avoid the possibility of persons being locked inside the storage room, one or more doors or loading ports should be operable from inside the room.

COLD-STORAGE MANAGEMENT AND PLANT OPERATION

Many cold-storage plants are not utilized to best advantage, either because of short-sightedness in management or failure to operate at maximum efficiency. During the cooling period many plants take in fruit faster than their equipment can cool it. As a result the fruit is not cooled to the holding temperatures until ripening is well advanced. Several managerial steps can be taken to improve conditions. Compressors and auxiliary apparatus need to be in good shape. Condensers must be clean and all available condenser surface used. Evaporating coils should be kept as free as possible from frost and the blowers used should circulate the maximum volume of air. Good management includes such handling of the fruit as will utilize the plant to best advantage and such control over the operation of the plant and over the care of the equipment as will keep both at top operating efficiency.

Handling the Fruit

REDUCING THE INITIAL FRUIT TEMPERATURE

The quantity of heat that must be removed from a package of fruit depends largely upon how warm it is when put into storage. If its average temperature can be reduced before storage it will lessen the load imposed on the plant by each box. Fruit picked in the afternoon is ordinarily warmer than that picked in the morning. Picked fruit left in boxes under the tree is considerably cooler in the morning than at evening. In some districts fruit left under the trees overnight or picked in the morning may be at a temperature of 55° F. as against 80° late in the afternoon. To cool 1 ton of fruit from 55° to 32° demands the removal of 41,400 B. t. u. of field heat, as compared with 86,400 B. t. u. for the warmer fruit. The cooling capacity of the cold storage would be more than doubled if the management could arrange for the delivery of the cooler fruit.

Leaving fruit out in the orchard to cool overnight frequently results in its cooling faster than it would in a cold-storage plant that is being crowded beyond its capacity. It also results in the fruit already in storage having a chance to cool faster and represents an exceptional situation where a few hours' delay in the orchard increases its storage life. The advantages to be gained warrants the curtailing of afternoon deliveries with such fruits as apples and pears and correspondingly increasing early morning deliveries, especially in plants of limited cooling capacity, even at the expense of some difficulty and inconvenience in handling and hauling.

SEGREGATION OF LONG-STORAGE FRUIT

The Delicious variety causes the most serious storage problem in western apple districts because of its storage-temperature requirements, its large tonnage, and its relatively short harvest period. If the cooling capacity is sufficient to cool all these apples as fast as harvested, it might be desirable to cool all the fruit as quickly as possible. Since this is not usually the case, an attempt to cool all of it with equal promptness means that none of it is cooled quickly. In general, the longer a box of apples is to be held, the more important it is to cool it quickly. This is illustrated graphically in figure 18. This suggests that long-storage lots of fruit should get more than an equal share of refrigeration at harvesttime and short-storage lots less. Those for long storage should be put in rooms where the receipts would be limited to a quantity that could be cooled rapidly. Fruit for shipment during the harvest season or shortly thereafter would be deliberately withheld from any of the cold-storage rooms in order to save the refrigeration for long-storage lots. Apples for immediate shipment would be cooled as quickly as possible without penalizing the long-storage lots.

The procedure of segregating apples for long-, intermediate-, and short-storage periods places demands upon the management for more planning before harvest than a procedure whereby all the apples are treated alike. This planning should include the selection of apples that are of optimum maturity and freest from inherent defects for preferential refrigeration over the long period on the one hand and the early marketing of weak overmature fruit on the other. It may necessitate the use of cold-storage-in-transit privileges and shipping the fruit under the standard refrigeration service provided by the railroads for a part of the tonnage scheduled for intermediate and early marketing, in order to conserve local refrigeration for promptly and adequately cooling the tonnage intended for marketing after December. It should be emphasized that such a sacrifice in cooling early shipments is an expedient and is desirable only when limited capacity prevents prompt cooling of the entire crop.

