7
Technology of Storage

It has long been known that the preservation of fresh fruit, vegetables and ornamental plants is governed by three major parameters:

1. they keep better when cold;
2. they are damaged by freezing; and
3. they shrivel or wilt in dry air.

On the basis of this knowledge, control of the temperature and RH of the air around produce has been practised with increasing sophistication and success. A fourth parameter, the composition of the atmosphere, has been recognised more recently so that controlled or modified atmosphere storage is a more modern innovation.

METHODS OF STORAGE

In-ground storage

Pit storage, or clamp storage, is a simple low technology on-farm technique that is still beneficially practised in some countries. Hard vegetables, such as potato, turnip and late season cabbage, are piled into pits dug into a hillside or in some other well drained position. The pits are lined with hay or straw; the produce is then covered with straw followed by 10–20 cm of sods and earth to protect it against freezing or from excess heat and to deflect rain. It is advantageous to include piped ventilation to the outside to reduce respiratory self-heating. Clamp storage has been shown to be suitable for storage of cassava for up to 2 months in the tropics (Figure 7.1). In Europe, perishable produce was initially stored in cellars and caves that, being below ground, were cooler than above-ground buildings in warm weather, and warmer in winter. These methods are still commonly practised in the People's Republic of China.

Cellars are more sophisticated forms of below-ground storage; they may be part of above-ground buildings or underground rooms, often in hillsides, where access is easier. Again, good drainage and protection from rain are

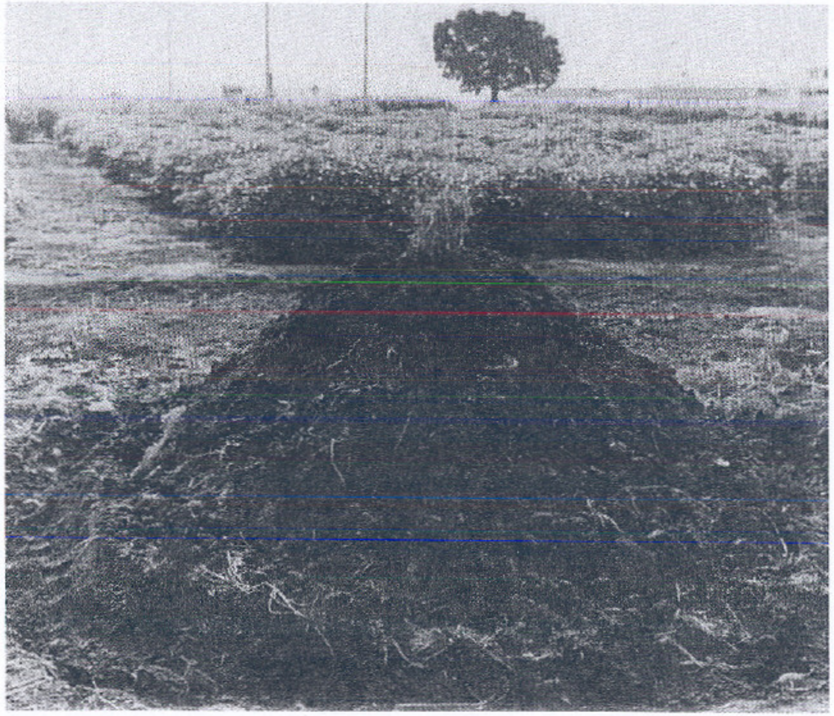


Figure 7.1
Cassava storage clamp. (Courtesy of R.H. Booth, Food and Agriculture Organization of the United Nations, Rome.)

essential. The performance of cellars is improved by providing controlled ventilation openings to enable cold air to enter and warm air to leave by convectional circulation when cooling is required. Although temperatures generally are not optimal, a good cellar will provide satisfactory storage for hard vegetables and long-keeping fruits such as apples.

Air-cooled stores

These are simple insulated structures above ground, or partly underground, which are cooled by the circulation of colder outside air. When the temperature of the produce is above the desired level, and if the temperature of the outside air is lower (generally at night), air is circulated throughout the store by convectional or mechanical means through bottom inlet vents and top outlets fitted with dampers. Fans may be installed and are controlled manually, or automatically with differential thermostats. The air may be humidified, a process that can

also be automated. Air-cooled stores are inexpensive to construct and operate and are still widely used for the storage of potato and sweet potato, both of which need relatively high storage temperatures to avoid accumulation of sugar and chilling injury, respectively.

