11

Cooling Horticultural Commodities

James F. Thompson, F. Gordon Mitchell, and Robert F. Kasmire

Controlling product temperature and reducing the amount of time that product is at less-than-optimal temperatures are the most important methods of slowing quality loss in perishables (see chapter 4). Postharvest temperature management begins with planning the harvest and field handling. Some products are so sensitive to temperature abuse that they should not be harvested when temperatures are too warm. For example, table grapes show signs of stem shrivel at about 2% weight loss, and if stem quality is to be maintained at consumer level, the fruit should not be subject to more than about 0.5% weight loss between harvest and the beginning of cooling. Although grapes can be held for more than 8 hours at 20°C (68°F) before cooling, at 30°C (86°F) cooling should begin within 1.5 hours after picking (fig. 11.1). A few growers harvest at night to prevent exposure to excessive heat after harvest.

Other methods of protecting product from temperature-caused damage are to

- Make frequent trips between the field and the cooler to minimize temporary field storage.
- Pack in light-colored containers.
- Cover containers with lids if left in direct sun.
- Use a shaded area for temporary field storage. Remember, shade cast by a tree moves with the sun during the day.
- For short trips, use covered trucks to transport product to cooler. Long trips need refrigerated trucks.
- Begin cooling as soon as possible after product arrives at the cooling facility.

Some commodities can withstand a fairly long time between harvest and cooling. For example, apples placed in controlled atmosphere storage often do not reach optimal storage temperature until several days after harvest; exported California oranges may not reach best storage temperature until they have been at sea for several days. Products that do not require fast cooling generally have slow respiration rates, low moisture loss (transpiration) rates, and are often grown in climates with mild temperatures.

The first part of this chapter describes the variety of cooling systems available for horticultural commodities and the issues that need to be understood in their use. The second part describes a systematic approach for selecting a cooling system for a particular operation.

COOLING METHODS

Initial cooling of horticultural products to near their optimal storage temperature can be done with several cooling methods, including room cooling, forced-air cooling, hydrocooling, package icing, and vacuum cooling. Mechanical refrigeration in ships or refrigerated marine containers may be used for cooling a few commodities during transport. A few cooling methods (e.g., room cooling, forced-air cooling, and hydrocooling) are used with a wide range of commodities. Some commodities can be cooled by several methods, but most commodities respond best to one or two cooling methods.

Most users are concerned with the time to "complete cooling," which usually means the time to reach a desired temperature before

Figure 11.1

Effect of grape temperature at harvest on the time needed for the berries to lose 0.5% of their harvested weight.

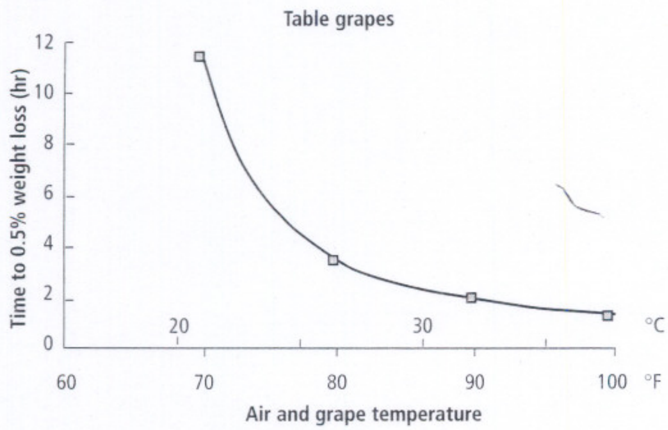
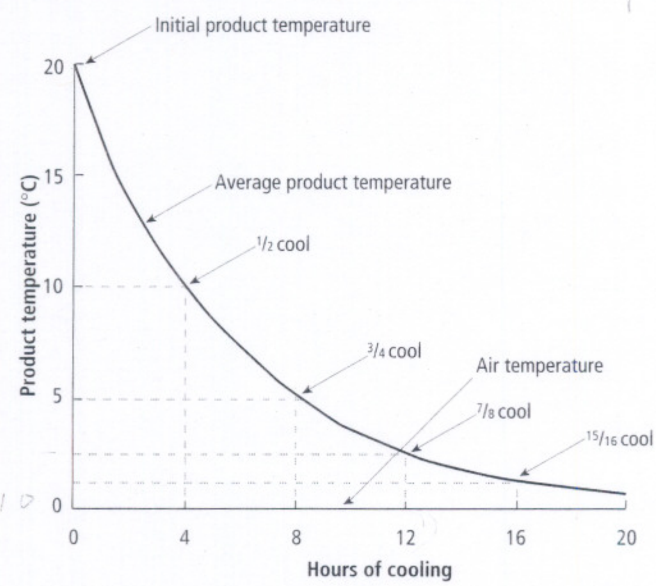


Figure 11.2

Typical cooling curve for perishable products. Cooling times are typical for large fruit, like peaches, exposed to moderate amounts of airflow.



transfer to storage or transport. Yet cooling times are usually reported as "half-cooling" or "seven-eighths-cooling" times. Half-cooling time is the time to cool the product halfway from its initial temperature to the temperature of the cooling medium. Seven-eighths cooling time is three times longer than half cooling and is the time needed for the product temperature to drop by seven-eighths of the difference between the initial product temperature and the temperature of the cooling medium. Both of these cooling times are constant values for a given package type in a given cooling system and are not affected by varying initial product temperatures or varying cooling medium temperature.

As horticultural products cool, their rate of temperature drop slows as cooling progresses. For example, for peaches with an initial pulp temperature of 20°C (68°F), half-cooling them in a forced-air cooler at 0°C (32°F) (i.e., cooling them to 10°C [50°F]) takes 4 hours. It takes an additional 4 hours to cool them to 5°C (41°F) and 4 more hours to reach seven-eighths cooling (about 2.5°C [36.5°F]) (fig. 11.2). Seven-eighths-cooling, or three half-cooling times (in this example, 12 hours), is often used as a reference cooling time.

Both initial product temperature and coolant temperature influence cooling time of a product. The peaches in the example mentioned above might be harvested in the morning, but by late afternoon on a hot California day they could have pulp temperatures near 40°C (104°F), in which case, with 0°C (32°F) cooling air, one additional 4-hour half-cooling period (16 hours total time) would be required to reach the same 2.5°C (36.5°F) pulp temperature as fruit harvested in the morning. If the cooling air temperature was 1.2°C (about 34°F), cooling peaches with initial temperature of 20°C would also require 4 half-cooling periods, or 16 hours.

In room and forced-air coolers, the product closest to the cold air cools noticeably faster than the product farthest from the cold air. Coolers should be managed so that the warmest product reaches acceptably low temperatures before the cooling process is halted.