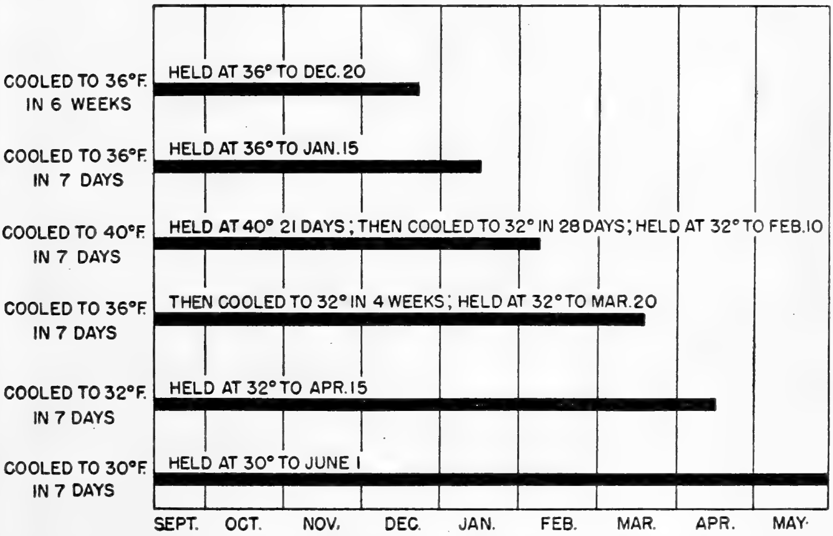

FIGURE 18.—Normal storage life expectancy of Delicious apples when cooled at different rates and stored at different temperatures. For each week of exposure at 70° F. before storage, deduct 9 weeks of storage life at 32°; for each week of delay at 53°, deduct 1 month of storage life at 32°.

SEGREGATING TO AVOID SOFT SCALD

Development of soft scald in Jonathans and other varieties of apples, including Winesaps, is erratic and unpredictable. It usually can be traced to a quick reduction in fruit temperature to 30° to 32° F. when the fruit is somewhat advanced in maturity or is delayed at relatively high temperatures after picking before going into storage. When such delays are unavoidable, the disorder may be prevented by holding the fruit at 36°, or slightly above, for the first few weeks of storage. When it is impossible to get susceptible varieties into cold storage promptly, they should not be cooled to the 30° to 32° range generally recommended for apples but only to a moderate temperature (36°) and segregated for early disposal. It is therefore highly desirable to avoid putting them in the same room with a variety like Delicious, which should be held at 30° to 32°. Storage in separate rooms in which the temperature can be controlled independently is desirable. The fruit will not keep so long at this higher temperature, but the risk from soft scald will be avoided.

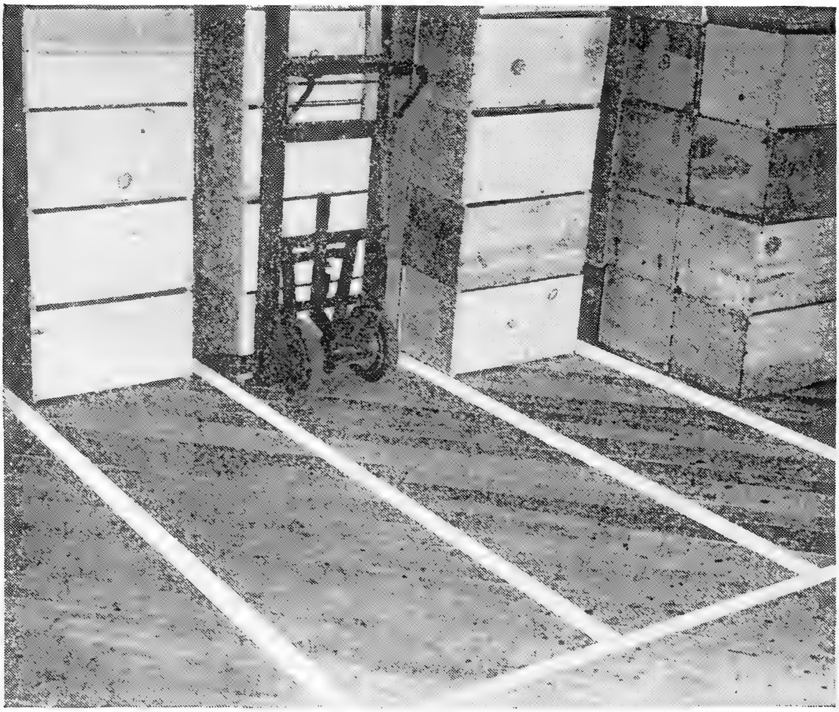

FIGURE 19.—Lines painted on the floor as a guide in stacking packages facilitate warehousing and help in providing uniform spaces for the movement of cold air through the stored fruit.

