Design of Room Cooling Facilities: Structural & Energy Requirements

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Contents

Proper temperature control is essential to protecting the quality of fresh produce. By constructing and maintaining their own cooling facilities, farmers, packers, and roadside vendors can substantially reduce the overall cost of owning one of these useful structures. This publication describes how to plan a postharvest cooling facility of modest size and how to determine the structural and energy requirements.

Why Cool?

Most fruits and vegetables have a very limited life after harvest if held at normal harvesting temperatures. Postharvest cooling rapidly removes field heat, allowing longer storage periods. Proper postharvest cooling can:

- Reduce respiratory activity and degradation by enzymes;
- Reduce internal water loss and wilting;
- Slow or inhibit the growth of decay-producing microorganisms;
- Reduce the production of the natural ripening agent, ethylene.

In addition to helping maintain quality, postharvest cooling also provides marketing flexibility by allowing the grower to sell produce at the most appropriate time. Having cooling and storage facilities makes it unnecessary to market the produce immediately after harvest. This can be an advantage to growers who supply restaurants and grocery stores or to small growers who want to assemble truckload lots for shipment. Postharvest cooling is essential to delivering produce of the highest possible quality to the consumer.

Planning Before You Build

Although small, commercial, contractor-built cooling rooms are available, they are often much more expensive than owner-built structures. In addition to avoiding a substantial amount of the construction cost, you can tailor a cooling facility to your individual needs by designing and building it yourself. Whether the cooling facility is built or bought, you can ensure its effectiveness by giving careful thought to the topics discussed in the following sections.

Types of Produce. Different types of produce have different cooling requirements. For example, strawberries, apples, and broccoli all require near-freezing temperatures, whereas summer squash or tomatoes can be injured by low temperatures (Table 1). If small quantities of produce with different cooling requirements must be cooled or stored together, the temperature will have to be set high enough to prevent chill injury of susceptible produce. This temperature, however, will not provide optimum quality and storage life for other types of produce.

Table 1. Products That Sustain Cold Injury

Chill sensitive (below 40-45 F)	Freeze Sensitive (below 32 F)
Beans (all types)	Apples
Eggplant	Asparagus
Okra	Brambles
Peppers	Cabbage
Potatoes	Peaches
Pumpkins	Sweet corn
Squash (summer)	Strawberries
Sweetpotatoes	Squash (winter)
Tomatoes	
Watermelons	

Some fruits and vegetables produce ethylene gas as a natural product of ripening and respond to this gas by accelerating their ripening. Others do not produce ethylene but are very sensitive to it (Table 2). For sensitive produce, minute quantities of ethylene gas will greatly accelerate the ripening process even at low storage temperatures. It is *very important* not to store items sensitive to ethylene with those that produce this gas.

Table 2. Products That Produce Ethylene or Are Ethylene Sensitive.

Ethylene Producers	Ethylene Sensitive
Apples	Broccoli
Cantaloupes	Cabbage
Honeydew melons	Carrots
Peaches	Cucumbers
Pears	Cut flowers
Plums	Eggplant
Tomatoes	Green beans
	Leaf greens
	Okra
	Peas
	Peppers
	Squash
	Sweetpotatoes
	Watermelons

In addition to ethylene sensitivity, some types of produce generate odors that are readily absorbed by other items. The odor of apples and onions in particular are easily transferred to other produce items. Consequently, care should be exercised when storing other products with either of these items.

Most conflicts in storing mixed produce are avoidable, but serious problems may develop if the unique requirements of each commodity are not kept in mind. Complete information on postharvest cooling and storage requirements of most types of North Carolina fresh produce may be obtained from Extension Publication AG-414-1, *Introduction to Proper Postharvest Cooling and Handling Methods*.

Quantity and Movement of Produce. Although the primary function of any cooling facility is to remove field heat, an important secondary function is to provide cold storage space. Cooling capacity and storage capacity are separate characteristics, but together they determine the size of the facility. Cooling capacity and, to a lesser degree, storage capacity depend upon the size of the facility and the capacity of its refrigeration system. Therefore, it is important to determine the amount of produce you are likely to cool and store.

A refrigeration system can be thought of as a pump that moves heat from one place to another. Refrigeration capacity, a measure of the rate at which a system will transfer heat energy, is normally expressed in tons. A ton of refrigeration capacity is the ability to transfer the amount of heat required to melt 1 ton of ice in a 24-hour period (288,000 Btu). Said another way, a refrigeration system of 1-ton capacity is theoretically capable of freezing 1 ton of water in 24 hours. That is, it can transfer 288,000 Btu in 24 hours or 12,000 Btu per hour.