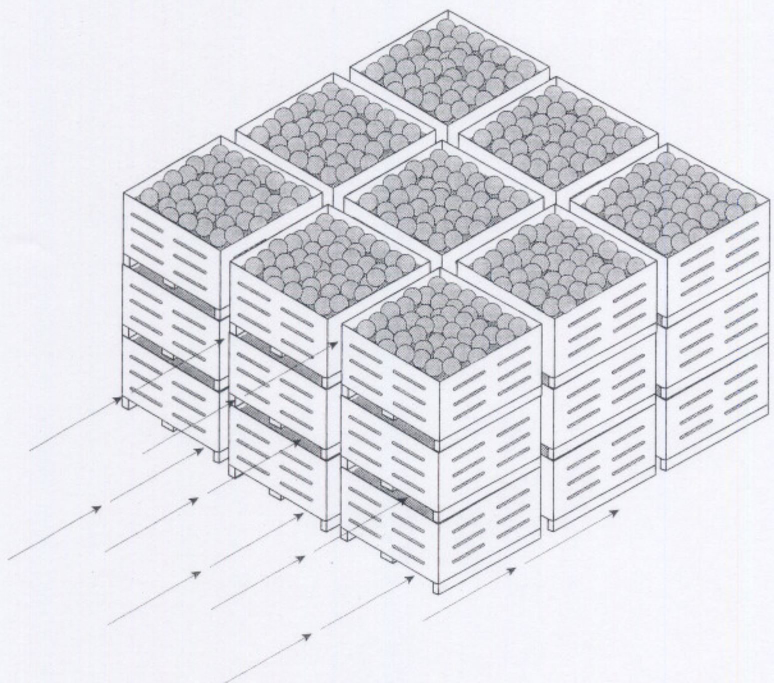
ROOM COOLING

This widely used cooling method involves placing field or shipping containers of produce into a cold room. Its most common use is for products with a relatively long storage life that are stored in the same room in which they are cooled. Examples include cut flowers before packing, potatoes, sweet potatoes, citrus fruits, apples, and pears.

In room cooling, cold air from the evaporator coils sweeps past the produce containers and slowly cools the product (fig. 11.3). The main advantage of room cooling is that produce can be cooled and stored in the same room without the need for transfer. Its disadvantages are that it is too slow for most commodities; it may initially require empty floor

Figure 11.3

Diagrammatic view of air path during room cooling of produce in bins. Air circulating through the room passes over surfaces and through forklift openings in returning to the cooling coils. In this system the air takes the path of least resistance in moving past the product. Cooling from the surface to the center of bins is largely by conduction.



area between stacked containers for air channels to speed cooling and subsequent rehandling after cooling is finished; and for some products, it can result in excessive water loss compared with faster cooling systems. Room cooling requires days for packed product to reach desired temperature, but it can be faster for unpacked products with good exposure to the cold air. For example, bunched flowers in buckets can cool in 15 minutes, but the same flowers packed in boxes and loaded on a pallet take days to cool.

For best results, containers should be stacked so that the moving cold air can contact all container surfaces. Total fan airflow should be at least 0.3 m^3/min per ton of product storage capacity (100 cfm/ton) for adequate heat removal. (For several commonly used airflow systems for room cooling, see fig. 12.3 in chapter 12.) Well-vented containers with vent alignment between containers greatly speed room cooling by allowing air movement through containers. After cooling is complete, airflow can be reduced to 20 to 40% of that needed for initial cooling.

Cooling bays

For both cooling and storage, a single large room is divided into bays by installing partitions partway into the room from each side (fig. 11.4). Air supply channels direct the air into the back of each bay. When a single bay is filled with warm product, supply ducts are opened to direct a large volume of cold air behind the product. Air return occurs down the center forklift aisle. When cooling is completed, the air supply is reduced in that one bay to create the desired storage conditions. If each cooling bay has a separate cold air supply, cold product in one bay is not warmed by warm product in other bays.

FORCED-AIR COOLING

Forced-air cooling is adaptable to a wider range of commodities than any other cooling method. It is much faster than room cooling because it causes cold air to move through, rather than around, containers. This allows cold air to be in direct contact with warm product. With proper design, fast, uniform cooling can be achieved through stacks of pallet bins or unitized pallet loads of containers. Water loss varies with the moisture loss characteristics of individual products and can range from virtually none to 1 to 2% of initial weight. Forced-air is the most widely adaptable and fastest cooling method for small-scale operations.

The speed of forced-air cooling is controlled by the volume of cold air passing over the product. Maximum feasible cooling requires about 0.001 to 0.002 $m^3 \cdot sec^{-1} \cdot kg^{-1}$ of product (1 to 2 cfm/lb). Rates greater than this only slightly reduce cooling time, but as the air volume increases, the static pressure required greatly increases, raising the energy consumption of the fan. Some products can withstand slower cooling and use air volumes of 0.00025 to 0.0005 $m^3 \cdot sec^{-1} \cdot kg^{-1}$ of product (0.25 to 0.5 cfm/lb). Static pressure needed to produce the desired airflow is very dependent on container vent design and the use of interior packaging materials. A complete description of this issue is included in the UC ANR publication *Commercial Cooling of Fruits, Vegetables, and Flowers* (Thompson et al. 1998).

Various airflow designs can be used, depending on specific needs. Converting existing cooling facilities to forced-air cooling is often simple and inexpensive if enough

Figure 11.4

Top view of a cold room divided into cooling bays.

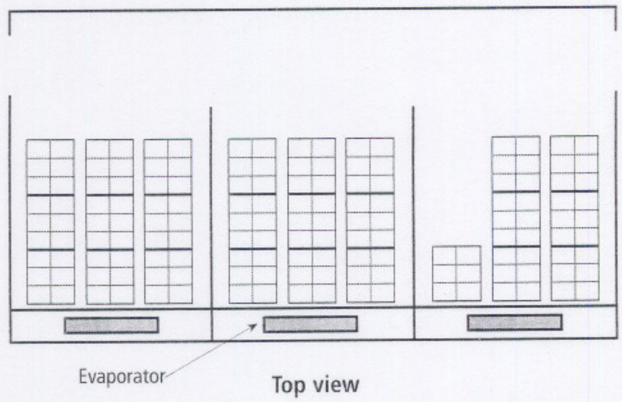
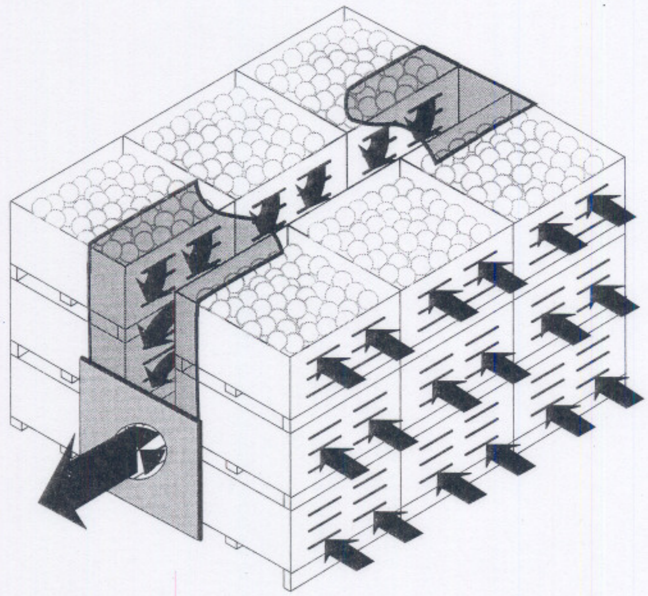


Figure 11.5

Diagrammatic view of a forced-air cooling tunnel. Either bins or palletized containers can be placed to form a tunnel from which air is exhausted. The negative pressure then causes cold air from the room to pass through ventilation slots to directly contact the warm product.