STACKING PACKAGES

Lines are ordinarily painted on the floor of storage rooms (fig. 19) to indicate the spaces for placing rows of boxes and to facilitate even stacking. It is important to maintain an air space between rows at all points. A uniform spacing of 2 to 3 inches between rows has been found to be practically as effective in permitting cooling as spacing up to 5 or 6 inches if there is sufficient headroom between boxes and ceiling. Careless stacking, however, in which some boxes in one row touch or approach those in another, restricts air movement and retards cooling. A spacing of 2 to 3 inches is needed to release box trucks when trucking fruit into rows, and convenience in trucking has regulated spacing in most storage houses. To overcome slight irregularities in stacking, 3 inches may be considered a satisfactory spacing for the bottom boxes. The rows should be so laid out that the general direction of air movement is along the rows instead of across them.

Stacking packages in contact with outside walls or floors should be avoided, as there is some heat transfer through conduction that affects the temperature of fruit in outside or bottom packages. When boxes or cartons are being stacked, spacing between the walls and the packages may be insured by using side rails, as illustrated in figure 20 or by fastening 2- by 6-inch planks to the floor around the outside of the room. On a ground floor it is particularly desirable to provide an air space beneath fruit by stacking on strips or on a false floor.

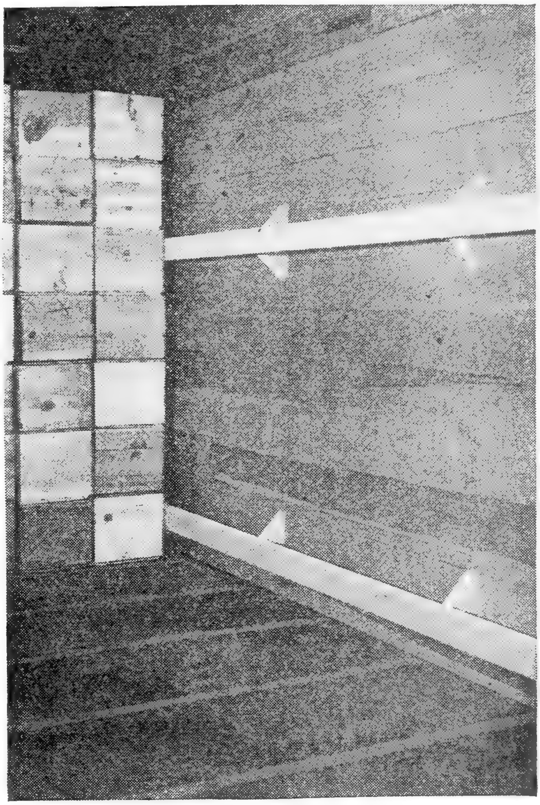

FIGURE 20.—Side rails used in cold-storage rooms to prevent stacking against the walls.

In large rooms warm fruit may be brought in over a long period; this means that fruit that has been in the room for some time and has cooled is sometimes warmed up by incoming fruit. This effect is unavoidable in some rooms, but by judicious stacking it can be kept at a minimum. In some cases it is possible to stack the first fruit brought in nearest to the air-discharge ports so that after it is cooled it is not exposed to air coming from warm fruit brought in later. In plants that have two levels separated by a slotted floor it is good practice to load the lower floor first so that as the fruit on the upper floor is cooled it will not be affected by warm air rising from warmer fruit below.

OVERHEAD SPACE

In most storage rooms air circulation is planned so as to have the primary movement over the tops of the boxes and through aisle spaces. The cooling in the interior of the stacks is accomplished partly by secondary, or convection, currents up and down the spaces between boxes. This cooling is effective only insofar as the warm air that rises to the ceiling is moved away and replaced by colder air. Leaving reasonable space overhead permits sufficient circulation for carrying off the heated air (fig. 21). If the space is limited there is a tendency for the air to move along aisles or unfilled channels in preference to the ceiling space; when fruit is stacked too close to the ceiling, air movement is restricted, cooling is retarded, and it cannot be accomplished evenly (fig. 22). No rule has been established on the minimum space required over the boxes to permit good circulation, but it is good practice to leave a space of several inches even if the ceiling is free from girders or other obstructions.