The correct size for a refrigeration unit is determined by three factors, the first of which is the weight of produce to be cooled. Since most produce is sold by volume (by crates, boxes, or bushels) you may have to determine its weight per unit of volume. Obviously, the more produce to be cooled, the larger the refrigeration unit must be.

The second factor is the minimum time required from start to finish of cooling. Ideally, cooling should take place fast enough to prevent serious degradation of the produce but no faster. Cooling produce faster than necessary is unduly expensive because the refrigeration system must be larger and the demand cost for electrical energy is greater. To cool a load of produce in 2 hours instead of 4 may require twice the refrigeration capacity, and the cost of electricity may be three times as high.

The third factor is the nature of the refrigerated space: its size, how well it is insulated, and how it is to be operated. Because as much as one-half of the refrigeration capacity in a typical facility is used to overcome heat gained through the floor, walls, ceiling, and doors, it is important to minimize these gains. Selecting a refrigeration unit of the proper size will be discussed in a later section.

Storage Capacity. The decision to cool and ship produce immediately or to store it for a time often depends not only on the type of produce and market conditions but also on the availability of space in the storage facility. The type of produce you grow will determine, in part, how much storage space you need. Obviously, highly perishable produce requires less storage space than less perishable items simply because it cannot be held for long periods without losing quality.

If the construction budget will allow, it is advisable to construct enough storage space for at least one day s maximum harvest of the most perishable commodities and even more for the less perishable items. It is much easier to build adequate storage space initially than to add space later. Cost per square foot decreases and energy efficiency increases with the size of the facility. Adequate storage space should not be overlooked, since one of the major benefits of a postharvest cooling facility is the marketing flexibility it allows by providing short- term storage. On the other hand, excess (unused) storage space is a waste of energy and money.

To determine the amount of refrigerated space to build, use the following formula:

$$V = 2.5 \times (C + S)$$

Where:

V = volume of the refrigerated space in cubic feet
C = maximum number of bushels to be cooled at any one time
S = maximum number of bushels to be stored at any one time

After you have determined V, divide it by the ceiling height in feet to obtain cooling room floor area in square feet. Keep in mind that the ceiling height should be no more than 18 inches greater than the maximum stacking height of the produce you intend to cool. For produce packaged in bulk, volume must be converted to bushels before applying the above equation.

Produce Packages. The fresh produce industry uses a bewildering array of packaging containers, such as fiberboard cartons, bulk boxes, baskets, wirebound cartons, and trays (Figure 1). The types of package you select should always conform to the standard type used by the wholesale market. Produce marketed in nonstandard containers often does not sell easily.

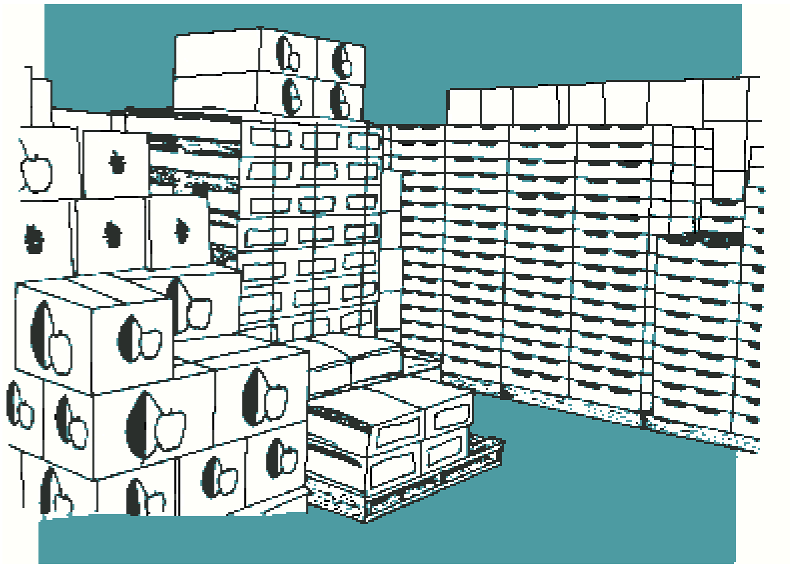

Figure 1. Common produce packages.

Be sure to allow enough space in your floor plan for aisles and walkways. They must provide ready access to all the produce stored in the room. For small to medium cooling rooms, devoting 25 percent of the total floor space to aisles and walkways is not excessive. Since produce containers should never be allowed to touch interior or exterior walls, reserve at least an additional 6 inches of space for good air circulation.