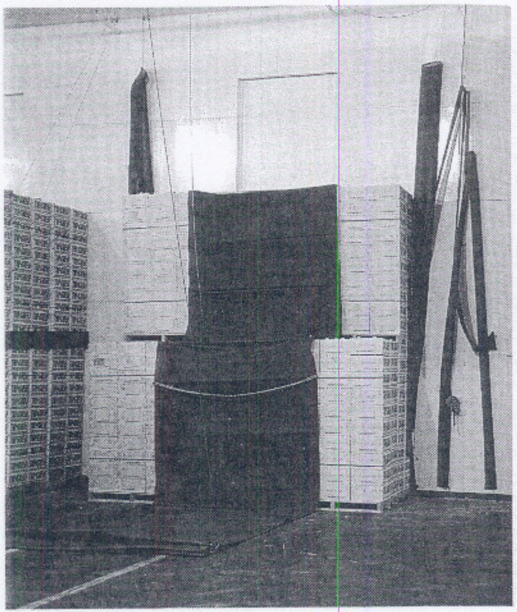
refrigeration capacity is available. A well-designed forced-air cooler is a separate room from cold storage rooms.

Tunnel-type forced-air cooling

In tunnel-type forced-air cooling, the most-used forced-air cooling system, a row of palletized containers or bins is placed on either side of an exhaust fan, leaving an aisle between the rows. The aisle and the open end are then covered to create an air plenum tunnel (fig. 11.5). The exhaust fan creates

Figure 11.6

Forced-air cooling tunnel is in operation, cooling packaged produce on unitized pallets. Air-circulating fan circulates air through fruit and over cooling coils. Canvas plenum cover is designed to fit varying cooling loads.



low air pressure within the tunnel. Cold air from the room moves through the openings in or between containers toward the low-pressure zone, sweeping heat away from the product. The exhaust fan is usually a permanent unit that also circulates air over the refrigeration coils and returns it to the cold room (fig. 11.6). The exhaust fan can also be a portable unit that is placed to direct the warm exhaust air toward the air return of the cold room or refrigeration evaporators.

Cold wall

This forced-air cooling system uses a permanent air plenum equipped with exhaust fans (fig. 11.7). The air plenum is often located at one end or side of a cold room, with the exhaust fans designed to move air over the refrigeration coils. Because openings are located along the room side of the plenum, against which stacks or pallet loads of containers can be placed (fig. 11.8), this method is not often used for products in bins. Various damper designs can be used to ensure that airflow is blocked except when a pallet is in place. Each pallet starts cooling as soon as it is in place, so there is no need to await deliveries to complete a tunnel. Shelves may be built so that several layers of pallets can be cooled. Different packages and even partial pallets

Figure 11.7

Cross section of a cold-wall type forced-air cooler.

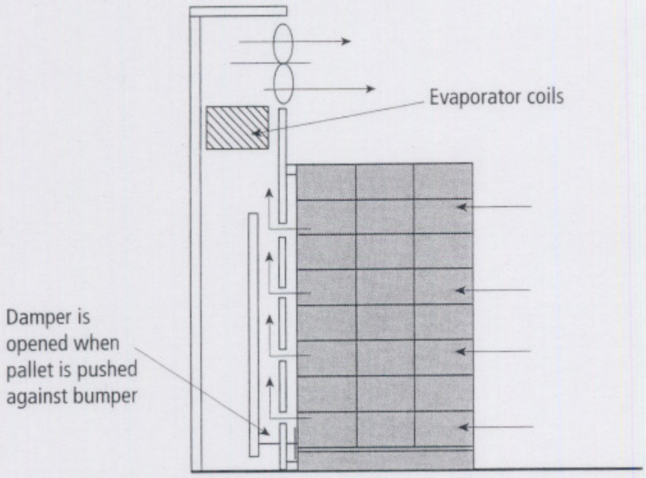


Figure 11.8

Cold-wall type forced-air cooler for use with stacks of flower containers. Open end-vents allow air to be pulled through the containers for rapid cooling but allow closing during shipment.

can be accommodated by proper design of the damper system. This is a benefit in operations that handle a range of commodities. Each pallet must be independently monitored for temperature and promptly moved from the cooler as soon as it is cold in order to avoid desiccation from continued rapid airflow over the product.

Serpentine cooling

The serpentine system is used for forced-air cooling of produce in bins. Bins must have bottom ventilation slots. Ventilation on the sidewalls of the bins does not aid cooling, although it probably does not hinder it either. The system requires modification of the cold-wall design to allow the forklift openings between bins to be used as air supply and return plenums. The cold air moves vertically through the product in each bin, causing a slight pressure difference between plenums (fig. 11.9). Bins may be stacked up to six rows deep against the cold wall, depending on the cooling speed desired and the available airflow. The airflow capacity of the small forklift opening plenums usually limits airflow to less than 0.0005 $m^3 \cdot sec^{-1} \cdot kg^{-1}$ of product (0.5 cfm/lb), and cooling is usually slower than tunnel coolers. To achieve the desired airflow pattern, openings are placed in the cold wall to match alternate forklift openings, starting one bin up from the floor. On the room side of the bins, these same openings are then blocked (fig. 11.10). Air flows into an open slot between bins and passes up or down through one bin of product to reach the return plenum. This system requires no space between rows of bins, and bins can be stacked in even numbers as high as the cold store or forklifts can reach.

Forced-air evaporative cooling

In forced-air evaporative cooling, the air is cooled with an evaporative cooler instead of with mechanical refrigeration. If designed and operated correctly, an evaporative cooler produces air a few degrees above the outside wet bulb temperature, and the cooler air is above 90% RH. In most areas of California, product temperatures of 16° to 21°C (60° to 70°F) can be achieved. A typical forced-air evaporative cooler is shown in figure 11.11. This cooling method may be adequate for some products that are best held at moderate temperatures such as tomatoes or for products that are marketed quickly after harvest. In most cases, growers can build their own forced-air evaporative coolers. They are much more energy-efficient than mechanical refrigeration, and if properly designed they provide high-humidity cooling air.

Container venting

Effective container venting is essential for forced-air cooling to work efficiently. Cold air must be able to pass through all parts of a container. For this to happen, container vents must remain unblocked after stacking. If containers are palletized in-register (aligned with one another), container side or end vents will suffice, provided they are properly located in relation to trays, pads,

Figure 11.9

Pattern of airflow in a serpentine forced-air cooling system. This system is specific for cooling fruit in field bins. By blocking alternate forklift openings on cold-wall and room sides, with fans operating, air is forced to pass vertically through bins to cool fruit.

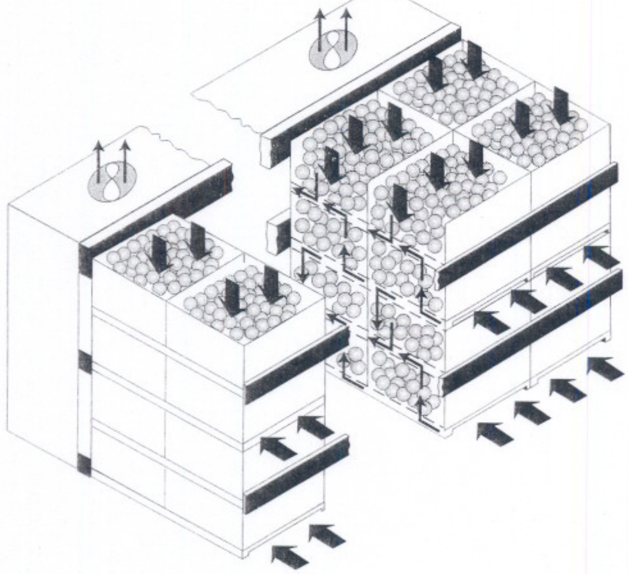


Figure 11.10

Serpentine forced-air cooler in operation. Plastic straps are placed over every other forklift opening from bottom to top. These close off the openings in the room side of the cooler. Air entering the open channels then must move up and down through the product to return to the cold wall. Note that bins can be tightly stacked in rows since no center airflow plenum is needed.

and other packaging. If cross-stacking is used, matching side and end vents is essential. For the 400 by 300 mm (or 16 by 12 in) container cross-stacked on the 1,200 by 1,000 mm (or 48 by 40 in) pallet, vertical vent slots on 100-mm (4-in) centers around the container perimeter should be considered, because they remain matched when cross-stacked (fig. 11.12).