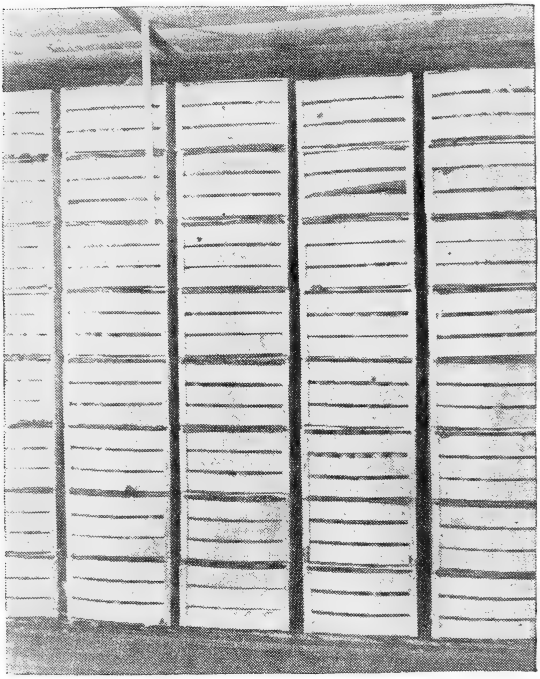

Figure 21.—Packages properly separated and with adequate space overhead.

If the primary air circulation can be forced to move through the spaces between stacks, more rapid cooling can be accomplished. Reducing the space over the boxes will tend to move more of the primary circulation through the spaces, but it will also divert more of it through aisles or other open channels. Unless such channels are avoided, loading close to the ceiling or putting baffles across the ceiling to force more air into the box spaces may result in moving most of the air through the aisles, where it is least effective for cooling.

For storage rooms in which relatively slow cooling is not objectionable the type of circulation that provides for flooding the ceiling space with moving air and depends upon natural convection to cool the interior of the stacks will provide fairly uniform temperatures throughout the room, with a minimum of care in laying out the loading arrangement. Sometimes in order to hasten cooling, the primary air is forced through the space between boxes, and little space is left between boxes and ceiling. In this case the natural convection from the ceiling down into the stacks is greatly reduced, but the forced circulation among the boxes gives better cooling on account of the higher air velocity.

It will be seen that if natural convection is sacrificed by reducing the ceiling space, it is important that forced circulation take its place. Otherwise the effectiveness of cooling will be reduced instead of increased. For this reason, if it is attempted to force air through the box spaces by cutting down circulation over the fruit, great care must be exercised in arranging the boxes. Uniform spacing becomes even more important, and air channels that will permit diversion of air around the stacks of boxes must be avoided. Precooling rooms in which these conditions are met provide much faster cooling than rooms in which natural convection is depended upon for cooling the interior of the stacks.

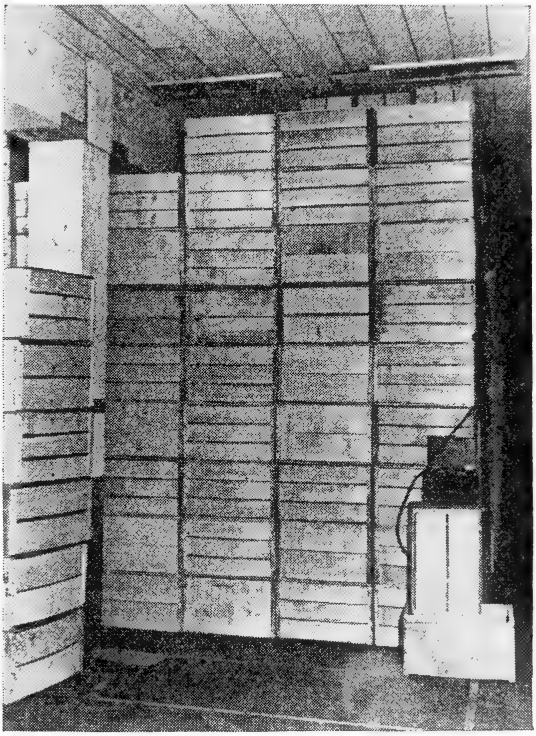

Figure 22.—Packages stacked without spacing and too close to the ceiling. This prevents uniform distribution of refrigeration.

Control of the Plant

In a cold-storage plant the relatively large investment in machinery and construction can be justified only if it increases the value of the fruit stored. The value of a plant in maintaining this condition is largely determined by the way it is operated. Even the best designed plant with automatic equipment needs more or less continuous attention to insure the best results.

CORE TEMPERATURE

To make the best use of a plant it is important to know what temperatures are being maintained. One or two thermometers for showing aisle-air temperatures do not indicate the performance of a plant.