Potatoes are commonly stored in bulk piles in stores with air delivery ducts under the floor, or at floor level, and with suitably spaced air outlets. A system of ventilating bulk piles or bins of onions with air provides an economical way to ensure that the outer scale leaves remain dry and free of decay. Garlic corms are similarly ventilated with air to prevent mould growth.

Ice refrigeration

An advance on air-cooled storage was the use of natural ice as a refrigerant. The lower temperatures enabled longer storage of meat and other perishable foods, including horticultural produce. In North America and Northern and Central Europe, ice was harvested in the winter from frozen lakes and ponds and stored in insulated 'ice houses'. The melting of 1 kg of ice absorbs 325 kJ, but the considerable bulk of ice needed and the disposal of the melted water are disadvantages. The introduction of the small 'ice box' or 'ice chest' was a great advance in the domestic and small-scale commercial preservation of perishable foodstuffs. Ice produced by mechanical refrigeration has several modern commercial applications as an adjunct to refrigeration (Chapter 4).

Mechanical refrigeration

The father of modern refrigeration was undoubtedly the Australian James Harrison. By 1851 he had designed and built the first ice-making plant in the world incorporating a small refrigeration compressor with its auxiliary equipment and ice tank at Geelong in Victoria. In 1854 Harrison was granted British Patent No. 717 for 'the production of cold by the evaporation of volatile liquids in vacuo', an invention probably equal in importance to that of the steam engine. The general principles of Harrison's design remain virtually unchanged in modern refrigeration plants. The system developed rapidly, and mechanically refrigerated cold stores, insulated with natural materials such as sawdust or cork, were operating within a few years. A shipment of frozen beef from Australia to England in 1879 was the first successful long distance shipment of perishable food by sea; soon after, the first mechanically refrigerated cool stores for apples and pears were in operation.

A refrigeration plant consists of four basic components: the compressor in which the refrigerant gas (either ammonia or halogenated hydrocarbons) is compressed (and unavoidably heated); the condenser, either air-cooled or water-cooled, in which the hot gas is cooled and condensed to a liquid; the expansion valve; and the evaporator coils, in which the liquid is permitted to boil and so remove heat from its surroundings (Figure 7.2). Fans are usually necessary to circulate the storage air over the cooling coils of the evaporator and through the stacks of produce in the store. The main agent for the transfer of heat from the interior of the store to the cooling coils is air movement, although radiation and convection may play a small part. In addition to these four basic components of a refrigeration plant and fans or correctly placed air ducts, various items of ancillary control equipment such as a liquid receiver and some means of defrosting the coils are required.

The removal of heat from the circulating air in a cool room by the evaporator coils is referred to as the 'direct expansion system'. Inevitably, the surface temperature of the evaporator coils must be lower than that of the produce to ensure that heat from all sources in a cool room is removed and the produce remains at a constant temperature. This temperature gradient is accompanied by a vpd between the produce and

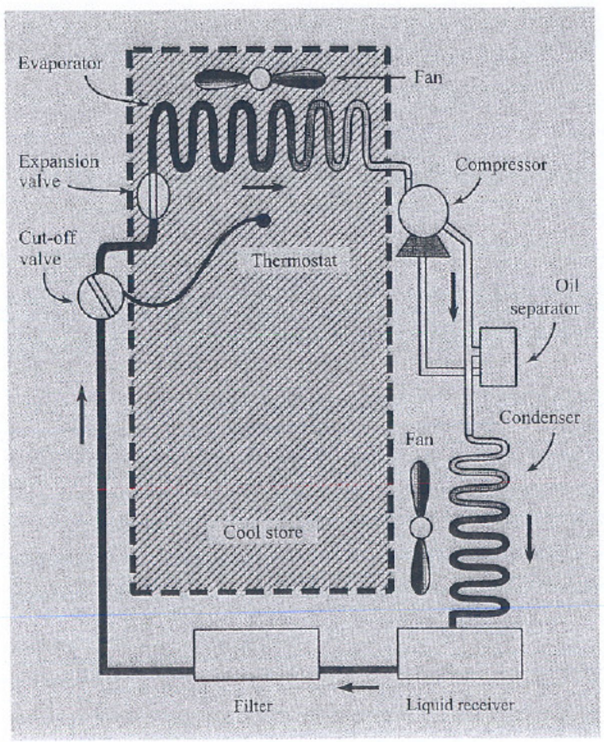


Figure 7.2
Basic component parts of a mechanical refrigeration plant. The part of the cycle from the compressor to the thermal expansion valve operates under high pressure to enable condensation of the hot gaseous refrigerant. The evaporator coils operate at low pressure to enable the refrigerant to boil. The condenser may be either air or water cooled.