Too little venting restricts airflow; too much venting weakens the container. A reasonable compromise appears to be about 5 to 6% side or end wall venting. A few large vents are more effective than many small vents for speeding the cooling rate. Locating vents midway from top to bottom is adequate unless trays or other packing materials isolate some of the product. Vertical slots at least 12 mm (½ in) wide are better than round vents. Vent design should minimize the effect of product blocking vents. Any type of unvented bag, liner, or vertical divider inside the package may block vents and reduce airflow. If a solid liner is used, slow but acceptable cooling times can be obtained if the box is designed so that cold air can flow over and under each box, and boxes are fairly shallow.

Flower boxes often have closable vents. This allows closing after cooling so that flowers shipped on unrefrigerated transport can maintain temperatures longer than if shipped in a box with open vents.

Cooling in transport

Marine containers and break-bulk ships have enough airflow and refrigeration capacity to achieve slow forced-air cooling. In-transit cooling is used for products produced in areas without cooling facilities. But it is usually better to cool the product before it is loaded in the ship or container, since most transport modes do not have the extra refrigeration capacity needed for fast cooling.

Refrigerated ships and most marine containers have a bottom-delivery air supply system. Air travels from the refrigeration system to a floor plenum. It then flows upward through the boxes and returns to the refrigeration system in the space above the product. To work well, boxes must have vent holes on the top and bottom, and the vent holes must align if boxes are cross-stacked. The floor must be covered to prevent air from bypassing the load.

Refrigerated highway trailers with a top-delivery air supply system do not have enough airflow to allow transport cooling.

Figure 11.11

Cutaway view of an evaporative forced-air cooler. Air is cooled by passing through the wet pad before it passes through packages and around the product.

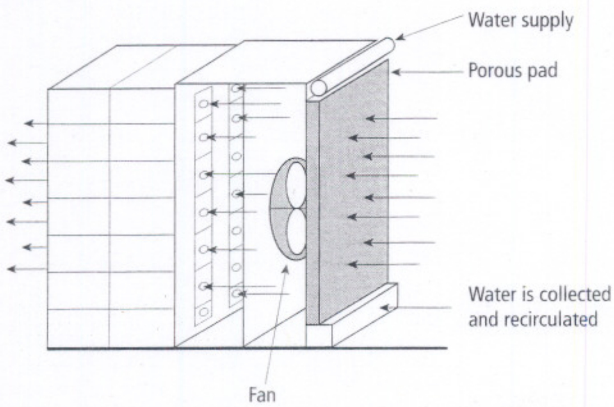


Figure 11.12

Recommended box vent design to allow good airflow or water flow while maintaining package strength.

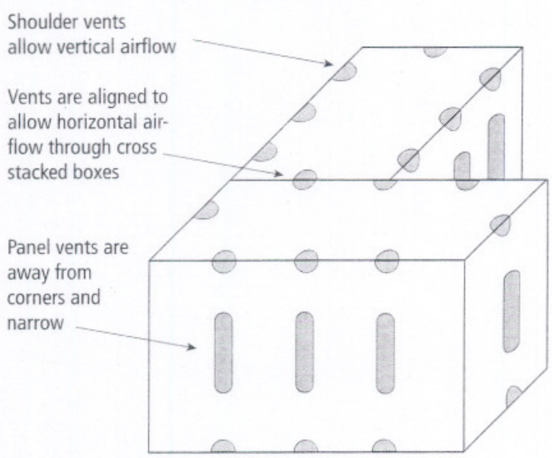
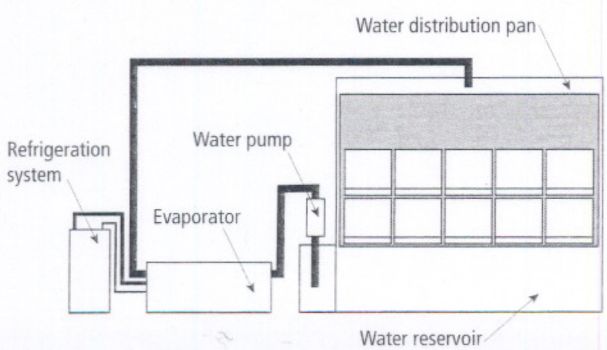


Figure 11.13

Side view of a batch-type hydrocooler for pallet bins.



HYDROCOOLING

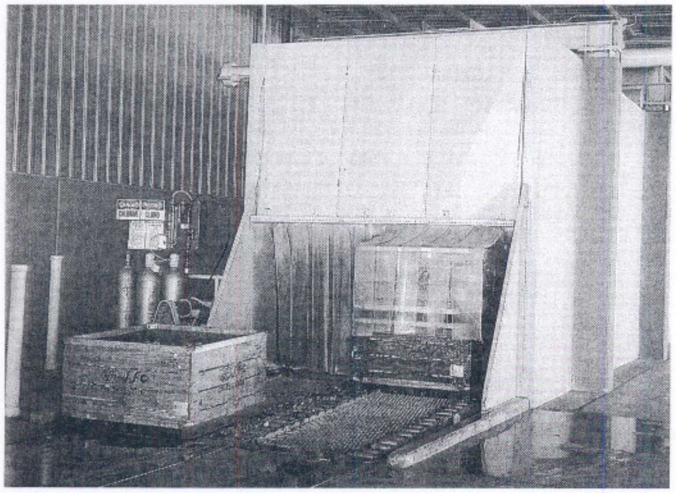
Cold water is an effective method for quickly cooling a wide range of fruits and vegetables in containers or in bulk (figs. 11.13 and 11.14). Typical seven-eighths cooling times are 10 minutes for small-diameter products like cherries and up to 1 hour for large products such as melons. Hydrocoolers can use either an immersion or a shower system to bring products in contact with the cold water. Hydrocooling avoids water loss and may even add water to a slightly wilted commodity, as is often done with leafy green vegetables. Hydrocoolers can be portable, extending the cooling season. Containers used in hydrocooling must be water-tolerant.

In a typical shower-type hydrocooler, cold water is pumped to an overhead, perforated distribution pan. The water showers over the commodity, which may be in bins or boxes, or loose on a conveyer belt. The water leaving the product may be filtered to remove debris, then passed over refrigeration coils (or ice), where it is recooled. The refrigeration coils are located under or beside the conveyer or above the shower pan. Some commodities, such as leafy vegetables and cherries, are sensitive to water-beating damage. For products like these, the distribution pan should be no more than 20 cm (8 in) above the exposed product. These products can also be cooled in an immersion hydrocooler.