An operator needs to know core temperatures of the fruit, especially in parts of the room where cooling is difficult. Periodic observations of fruit temperatures will indicate what methods of stacking and air distribution will give best results and what parts of the room need special attention. Reliable thermometers or thermocouples are necessary for this purpose. An investment in equipment for obtaining accurate records of temperature in all parts of a storage is worth while.

Frequently when actual fruit temperatures are measured the results are disappointing. If they are it is sometimes possible to improve conditions markedly with little cost or inconvenience. In any case, it is to an operator's advantage to know just how quickly he can cool the fruit and how uniform he can hold the temperatures after it is cooled.

In addition to the management's responsibility to ascertain whether core temperatures are what they should be in all parts of the cold-storage plant, there is the further responsibility of checking on fluctuations in temperature during the operating season. This is best done by the continuous operation of a recording thermometer, or thermograph, at a central point in each room. One type of such instrument is illustrated in figure 23. A file of temperature records affords the management a protection against complaints of grossly irregular temperatures, but does not insure optimum core temperatures at all positions throughout the stored fruit.

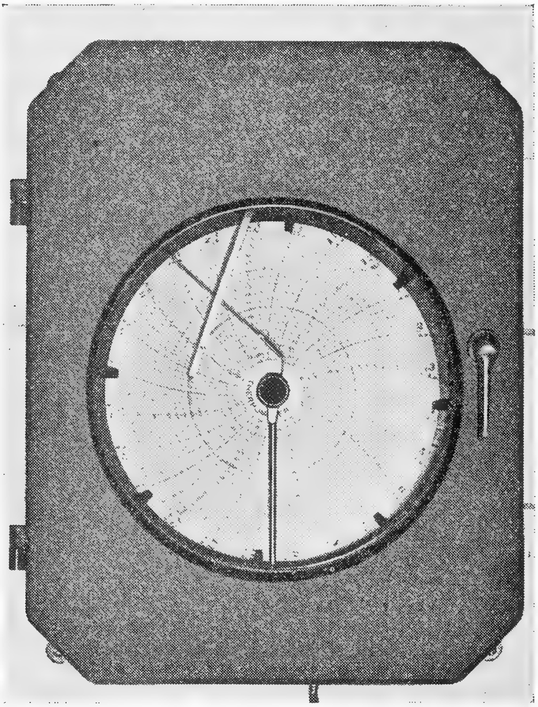

FIGURE 23.—Recording thermometers are useful for giving temperature fluctuations and providing a permanent file on cold-storage performance.

MAINTAINING HUMIDITY

Periodic determinations of the relative humidity in storage rooms are necessary to avoid atmospheres that are relatively dry and likely to cause subsequent shriveling of the fruit. Several types of instru-