the evaporator coils. This enhances water loss from the produce. For produce with high transpiration rates — such as leafy and root vegetables, mushrooms and cut flowers — a preferred system is to cool and humidify the room air by passing it through a shower of cold water that has been cooled by mechanical refrigeration. This indirect expansion system provides air at 1–2°C and RH of more than 98%. A variation of this system allows accumulation of ice on the evaporator coils (ice bank) to augment cooling capacity at times of high demand and to take advantage of lower off-peak electricity charges if this concession is available.

DESIGN AND CONSTRUCTION OF COOL STORES

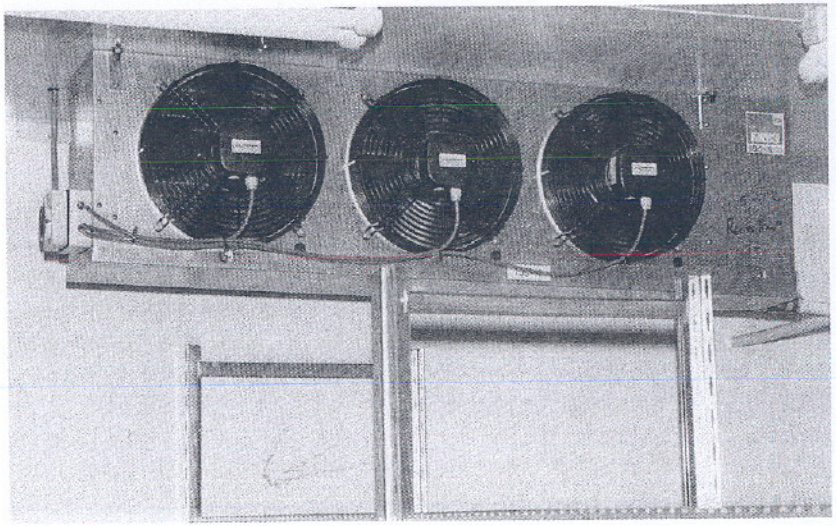
A cool store is a large, thermally insulated box, with doors for entry and some means of cooling the interior. Cool stores for horticultural produce have special requirements in comparison with other refrigerated stores. These include a high cooling capacity, close control of temperature, and RH greater than 90%. A common minimum design criterion is to provide capacity to cool a daily intake of 10 per cent of the capacity of the store at an initial rate of not less than 0.5°C per hour. Such a capacity requires 1 tonne (3.5 kW) of refrigeration capacity per 18 tonnes of produce for small stores of up to about 150 tonnes capacity, and about 1 tonne per 25 tonnes for larger stores. The capacity for larger stores can be varied by having two or more compressors or by the technique of cylinder unloading in one compressor.

Good temperature control requires spatial variation of no more than ±1°C and a variation in time in any one position of no more than ±0.5°C. A temperature difference of 1°C over the storage period has significant effects on most produce, especially those stored at less than 5°C. The optimum thickness of insulation in walls and the ceiling is the equivalent to 4 cm of cork per 10°C difference in temperature between the inside and outside. This will keep the overall heat transfer to about 0.3 $kJ/m^2/h$. This gives about the most economical ratio of the cost of refrigeration capacity to the cost of insulation, and also enables high humidities to be maintained. The best insulation is the cheapest that gives the required performance; it may be 6 cm thickness of polyurethane foam or 40 cm of sawdust. Floors generally require half the thickness of insulation that is used in the walls. A vapour barrier of thick polyethylene, laminated foil material, or the equivalent, having a low water vapour transmission rate is placed on the warm side of the insulation to prevent moisture from migrating to and condensing within the insulation.