Efficient cooling depends upon adequate water flow over the product surface. For product in bins or boxes, water flows of 13.6 to 17.0 $l \cdot sec^{-1} \cdot m^{-2}$ (20 to 25 gal/min/ft^2) of surface area are generally used. Bin hydrocoolers are often designed to accommodate two-high stacking of bins on the conveyors. Bulk product in shallow layers on a conveyor belt requires 4.75 to 6.80 $l \cdot sec^{-1} \cdot m^{-2}$ (7 to 10 gal/min/ft^2). Water is usually cooled by mechanical refrigeration, but ice may be used if it can be broken into fist-sized pieces and added fast enough to produce adequate cooling. In some areas, clean well water is cold enough to do initial cooling or even complete cooling. Hydrocoolers should be drained and cleaned at least daily or be equipped with special filters to clean the water. Low concentrations (100 to 150 ppm)

Figure 11.14

Conveyor-type bin hydrocooler in operation. Ice water is pumped into the top pan, where it runs down through the product in the bin. Dwell time in the cooler is controlled by conveyor speed.



of active chlorine are usually used to disinfect the water and minimize the spread of postharvest decay of products.

Hydrocooling has some potential limitations. The product and any packages and packing materials must be tolerant of wetting, and they must also be tolerant of chlorine (apricots sometimes show chlorine damage) or other chemicals that are used to sanitize the hydrocooling water. Shower-pan holes must be cleaned regularly to avoid plugging, which causes uneven water flow over the product. Arriving warm produce may have to remain at ambient temperatures for some time when the hydrocooler is operating at peak capacity. Cooled product must be moved quickly to a cold room or else rapid rewarming occurs. Hydrocooling operations can also require rehandling of the pallet bins before packing or storage.

Hydrocooling can be energy-efficient provided that the hydrocooler is operated continuously at maximum capacity and is inside a cold room or an insulated enclosure.

Shower-type hydrocoolers (conveyor or batch units) are the most commonly used hydrocooling systems, but immersion hydrocoolers are sometimes used. Fresh-cut vegetables are commonly cooled as they are conveyed in a water flume. In this case, the product, normally in bulk, is in direct contact with the cold water as it moves through a long tank of cold water. This method is best suited for products that do not float. Because slow cooling would result if the product simply moved with the water, immersion hydrocoolers convey product against the direction of water flow and often have a system for agitating the water. Conveyors must be designed for positive movement of the product through and out of the water.

PACKAGE-ICING

Some commodities are cooled by filling packed containers with crushed or flaked ice. Initially, the direct contact between product and ice causes fast cooling. However, as the ice in contact with the product melts, the cooling rate slows considerably. The constant supply of meltwater keeps a high RH around the product. Liquid ice, a slurry of ice and water, distributes ice throughout the box, achieving better contact with the product (figs. 11.15 and 11.16). Ice can be produced during off-peak hours when electricity is cheapest and stored for daytime use.

Package-icing requires expensive, water-tolerant packages. The packages should be fairly tight but should have enough holes to drain meltwater. In small operations the ice is hand-raked or shoveled into containers. Large operations use liquid-ice machines to automatically ice pallet loads of packed cartons. The process, which requires only a few minutes, is used for cooling some field-packed vegetables, particularly broccoli. The iced packages should be placed into a cold room after filling to minimize ice melt.

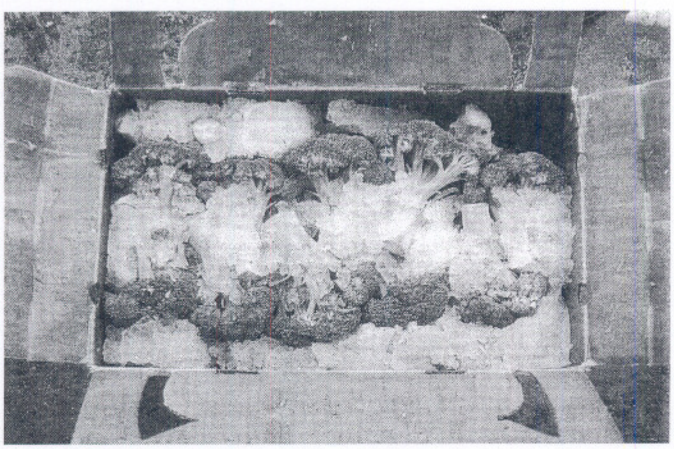
The product must be tolerant of prolonged exposure to wet conditions at 0°C (32°F). Some low-density products have excess space in which to load ice within the package, and ice not melted during cooling can remain in the package even after transport. This excess ice can keep the product cold if the cold chain is broken. However, this is an inefficient use of ice, and the weight of the ice can add significantly to the freight load, sometimes limiting the amount of product hauled. An ice weight equal to 20 to 30% of the product weight is needed for initial cooling, but liquid icing often adds an ice weight equal to the product weight. Also, during transport of mixed loads, water from melting ice can damage neighboring boxes that are not water-tolerant, and vehicle insulation can become wet. Ice and meltwater can be a safety hazard at wholesale distribution.

Figure 11.15

Pallet liquid-icing machine in operation. The high-volume flow of the ice-water mix is pumped into chamber and flows through container vents to deposit the ice throughout the package.

Figure 11.16

A package of liquid-iced broccoli is opened to show the penetration of ice throughout the package.



Cut flowers are often forced-air cooled, but if the box is handled in an unrefrigerated environment, bags of ice may be added to the box to prevent heating. This system allows a measured amount of ice to be added, and the melt water is contained, preventing damage to the product and fiberboard boxes.

VACUUM COOLING

Vacuum cooling takes place by evaporating water from the product at very low atmospheric pressure. Products that easily release water may cool in 20 to 30 minutes. Vegetables that have a high surface-to-mass ratio and that release water rapidly, such as leafy green vegetables (especially iceberg lettuce), are best suited to this method. It is also sometimes used to cool celery, some sweet corn, green beans, carrots, and bell peppers. It is used with carrots and peppers primarily to dry the surface and stems, respectively, and to inhibit postharvest decay. Even boxes of film-wrapped products can cool quickly provided the film allows easy movement of water vapor.

Moisture loss and consequent cooling is achieved by pumping air out of a large steel chamber containing the product (fig. 11.17). Reducing the pressure of the atmosphere around the product lowers the boiling temperature of its water, and as the pressure falls, the water boils, quickly removing heat from the product. Water vapor is removed by condensing it on refrigerated coils located between the ports and the vacuum pump. Vacuum cooling causes about 1% product weight loss (mostly water) for each 6°C (11°F) of cooling. This amount of weight loss can be objectionable for green onions, celery, and some leaf lettuces. Some coolers are equipped with a water spray system that adds water to the surface of the product during the cooling process. Like hydrocooling water, this water must be disinfected if it is recirculated. Water can also be sprayed on the product before it enters the cooler. The rapid release of the vacuum at the end of the process can force surface water into some vegetables, giving them a water-soaked appearance.

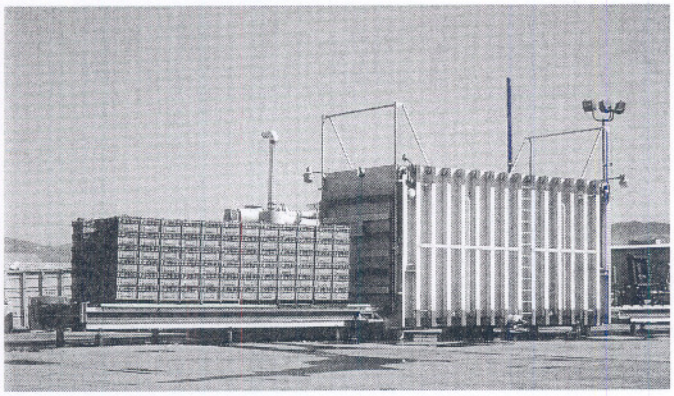
A typical vacuum tube, sometimes called a retort, holds 800 boxes of iceberg lettuce (20 pallets). Some small vacuum coolers hold only a single pallet. Most vacuum cooling equipment is portable and is used in two or more production areas each year, allowing the high capital cost of vacuum coolers to be amortized over a longer operating season. Most coolers used today have mechanical refrigeration and rotary vacuum pumps.