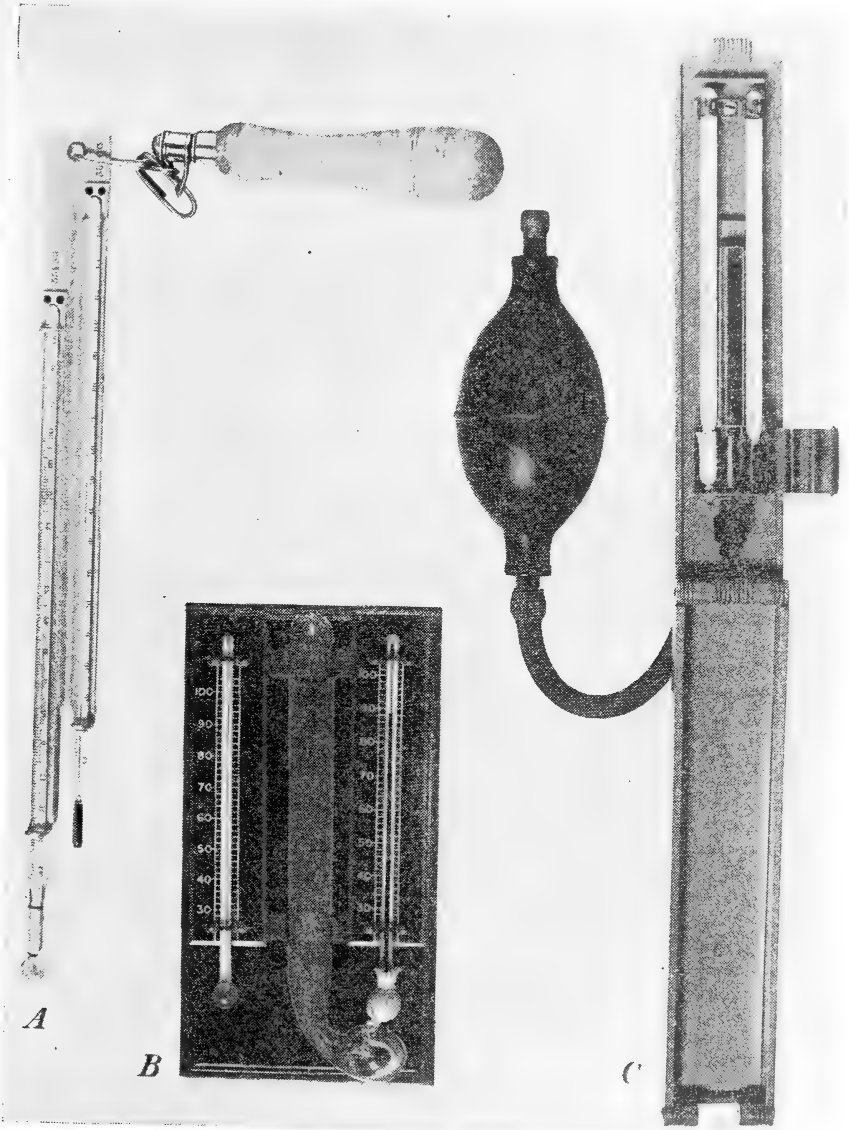

FIGURE 24.—Psychrometers consisting of wet- and dry-bulb thermometers that can be used for determining the relative humidity of storage rooms: *A*, Sling type; *B*, wall type; *C*, hand-aspirated.

ments are available for this purpose (fig. 24). When type A or type C psychrometers are used the relative humidity may be found by reference to table 8.

TABLE 8.—*Relative humidity (percent) of atmosphere by wet- and dry-bulb thermometers*

Air temperature (° F.)	Relative humidity when depression (° F.) of wet-bulb thermometer[1] is—									
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
20	92	85	77	70	62	55	48	40	33	26
25	94	87	81	74	68	62	55	49	43	37
29	94	88	83	77	72	66	60	55	50	44
30	94	89	83	78	73	67	62	56	51	46
31	94	89	84	78	73	68	63	58	52	47
32	95	90	84	79	74	69	64	59	54	49
33	95	90	85	80	75	70	65	60	56	51
34	95	90	86	81	76	71	66	62	57	52
35	95	91	86	81	77	72	67	63	58	54
36	95	91	86	82	77	73	68	64	60	55
40	96	92	87	83	79	75	71	68	64	60
45	96	93	89	86	82	78	74	71	67	64
50	96	93	90	87	83	80	77	74	71	67

[1] Difference between dry-bulb and wet-bulb readings. Water should not be freezing on the wet bulb while a reading is made. The humidities shown in this table apply only when the air is moving rapidly past the thermometers, as with the sling or aspirating psychrometer.

MAXIMUM USE OF EQUIPMENT

If during the cooling period it is necessary to shut off some of the compressors to avoid localized freezing at some points while fruit temperatures are too high at others, the capacity of the equipment is not being used to full advantage and some means for better distribution of the refrigeration should be found. This usually may be done by improving the air circulation or increasing its volume. While ample circulation cannot compensate for inadequate refrigeration, it does permit maximum use of the refrigeration available.

Pending the time when the air circulation system can be overhauled to give maximum use of the compressors, the management may take temporary steps to prevent freezing at local points during the cooling period. These usually involve removal of fruit or covering it where air is introduced and employing portable fans to accelerate the movement of air away from the cold spots towards points where fruit temperatures are high.

OPERATING EFFICIENCY

KEEPING EQUIPMENT BALANCED

To get the best results from a plant the various steps in the mechanical removal of heat must be balanced. That is, the heat picked up in the room must be transferred in succession from the fruit to the air, from the air to the cooling coils, from the coils to the compressor, and from the compressor to the condenser, where it is discharged to the cooling water. If in one or more of these steps the quantity of heat that can be transferred is unduly restricted, the equipment performing the other steps cannot be worked to greatest capacity. The condenser is doing its part if the head pressure is not excessive; and the cooling coils are not unduly limiting the capacity of the plant if the suction pressure is well up. It is less simple to know whether the air circulation system is in balance with the rest of the equipment.