Cool stores may be constructed in many ways. As long as the above conditions are met, all can be satisfactory. Many modern cool rooms are either of sandwich panel construction with polystyrene foam slabs as the insulation in the prefabricated panels, or foamed-in-place polyurethane is applied to the inner faces of the structure. The 'skins' on the outsides of the insulation are metal, commonly either aluminium or zinc-coated steel or waterproof plywood (Figure 7.3). Floors are constructed of reinforced concrete capable of carrying point loads from fork lifts as well as stacking loads. Cooled air is generally supplied by forced or induced draft coolers (Figure 7.4), consisting of framed, closely spaced and finned evaporator coils fitted with fans to circulate the air over the coils. Some means of defrosting the coils is also required when storage temperatures are low and the coil surface operates at temperatures below 0°C.

Figure 7.3
Modern cool room being constructed of metal clad panels insulated with polystyrene insulation. A Colorbond finish has been applied to the panels to facilitate cleaning the cool room. All joints and entry points for electrical cables and plumbing are sealed with waterproof silicone mastic to prevent entry of water into the insulation.

Figure 7.4
A modern cool room in which the cool air is blown through the coils by fans mounted at the back of the coils (forced draft cooler). The more common arrangement is to mount the fans in front of the coils (induced draft cooler). IDCs are preferred because they give better air distribution. In this example the palletised produce is placed on racks.



DESIGN AND CONSTRUCTION OF CONTROLLED ATMOSPHERE STORES

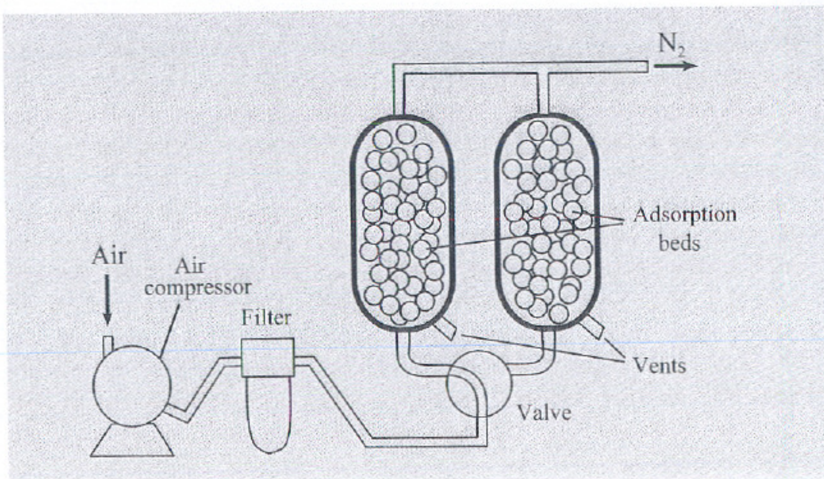
Controlled atmosphere storage of apples and pears was initially a system of ventilated gas storage, in which the atmosphere was generated by the accumulation of carbon dioxide from fruit respiration, and the level of carbon dioxide was maintained at the desired level by ventilation with outside air. Atmospheres of such stores typically contained 5–10 per cent carbon dioxide and 6–11 per cent oxygen as one volume of carbon dioxide is produced by the fruit for each volume of oxygen consumed. Further research revealed that some important cultivars were damaged by carbon dioxide concentrations above 3 per cent and that significant benefits could be obtained if store oxygen concentrations were in the range of 2–3 per cent. An atmosphere of 2–3 per cent carbon dioxide with 2–3 per cent oxygen was, therefore, found to be suitable for many apple and pear cultivars at cool storage temperatures (Chapter 6). To be able to maintain such a low oxygen atmosphere, a much more gas-tight room was required. This required highly specialised methods of construction. Furthermore, ventilation of the store with outside air to control the carbon dioxide concentration was not possible as it would introduce too much oxygen; therefore, some means of absorbing or 'scrubbing out' the excess carbon dioxide was required. Early carbon dioxide scrubbers relied on chemical absorption of the carbon dioxide in alkaline solutions, such as potassium hydroxide or calcium hydroxide. Later, less cumbersome and less messy methods were developed by which carbon dioxide was adsorbed physically or absorbed chemically with dry hydrated lime.