COOLING BEFORE PACKING

Cooling problems with products in unitized pallets, or liner-packed products, can be avoided by cooling the products before packing. However, this increases cooling costs if the products are cooled before culling and sorting operations. If 20% cullage occurs after cooling, the cooling cost increases 25%. If 50% is culled (for example, diverting pears to a processor), the cooling cost per ton of packed product

Figure 11.17

Vacuum cooler being loaded. Batches of product are filled into the chamber, which is then closed and the vacuum is drawn. This unit uses a patented process that introduces water during the cooling cycle to reduce water evaporation from the product.



doubles. Another disadvantage to cooling before packing is that cold fruit is more subject to mechanical damage in packing than warm fruit. For cantaloupes and cherries, these problems are avoided by removing most culls before hydrocooling.

Some rewarming occurs when produce is packed after cooling. A mild breeze can rewarm unpacked products to near ambient temperatures within 30 minutes. Some packers minimize this by only partially cooling the product before packing, followed by complete cooling after packing. One packer solves the problem another way: Fruit arriving from the field is forced-air cooled in bins; the bin dump is located in the forced-air bin cooling room. The cooled fruit moves from the cold room to a nearby packing area, where it is sorted, sized, and volume-filled into containers within 3 or 4 minutes. Packed containers are conveyed into a cold room for palletizing within 6 or 7 minutes of leaving the bin cooler. In this system, product rewarming is minimal; the product must be finish cooled.

SELECTING A COOLING METHOD

The physiological or physical characteristics of a product may limit the suitable cooling methods. For example, strawberries, which cannot tolerate free moisture because of disease and injury problems, cannot be cooled by hydrocooling or package-icing, and because they require fast cooling after harvest, room cooling is not suitable. Vacuum cooling is fast but causes noticeable moisture loss in berries. Thus, forced-air cooling is the only effective cooling method for strawberries. Other commodities, such as some deciduous fruits and many vegetables, are suited to several cooling methods. Table 11.1 lists the cooling methods commonly used for various types of fruits, vegetables, and flowers.

If a cooling facility is used for several types of commodities, it may or may not be possible to use the same method for all products. Table 11.1 shows that vacuum cooling, package icing, and room cooling are used for only a few products; hydrocooling is suited to a much wider variety; and forced-air cooling is adaptable to most products and is therefore ideal for operations where a wide variety of products must be cooled. This is why forced-air and room cooling are most often recommended for small-scale operations, which typically handle many commodities and may change the products they handle as the market changes from year to year. In some cases the product mix may require that more than one cooling system be used.

PRODUCT TEMPERATURE REQUIREMENTS

A facility that must handle products with very different optimal storage temperatures usually needs separate cooling facilities. Keeping chilling-sensitive commodities below their critical threshold temperature too long will cause damage.

If product temperature requirements are not very different, careful cooler management may allow a common cooler to be used. For example, summer squash can be forced-air cooled in a 0°C (32°F) room if it is removed from the cooler at 7°C (45°F) flesh temperature. It should then be stored at 7°C (45°F). Many chilling-sensitive commodities can be safely kept for short periods below their chilling threshold temperature.

COSTS OF OPERATING COOLERS

Capital costs vary significantly among different types of coolers. Liquid ice coolers are the most expensive to purchase, followed by vacuum coolers (including units equipped with water spray capability), forced-air coolers, and hydrocoolers. Figure 11.18 shows the capital cost, expressed in

Table 11.1. Cooling methods suggested for horticultural commodities

Commodity	Size of operation: Large	Small	Remarks
Tree fruits			
Citrus	R, FA	R	
Stone fruits	FA, HC	FA	Apricots cannot be HC
Pome fruits	FA, R, HC	R	
Subtropical	FA, HC, R	FA	
Tropical	FA, R	FA	
Berries	FA	FA	
Kiwifruit	FA	FA	
Grapes	FA	FA	Require rapid cooling facilities adaptable SO$_2$ fumigation
Leafy vegetables			
Cabbage	VC, FA	FA	
Iceberg lettuce	VC	FA	
Kale, collards	VC, R, WVC	FA	
Leaf lettuces, spinach, endive, escarole, Chinese cabbage, bok choy, romaine	VC, FA, WVC, HC	FA	
Root vegetables			
With tops	HC, PI, FA	HC, FA	Carrots can be VC
Topped	HC, PI	HC, PI, FA	
Irish potatoes	R w/evap coolers,		With evap coolers, facilities should be adapted to curing
Sweet potatoes	HC	R	
Stem and flower vegetables			
Artichokes	HC, PI	FA, PI	
Asparagus	HC	HC	
Broccoli, Brussels sprouts	HC, FA, PI	FA, PI	
Cauliflower	FA, VC	FA	
Celery, rhubarb	HC, WVC, VC	HC, FA	
Green onions, leeks	PI, HC, WVC	PI	
Mushrooms	FA, VC	FA	
Pod vegetables			
Beans	HC, FA	FA	
Peas	FA, PI, VC	FA, PI	
Bulb vegetables			
Dry onions	R	R, FA	Should be adapted to curing
Garlic	R		
Fruit-type vegetables			
Cucumbers, eggplant	R, FA, FA-EC	FA, FA-EC	Fruit-type vegetables are chilling-sensitive but at varying temperatures
Melons			
cantaloupes	HC, FA, PI	FA, FA-EC	
honeydew, casaba, crenshaw	FA, R	FA, FA-EC	
watermelons	FA, HC	FA, R	
Peppers	R, FA, FA-EC, VC	FA, FA-EC	
Summer squashes, okra	R, FA, FA-EC	FA, FA-EC	
Sweet corn	HC, VC, PI	HC, FA, PI	
Tomatillos	R, FA, FA-EC	FA, FA-EC	
Tomatoes	R, FA, FA-EC		
Winter squashes	R	R	

Table 11.1. Cont.

Commodity	Size of operation: Large	Size of operation: Small	Remarks
Fresh herbs			
Not packaged	HC, FA	FA, R	Can be easily damaged by water beating in HC
Packaged	FA	FA, R	
Cactus			
Leaves (nopalitos)	R	FA	
Fruit (tunas or prickly pears)	R	FA	
Ornamentals			
Cut flowers	FA, R	FA	When packaged, only use FA
Potted plants	R	R	

KEY:
FA = Forced-air cooling
FA-EC = Forced-air evaporative cooling
HC = Hydrocooling
PI = Package icing
R = Room cooling
VC = Vacuum cooling
WVC = Water spray vacuum cooling

cost per daily cooling capacity, of four types of coolers, based on 1998 data. The wide cost range for liquid icing reflects the variation in the amount of ice that is put in the carton. If just enough ice for product cooling is used, much less refrigerating capacity is needed and capital cost is lower. However, many broccoli shippers add extra ice to handle refrigerating needs in transport, and they also add an extra 4.5 kg (10 lb) of ice so that the box arrives at the market with unmelted ice.

The capital cost per unit cooled can be minimized by using the equipment as much as possible. Vacuum-cooling equipment is very compact and is often portable. In California, vacuum coolers are moved as harvest locations change during the year. It is common in the western United States for portable vacuum coolers to be used more than 10 months per year. Forced-air cooling facilities can be used for short-term storage of product during the harvest season and for long-term storage of product after the season ends.