During the cooling period, when the refrigerating equipment is operating to full capacity, the volume of air circulation may be considered in balance if the temperature difference between delivery and return air does not exceed 10° F. A lower split is desirable, but if it is greater than 10° an increased volume of air circulation will be found beneficial. As the load is cooled down and as less warm fruit is brought in, the split will decrease and should reach 1° to 2°. After fruit temperatures become about stationary, a split exceeding 1.5° is an indication of insufficient air volume. During this period further cooling is not required, but it is necessary to maintain uniform temperatures throughout the room.

Uniformity of temperature depends first on an adequate volume of air. If the volume is sufficient, as indicated by the split between delivery and return, and if temperatures in some parts of the room are still too high, the air is not being distributed to best advantage. This may sometimes be corrected by readjusting the delivery or return openings, giving special attention to increasing the volume of air entering the return ducts near the points of highest temperature.

AMMONIA PRESSURES

Routine observation of the gage pressures on the refrigeration equipment should be made. Too low suction pressures or too high head pressures are signs that the system needs attention. Ordinarily suction pressures below 20 to 25 pounds indicate that the cooling coils are not picking up heat as rapidly as they should. Head pressures of over 160 to 170 pounds indicate lack of sufficient cooling in the condenser. These limits depend upon the kind of system used, but the cause of any unexpected changes in pressure should be found and corrected. If pressures are normally outside the above limits the possibility of making adjustments or changes in the installation should be investigated in order to reduce power consumption and get more refrigeration. Table 9 shows how power consumption in-

Table 9.—*Relation of head or condensing and suction pressures to horsepower requirements per ton for typical ammonia compressors*

6- BY 6-INCH COMPRESSOR

Condensing pressure (pounds)	Suction pressure of—				
	10 pounds	20 pounds	25 pounds	30 pounds	35 pounds
85	1.30	0.90	0.77	0.66	0.56
105	1.42	1.04	.90	.79	.68
125	1.62	1.18	1.03	.91	.82
145	1.75	1.33	1.17	1.03	.93
165	1.94	1.47	1.31	1.17	1.05
185	2.12	1.60	1.44	1.30	1.17
205	2.29	1.76	1.57	1.42	1.29

9- BY 9-INCH COMPRESSOR

85	1.20	0.84	0.71	0.61	0.52
105	1.32	.97	.84	.73	.64
125	1.50	1.11	.97	.86	.77
145	1.67	1.25	1.10	.98	.88
165	1.83	1.39	1.23	1.11	1.00
185	2.00	1.53	1.36	1.23	1.11
205	2.17	1.67	1.50	1.36	1.24

creases as the head pressures increase and the suction pressures decrease with ammonia compressors. Suction pressures as high as 35 to 40 pounds and head pressures as low as 100 to 120 pounds can be obtained under favorable conditions. Pressure gages should be checked occasionally for accuracy, since they may get out of adjustment after long use. The temperature of liquid ammonia at various gage pressures is given in table 10.

TABLE 10.—*Temperatures of liquid ammonia at various gage pressures*

Range	Gage pressure	Temperature
	Pounds	*°F.*
(1)	0	−28
	5	−17
Suction pressure (usual range)	10	−8
	15	−1
	20	5
	25	11
	30	17
	35	21
(1)	40	26
	50	34
	75	50
Head pressure (usual range)	100	63
	125	75
	150	84
	175	93
	200	101

[1] Suction pressures seldom occur below 10 or above 35 pounds; head pressure seldom below 100 or above 200 pounds.

FROSTED COILS

Accumulation of heavy layers of frost on cooling coils retards the passage of heat (fig. 25). Pipes or finned coils need to be defrosted frequently to get the most from a cooling system. Disposal of the ice