Thus the controlled atmosphere store has to be relatively gas-tight, and fitted with a means of measuring and controlling the concentrations of both carbon dioxide and oxygen. Being a sealed chamber, the refrigeration system has to be completely reliable, and the room has to be fitted with adequate, accurate and reliable remote-reading thermometers.

In the early 1970s an external generator was developed that consumed oxygen in the air much more rapidly than the produce could consume by respiration. The generator operated on gaseous fuel, which either produced a low oxygen atmosphere with the required carbon dioxide content to flush out the oxygen from the room (flushing system) or consumed the oxygen from the air in the room itself (recirculating system). A carbon dioxide absorber was required to absorb the excess carbon dioxide produced by the generator and by the fruit. Such a generator enabled a 2–3 per cent oxygen atmosphere to be maintained in a relatively leaky room. In modern practice, low oxygen atmospheres

can be achieved by flushing the room with liquid or compressed nitrogen in locations where nitrogen is relatively cheap. External generators are being superseded by gas separators such as the pressure swing adsorption (Figure 7.5) or hollow fibre membrane systems (Figure 7.6), which can generate gas streams containing low oxygen concentrations by separating oxygen and nitrogen from air. These separators have the major advantage of not producing any undesirable products arising from the incomplete combustion of fuels. Oxygen concentrations can be reduced rapidly by flushing the cool room. Once the required oxygen levels are reached, carbon dioxide concentrations are controlled by scrubbing with activated charcoal adsorbers. These modern carbon dioxide scrubbers have largely replaced the more cumbersome system of using hydrated lime in paper sacks. The operation of low-oxygen stores is now relatively simple and is frequently automated. Despite these advances, it is imperative to build gas-tight stores to ensure that separators are used economically. These land-based systems for generating and maintaining controlled atmospheres have now been adapted to ship refrigerated holds and to refrigerated shipping containers.

Figure 7.5
Pressure swing adsorption machine. Filtered dry compressed air is passed alternatively through chambers packed with a molecular sieve that retains oxygen when under high pressure and allows compressed nitrogen of at least 99 per cent purity to be generated. When the adsorption capacity in one chamber is nearing completion, the compressed air is automatically switched to the second chamber and the first is purged at atmospheric pressure to release the adsorbed oxygen.



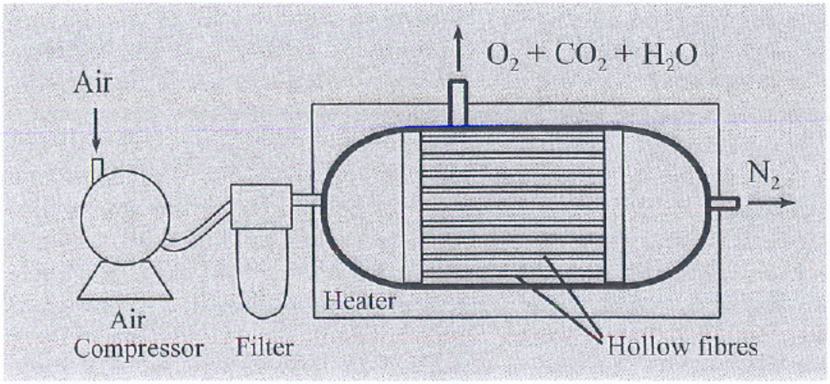


Figure 7.6
Hollow fibre membrane system. High pressure, dry, oil-free air is passed through hollow fibres constructed from a polymer that is differentially permeable to gases. Oxygen, carbon dioxide and ethylene permeate the fibres rapidly and are purged to the atmosphere, enabling the generation of a high pressure stream containing up to 99.5 per cent nitrogen.

Construction

An essential feature of a controlled atmosphere store is the provision of an effective gas barrier, which is most conveniently placed directly on the inside of the insulated surface. If the external vapour barrier is defective, however, moisture that penetrates this barrier will then be contained on the inside of the gas barrier, leading to water-logging and destruction of the insulation. During the early days of controlled atmosphere storage of apple and pears, existing cool rooms were frequently converted. The range of sealants was limited and it was frequently difficult to achieve sufficient gas tightness. The concept of the 'jacketed' room overcame these problems and allowed the gas barrier to remain readily accessible. The system provides a gas-tight lining inside a cool room, with an air space between the insulated walls and the lining. Cold air is circulated through this narrow space to remove the heat. An expensive disadvantage of the system is the need for air ducts under the floor. The 'blanket' type of store is a variation of the jacket type, and has a normal floor that reduces the cost of construction. Primary cooling air circulates over the ceiling and around the walls. A further variation is a room in which a plastic film acts as a blanket (i.e. 'plastic tent' controlled atmosphere storage). The tent is flexible and automatically varies the internal volume as pressure differentials develop, thus avoiding significant pressure effects.