Energy costs

The energy cost of cooling varies greatly among coolers (fig. 11.19). Energy use is expressed in terms of an energy coefficient (EC), defined as

$$EC = \frac{\text{cooling work done (expressed in kilowatt-hours)}}{\text{electricity purchased (kWh)}}$$

High EC numbers indicate an energy-efficient operation. The range of EC for each type of cooler reflects differences in design and operation procedures between coolers of the same type.

Actual energy costs for operating a cooler can be calculated using the formula below (assuming a value for EC). Energy costs can be less than 5% of total costs in efficient cooling systems.

In English units:

$$\text{Electricity cost} = \frac{W \times TD \times R \times Cp}{3{,}413 \times EC}$$

where
W = weight cooled (lb)
TD = temperature reduction in product (°F)
R = electricity rate ($/kWh)
EC = energy coefficient
Cp = 1 Btu/lb-°F
3,413 Btu/kWh

In SI (metric) units:

$$\text{Electricity cost} = \frac{W \times TD \times R \times Cp}{3.6 \times EC}$$

where
W = weight cooled (kg)
TD = temperature reduction in product (°C)
R = electricity rate ($/kWh)
EC = energy coefficient
Cp = 4,184 J/kg-°C
3.6 J/kWh

Figure 11.18

Capital cost of commonly used cooling systems (in 1998 dollars).

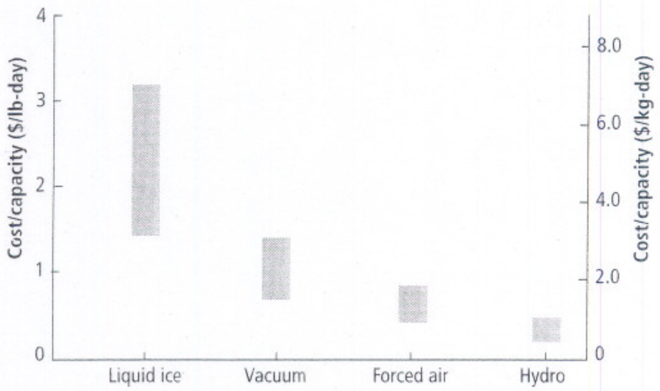
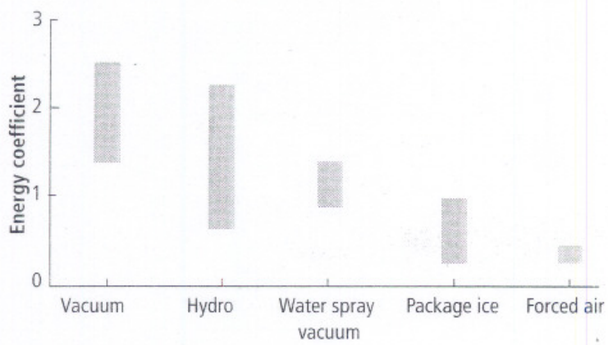


Figure 11.19

Energy use of commonly used cooling systems.



Labor and other equipment costs must be included in calculating total operating costs. Although no specific data are available for these costs, they can vary significantly. For example, a hydrocooler built into a packing line requires very little labor and other equipment, but stand-alone coolers used in field packing operations require operators and lift trucks for moving product in and out of the cooler.

If a cooling method requires that the product be packaged in a special carton, the extra cost of the carton should be included in a comparison of cooler types. For example, package icing, hydrocooling, and water-spray vacuum cooling need water-resistant packaging. This can increase the cost of an individual box by 25 cents to $1 depending on the design, size, and quantity of boxes purchased.

Other considerations

Marketing tradition may dictate the choice of a cooling method. For example, some markets require that broccoli boxes arrive with ice in them. Shippers selling in this market must select a package-ice cooling system.

Existing facilities may determine the type of cooler to be used. An existing cold-storage room can often be used for forced-air cooling of small amounts of product by installing a small portable fan. Larger amounts of product usually require installation of more refrigeration capacity and a permanent air handling system.

A short harvesting season in a particular location may cause an operator to consider using portable cooling equipment. The cooler can be moved to a grower's other production areas or leased to shippers in other areas, eliminating the cost of buying separate permanent coolers for each location. Some portable coolers can be leased or jointly owned by shippers and cooler manufacturers, eliminating or reducing the need for capital expenditure.

Some growers contract with commercial companies to do their cooling. This requires no direct capital investment and no operating or management costs. But the grower loses some control over the product, often cannot control when product is cooled, and loses the chance to make a profit from the cooling operation. Cooling cooperatives can give a grower some of the advantages of owning a cooler while reducing individual investment costs.

ESTIMATING REFRIGERATION CAPACITY

After deciding which cooling method or methods to use, the operator must estimate the amount of refrigeration capacity needed. This will help determine how large a cooler is needed. In general, 2.3 kW of refrigeration requires about 1 kW of compressor capacity, or 1 ton requires a little less than 2 horsepower of compressor capacity. Coolers requiring less than about 40 kW (11.4 tons) of refrigeration capacity can often be built by the grower.

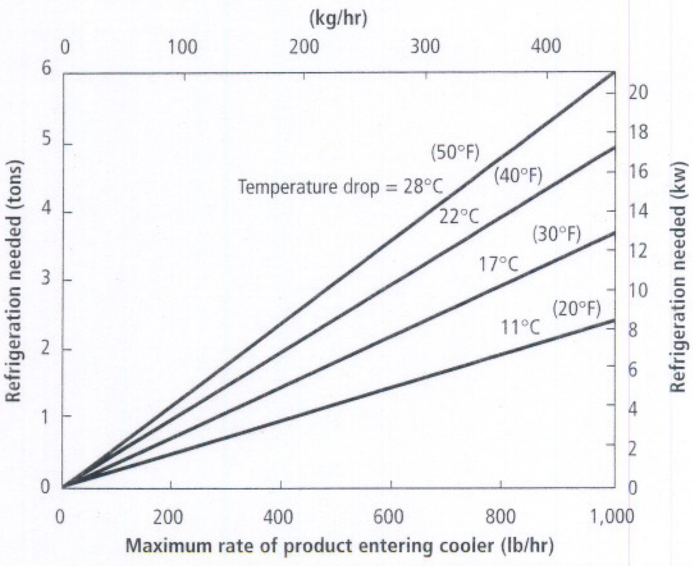
The refrigeration capacity needed for large systems must be determined by a refrigeration engineer. The engineer will consider a number of factors, such as

- amount of product cooled
- temperature of incoming product
- rate at which the product is received at the cooler
- required speed of cooling
- variety of products cooled and their unique cooling requirements
- building design and how it affects heat gain to the refrigerated volume
- heat input from lights, fan motors, forklifts, people, etc.

An estimate of the amount of refrigeration capacity needed for small-scale facilities does not require detailed calculations. Figure 11.20 can be used to estimate the refrigeration capacity needed for a cooler handling up to 450 kg/hr (1,000 lb/hr). For example, if a product is cooled from 23.9°C (75°F) to 1.7°C (35°F) (a temperature drop of about 22°C [40°F]), and the cooler must handle a maximum of 400 kg/hr (900 lb/hr), then 16 kW (4.5 tons) of refrigeration capacity is necessary. Estimates from this figure are based on reasonably fast cooling; slow cooling, as is achieved by room cooling, requires slightly less refrigeration capacity. The figure is also based on the assumption that heat input to the cooler from sources other than the product are less than 25% of the total.