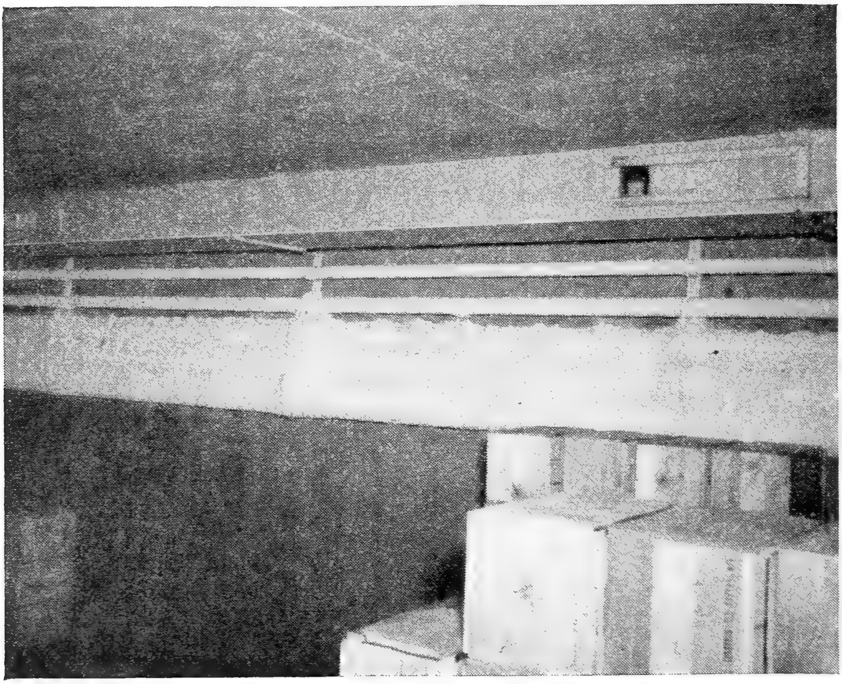

FIGURE 25.—The accumulation of frost on the coils lowers the efficiency of the plant.

and water from defrosting may be a problem in direct-expansion plants, but removal of the frost during the cooling period is important.

BRINE TREATMENT

In brine-spray plants the frost is washed off with brine, which is continually being diluted by the condensed water, making it necessary to drain off some at intervals and add more salt. The brine should not be any stronger than necessary to prevent accumulation of ice. One objection to brine-spray systems is that upon exposure to air the brine tends to become acid. Unless this tendency is checked the particles of brine carried by the air are very corrosive and may damage any metal with which they come in contact. The brine may be treated with a chemical to retard this corrosive effect. The instructions regarding such treatment, which are furnished by the company installing the equipment, should be followed carefully. Such instructions should be requested if they have been lost or forgotten.

CARE OF CONDENSER

The water used in condensers leaves on the pipes a deposit that, if allowed to accumulate, interferes with heat transfer. The water tubes of a condenser should be examined at least once each year, preferably prior to the harvest season, to make sure they are in good condition, and if necessary they should be given a thorough cleaning.

CARE OF COMPRESSOR

The compressor and other machines, including motors and pumps, need careful attention. Instructions furnished by the machinery manufacturers should cover operation of the particular machines in the plant and should be kept in the engine room and referred to frequently. Carelessness in operation or failure to observe the recommended routine may prove expensive in repairs.

CONTROLS

Automatic parts of the numerous types of control equipment used in various plants usually depend upon changes in temperature or pressure or are controlled by clocks. It will pay to become familiar with the principle of operation of each item involved in automatic control.

CARE OF FANS

In air-circulation systems fan size and speed are usually selected to deliver a certain volume of air against an estimated resistance. If the resistance is kept as low as possible, a maximum volume of air will be circulated. Frequently a fan will be found to have a film of dirt and grease accumulated on the blades and in the interior. This interferes with air flow and should be cleaned off.

DUCTS AND DAMPERS

The dampers and openings in ducts should be set open wide enough to permit the desired air distribution. In making adjustments the ports requiring more air should be opened to full capacity in preference to closing down dampers or openings at other points. When the temperature of the delivery air is too low the ports should not be closed down to prevent freezing; instead the temperature of the air should be raised and as much volume as possible permitted to circulate through the room. In many plants there is too little air circulation. This results in high temperatures in parts of the room, and sometimes an attempt is made to correct this by lowering the delivery-air temperature. If this becomes too low for safety, closing down the openings to prevent freezing aggravates the condition instead of improving it.

FREEZING NEAR COILS

In direct-expansion rooms the packages nearest the coils sometimes become too cold even though other fruit in the room may be too warm. This localized low temperature is caused by the radiation of heat directly from the packages to the coils, even though the air next to them may be above the freezing point. In this case, increased air circulation may keep the packages from getting too cold or it may be necessary to put a shield between the boxes and the pipes. This shield is not for deflecting the air but for preventing direct radiation, that is, to stop the "shining," or radiation, of heat from the boxes to the cold surface of the pipes. This radiation takes place regardless of the temperature of the air between boxes and pipes.

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