Jacketed systems and plastic tents have been superseded with the advent of foamed-in-place polyurethane. The use of polyurethane enables the satisfactory conversion of existing cool stores to controlled atmosphere operation, and also provides a cheap new method of construction by completely lining the interior of a simple metal chamber. If correctly applied, the polyurethane provides both insulation and a gas barrier. A pressure relief device (burp valve), usually a water trap, is fitted through the walls of such a rigid, gas-tight structure to avoid damage by limiting pressure differentials to 370 Pa (15 mm water gauge).

Controlled atmosphere stores are lethal

While controlled atmosphere stores support plant life at a low level, they will not support mammalian life. Controlled atmosphere stores should be treated with respect to ensure that no one is ever exposed to such an atmosphere, unless wearing an efficient respirator with its own oxygen supply. Transport vehicles, in which the atmosphere has been modified with liquid nitrogen or modern controlled atmosphere systems, are especially dangerous and, like controlled atmosphere stores, must be well ventilated before entry.

MANAGEMENT OF PRODUCE STORAGE

High quality produce will come out of storage only if it is of high quality on entering the store, and if management of the storage facilities is of high standard. Given correct selection and handling of the fruit, the success of subsequent storage depends on: quickly reducing the temperature of the fruit to the desired level and maintaining it with little variation; close maintenance of the desired humidity and gas concentrations in the storage atmosphere; and avoiding over-storage.

Precooling the rooms

Storage rooms are generally brought down to the appropriate temperature a few days before fruit is to be stored. Three days is enough for a fully insulated room, but rooms without floor insulation should be precooled for a week to ensure that the floor has cooled to equilibrium. Failure to precool the room before loading is often the cause of unsatisfactory temperature maintenance, slow cooling, and excessive shrinkage of the produce.

Temperature control

Air movement transfers heat from the fruit to the coils by natural convection in a room with overhead grids (cooling pipes); by forced circulation in rooms cooled by forced or induced draft coolers; or by a combination of natural and forced convection. It follows that the nature of the packages and the method of stacking packages must allow the air to move readily through all parts of the stack for the produce to be cooled quickly and uniformly.

Spatial variation in the temperature of produce in a good store should not exceed 1°C above or below the nominated storage temperature. Several factors influence the spatial distribution of temperature in a store. The most important single requirement for uniform produce temperature is uniform cooling over the entire area on the top of the stack. This applies equally to the distribution of air from forced air circulation systems and to the even distribution of the coils over the ceiling in natural circulation rooms. Also of importance is the uniformity of the air paths through the stow as air always takes the path of least resistance. Ideally there should be a continuous, narrow air slot in the direction of air flow past at least two faces of every box or carton and each side of every bulk bin, together with no large vertical gaps in the stack to allow short-circuiting by the cool air. The room should be well insulated to reduce heat leakage, and the coolers should have ample capacity to ensure a small difference between the temperature of the air and coil surface.

Selection, sorting and handling of produce

It is desirable to sort and grade the size of produce before storage. Not all commodities are fit for storage; some have better keeping qualities than others, some are blemished (and usually sold to processors), and some of the harvested produce is unmarketable. Refrigerated storage is expensive, and it is not economical to have cool storage space occupied by produce that is not fit for sale or produce that would be better marketed immediately. Sorting and sizing before storage, so that both quantity and quality in storage are known, is of great assistance in orderly marketing.

Loading

If possible, warm produce should be cooled in a separate cool room from that used for storage. If only one room is available, the designed daily intake (commonly 10 per cent of capacity) should not be exceeded. Otherwise, the life of the produce will be reduced and shrinkage promoted. Warm produce should be loosely stacked, and cooling can be improved with the aid of an auxiliary portable fan placed in front of the stack, with the suction side facing the produce to draw air through it (Chapter 4).