Figure 11.20

Approximate mechanical refrigeration requirements for small scale coolers based on maximum hourly product input and product temperature drop.



Some small-scale cooling operations purchase ice for cooling. Figure 11.21 can be used to estimate the daily amount of ice needed to operate a small cooler. For example, if 2,000 kg/day (4,400 lb/day) of product are cooled by about 22°C (40°F), a little more than 1,000 kg (1.1 tons) of ice would be melted. The figure is based on 50% of the ice being used for product cooling and the rest of the cooling potential lost to outside heat gain. This efficiency level is common for uninsulated hydrocoolers. For more details on designing and operating coolers, consult the UC ANR publication *Commercial Cooling of Fruits, Vegetables, and Flowers* (Thompson et al. 1998).

EFFECTIVE COOLER MANAGEMENT

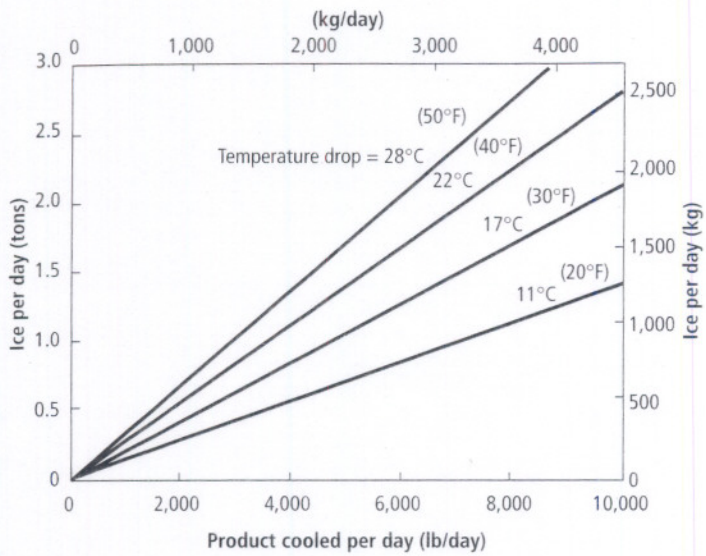
Proper management of a cooler involves effective product cooling at minimum cost. Records of cooler operation are vital to enable a manager to evaluate the cooler. Good records should include

- a sampling of incoming and outgoing product temperature for each lot and the type of product cooled
- the temperature of the cooling medium during each cooling cycle
- the length of cooling cycles
- the quantity of product cooled in each cycle
- operating conditions of refrigeration system, such as suction and head pressures
- monthly energy use

Knowledge of incoming product temperature is helpful in estimating the cooling time required; outgoing product temperature is essential for determining the quality of the cooling process. The average product temperature should be within acceptable tolerances, and, just as important, the warmest product temperatures should be within acceptable tolerances. A good operator checks outgoing product temperatures in various parts of the load to determine where the warmest product tends to be, and then controls the operation to get product in this area below required temperature. For example, in tunnel-type forced-air coolers, the warmest product is usually next to the return air tunnel in the pallet farthest from the fan. Hydrocoolers tend to cool product fairly uniformly,

Figure 11.21

Approximate amount of ice needed to operate small-scale coolers based on amount of product cooled per day and product temperature drop.



and the warmest product is in areas with restricted water flow, perhaps caused by misaligned box vents. Vacuum coolers tend to cool very uniformly. The performance of liquid icing systems is determined by the uniformity of ice added to each box.

Other factors are useful in determining the long-term performance of a cooler. For example, if cooling times begin to increase and the temperature of the cooling medium does not change, then there is a good chance that flow of the cooling medium through the product is being restricted (assuming that the type of product and its incoming temperature remain constant). If the temperature of the cooling medium shows a trend of increasing during the cooling cycle, there may be problems in the refrigeration system, or there may be too much product in the cooler. Changes in operating conditions of the refrigeration system can give clues to possible problems and their solutions.

Regular maintenance is important for all types of coolers. In vacuum coolers, door seals must be checked regularly and pressure gauges must be recalibrated about once per year. Daily cleaning is vital for proper hydrocooler operation. Trash screens, the water distribution pan, and the water reservoir must be cleaned each day and chlorine levels must be checked several times a day. Fluid levels and other features of the refrigeration system should be checked daily.

COLD ROOMS

Cooled product will quickly warm up unless it is loaded directly into refrigerated transport vehicles or placed in cold rooms. Rewarming wastes the benefits of cooling; and cooled products left in a warm environment are also subject to condensation, which may lead to disease. To help solve these problems, a cold room should be associated with the cooler. In some cases, the cooler may be a part of the cold room, as with forced-air coolers, but this is not recommended. Small cold rooms can be commercially constructed, purchased in prefabricated form and erected by growers, constructed by growers, or purchased as used refrigerated transport vehicles (rail cars, trailers, or marine containers). The cost of the cold room should be added to the total capital cost of a cooling facility.

SUMMARY

Effective cooling and temperature management requires a complete understanding of product and market requirements, and of the cooling methods available.

- Rapid thorough cooling and good product temperature management are essential for successful produce marketing.
- Cooling is part of the total system of handling perishables. Effects on cooling rate must be considered whenever a change is made in packaging or handling.
- Requirements for cooling and cold storage differ, and they should be considered as two separate operations.
- Four cooling methods and variations are available to achieve rapid cooling. Select a cooling method or methods that fit the needs of your customers and the range of commodities you handle.
- Fast cooling can often be achieved through minor modifications of existing cooling facilities. Design requirements should be determined by a qualified refrigeration engineer after evaluating the complete refrigeration system. The increased costs involved in achieving faster cooling may be relatively small when the total cost of the cooling system is considered.

- Cooling time can often be reduced by attention to details of air or water management, package design, packing material, and pallet stacking patterns.
- Keep careful records of cooling performance. Good cooler management requires systematic measurement and recording of product temperatures.

REFERENCES

Hardenburg, R. E., A. E. Watada, and C. Y. Wang. 1986. The commercial storage of fruits, vegetables, and florist and nursery stocks. USDA Handb. 66. 130 pp.

Isenberg, F. M. R., R. F. Kasmire, and J. E. Parson. 1982. Vacuum cooling vegetables. Cornell Univ. Coop. Ext. Bull. 186. 10 pp.

Jeffrey, J. J. 1977. Engineering principles related to the design of systems for air cooling of fruits and vegetables in shipping containers. Proc. 29th Intl. Conf. on Handling Perishable Agricultural Commodities. East Lansing: Mich. State Univ. 151–164.

Rij, R. E., J. F. Thompson, and D. S. Farnham. 1979. Handling, precooling, and temperature management of cut flower crops for truck transportation. Oakland: Univ. Calif. Coop. Ext. Leaflet 21058.

Sargent, S. A., M. T. Talbot, and J. K. Brecht. 1989. Evaluating precooling methods for vegetable packinghouse operations. Proc. Fla. State Hort. Soc. 101:175–182.

Thompson, J. F., and R. F. Kasmire. 1981. An evaporative cooler for vegetable crops. Calif. Agric. 35(3–4): 20–21.

Thompson, J. F., F. G. Mitchell, T. R. Rumsey, R. F. Kasmire, and C. H. Crisosto. 1998. Commercial cooling of fruits, vegetables and flowers. Oakland: Univ. Calif. Div. of Ag. and Nat. Res. Publ. 21567. 61 pp.

Watkins, J. B., and S. Ledger. 1990. Forced-air cooling. 2nd ed. Brisbane, Australia: Queensland Dept. of Primary Industries. 64 pp.