Stacking

It is bad practice to overfill a room as this results in variable temperatures and therefore a poor outturn of a proportion of the produce. Packaged produce is carefully stacked to give economy of space, adequate and uniform air circulation, and accessibility. The following requirements for stacking are essential for rapid cooling and good temperature control for any type of package:

1. Keep the stack 8 cm away from outer walls and 10–12 cm away from any wall exposed to the sun. This will ensure that heat coming in through the walls will be carried away to the coils by air moving freely between the stack and the wall without warming nearby produce.
2. Leave a clear air space of not less than 20 cm between overhead coil drip trays and the top of the stack. If unit coolers or other forced air circulation systems are used, the clear space between the top of the stack and the ceiling is generally not to be less than 25 cm. This ensures that a uniform layer of cold air blankets the whole stack. The full depth of the space in front of a forced draft cooler is kept clear for a distance of 2 metres to allow it to function properly and to avoid freezing produce.
3. An air plenum of about 8 cm is required between the floor and the stack. When bins and pallets of boxes are used, the pallet bases provide the necessary air gap above the floor. Wherever possible, they are placed with the pallet bases parallel to the direction of airflow (i.e. running towards the forced draft cooler).
4. Leave small, vertical air paths within the stack, not less than 1 cm wide between adjacent packages. Freely exposed cartons cool at a similar rate to that of packed boxes of the same dimensions. Cartons, having straight sides, require special treatment in stacks. A layer-reversed, open chimney stacking pattern will provide the necessary vertical gaps between cartons (1 cm) and at the same time provide a stable stack.
5. Bulk storage bins should have air gaps in the floor of 8–10 per cent of the base area. Rapid cooling of produce is possible in such bins. Bins of warm produce are first stacked only two-high overnight to allow quick removal of field heat from the produce. Next day they may be stacked to full height. Unless a high RH is maintained in the cool store, produce in bins that also have air gaps in the side may shrivel excessively. The sides of the bins can be lined to reduce shrinkage, but cooling will be slow if the slatted bottoms are lined. Vertical air gaps about 4 cm wide are left around each column of bins — at least at the sides, which are at right angles to the pallet-base bearers — as this allows free escape of the air rising by convection through the produce in the bin.

Weight loss and shrinkage

Excessive shrinkage is due to: immaturity of the produce; delay before storage; picking produce when hot and then placing hot produce in the cool store; packing produce into dry wooden boxes or cartons; high storage temperatures, including hot spots in the room; low humidities due to insufficient insulation or insufficient coil surface; slow cooling; and excessive air circulation. Fast cooling, uniformly low temperatures and high humidities in the store are therefore necessary for low weight loss. The extra cost of additional cooling and insulation, and a good vapour barrier, can be more than offset by reduced weight loss and better produce condition after storage.

Weight loss during cooling may also be greatly reduced by wetting warm produce, such as leafy vegetables, before it is put into the store. It is preferable to harvest produce early in the morning, when it is coolest, and to put it directly into the cool store. This reduces the load on the refrigeration plant and lowers costs. When it is necessary to harvest produce later in the day during hot, dry weather, it may be practicable to spray some types of produce with water, to leave produce overnight in the open to cool by a combination of evaporative cooling and radiation cooling (if the night sky is clear), and to place produce into store the next morning.

Orderly marketing and over-storage

Over-storage is still one of the most common faults in the cool storage of produce. It is good marketing practice to commence selling long-keeping produce, such as apples and pears, from the cool store early and to continue regularly throughout the season. To achieve orderly marketing, produce in the cool store needs to be segregated according to the expected keeping quality and removed for sale accordingly; as a general rule produce first in should be first out.

Over-storage of produce may be minimised by placing aside a few small units of the various lines of produce; these are removed to room temperature at intervals during storage, and the whole line should be marketed without delay at the first sign that the sample has deteriorated. A further important reason for making such regular inspection of samples during storage is that some fruit may look in fine condition in the cool store but may either develop physiological disorders or fail to ripen satisfactorily after removal to ambient temperature.

Sanitation

Cool rooms should be thoroughly cleaned at the end of each season and, if necessary, sterilised to reduce the risk of losses by mould attack. The walls and floor can be washed with a solution of sodium hypochlorite (chlorine) followed by fumigation with formaldehyde gas. Mouldy or otherwise contaminated bins and boxes should be cleaned and sterilised with steam or a fungicide before reuse. Grading machines are often an important source of mould contamination that leads to the development of rots in storage. These machines should be cleaned and swabbed or sprayed with a fungicidal solution daily. The equipment should be regularly inspected for defects and any points likely to cause produce injury should be repaired.

REFRIGERATED TRANSPORT

By land or by sea, much produce is transported long distances under refrigeration. Refrigerated road or rail vehicles can be regarded as insulated boxes fitted with modular mechanical refrigeration units powered from diesel units. Refrigerated ships have a central refrigerating plant; the whole ('reefer ships') or only part of the carrying space on a vessel may be insulated and refrigerated.

Much refrigerated sea freight is now carried in containers of 30 or 60 cubic metres capacity, which permit temperature control from door to door. One type of refrigerated freight container, the 'integral' container, has its own refrigeration unit, operated electrically, and perhaps also incorporates a diesel-powered generator (Figure 7.7). The other type, the 'porthole' container, is a passive unit that must be supplied with cool air from a clip-on refrigeration unit or from a central unit (Figure 7.8).

Economy of space is a prime requirement in all transport, and therefore refrigerated transport vehicles and containers are designed for high density stowage. They are not designed for rapid cooling, so successful refrigerated transport requires thorough precooling of the load. Respiratory heat is a significant proportion of the refrigeration load. Therefore, unless the journey is short, some air space must be provided between the packages during stowage of produce. Significant amounts of heat enter refrigerated road transport vehicles from solar radiation of the outside air, heat reflected from the road and from air leakage through the doors. To ensure the maintenance of even temperatures it is necessary to provide good circulation of cooling air around the load (Figure 7.9). Rules covering precooling, stowage and air circulation have been developed from research and commercial experience. Maximum acceptable loading temperatures are commonly specified and ought to be closely policed.

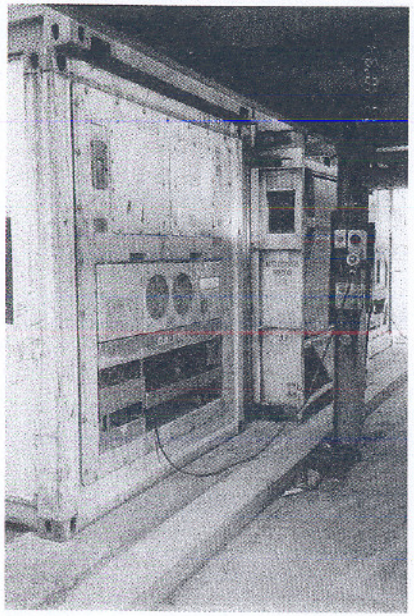


Figure 7.7
Integral-insulated shipping container with a built-in refrigeration unit.

Figure 7.8
A porthole refrigerated container must be coupled to either a clip-on refrigeration unit or to a source of cool air generated by a land-based or a shipboard refrigeration unit. In this example of a land-based system, the refrigeration plant can serve a battery of containers. When the containers are in place, the shutters are moved aside to allow connection to the air ducts.

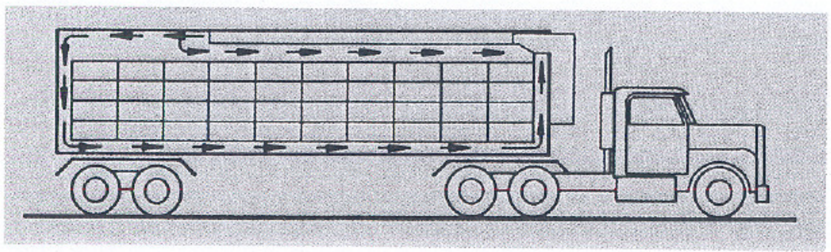


Figure 7.9
To ensure effective air circulation in a refrigerated road vehicle there must be an air delivery chute, ribs on the doors and walls, channels or pallets on the floor and a return bulkhead.
SOURCE A.K. Sharp, A.R. Irving and A.A. Beattie (1985) Transporting fresh produce in refrigerated trucks, *Agfact*, H1.4.3, NSW Department of Agriculture, Sydney.

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