There are also limits as to how high produce containers may be stacked. The maximum height varies with the commodity and type of package but should not exceed a safe level nor damage the produce. To allow for good air circulation, produce should never be stacked closer than 18 inches to the ceiling. Whether or not you anticipate the use of forced-air cooling, allow sufficient space for active cooling. That is, allow space to install forced-air fans or to spread the produce out for rapid cooling.

If the produce volume is sufficient to justify the use of a lift truck and hence palletized loads, their dimensions should be considered in the design of the facility. Doors and aisles should be no less than 1 1/2 times the width of the lift trucks. Ramps leading to floors above grade should be inclined at a slope of no more than 1 to 5. It is also convenient to include a raised dock for loading trucks and trailers.

Location and Layout. The location chosen for the cooling facility should reflect its primary function. If you plan to conduct retail sales of fresh produce from the facility, it should be located with easy access to public roads. A retail sales operation located away from the road, particularly behind dwellings or other buildings, discourages many customers. Adequate parking for customers and employees, if any, must be provided. If the cooling facility is used in connection with a pick-your-own operation, it is best to locate it near restrooms and retail sales areas.

If, however, the primary function of the cooling facility is to cool and assemble wholesale lots, ease of public access is less important. In this case, the best location may be adjacent to the packing or grading room. In addition to housing grading and packing equipment, the space could be used to store empty containers and other equipment and supplies when it is not needed for cooling. All cooling and packing facilities should have convenient access to fields or orchards to reduce the time from harvest to the start of cooling.

Regardless of how it is used, the facility will need access to electrical power and water. For larger cooling rooms requiring more than about 10 tons of refrigeration in a single unit, access to three-phase power will be necessary. The location of existing utility lines should be carefully considered, as connection costs can be prohibitive in some rural areas. Consult your local power company for details. In addition, it is a good idea to anticipate any future growth when locating and designing your facility.

Before you begin construction, familiarize yourself with any applicable laws, regulations, and codes pertaining to construction and electrical systems, worker health and safety, and the handling and storage of food products.

Design and Construction

Plan number 6145 for a moderate-sized refrigerated storage building with adjacent space for packing and sorting is included at the end of this publication. The plan includes an optional retail sales room that can be built if needed. This facility provides approximately 7,400 cubic feet of refrigerated space with a design storage capacity of approximately 3,000 bushels. The nominal design cooling capacity is 300 bushels per day with a 3 1/2 ton refrigeration unit. As explained earlier, however, the required refrigeration capacity cannot be accurately determined unless the types and amounts of produce to be cooled are known.

These plans illustrate only one of many workable designs. What may be ideal for one operation may not be suitable for another. In developing the overall design, therefore, give serious consideration to how the produce will move through *your* facility. Doors, loading docks, and adjacent work areas should be conveniently located to accommodate the flow of material. Remember the cardinal rule of industrial engineering, Always make it easy to do the right thing.

The construction of a produce cooling and storage facility is an investment in quality maintenance. Therefore, the materials and workmanship of the facility itself should be of the best possible quality. Many different construction materials are suitable for such a project. The difficulty is deciding which ones are the most appropriate and cost effective for your application. Many problems can be avoided by paying particular attention during the construction phase to the items discussed in the following sections.

Foundation and Floor. Almost all postharvest cooling facilities built nowadays are constructed on an insulated concrete slab with a reinforced, load-bearing perimeter foundation wall. The slab should be built sufficiently above grade to ensure good drainage away from the building, particularly around doors. The floor should also be equipped with a suitable inside drain to dispose of wastewater from cleaning and condensation.

The floor of a refrigerated room must support heavy loads and withstand hard use in a wet environment but still provide an acceptable measure of insulation. The slab floor should be at least 4 inches of wire-mesh-reinforced concrete over 2 inches of waterproof plastic foam insulation board such as DOW Styrofoam or equivalent. Five or even 6 inches of concrete may be necessary for situations where loads are expected to be unusually heavy.

The need for floor insulation is often poorly understood and therefore neglected to cut cost. This is false economy, however, since the insulation will pay for itself in a few seasons of use. If the room is to be used for long-term subfreezing storage, it is essential that the floor be well insulated with at least 4 inches of foam insulation board (having a rating of R-20 or greater) to prevent ground heave.

Any framing lumber in contact with the concrete floor must be pressure treated to prevent decay, especially the sill plates and lower door frames, which may be in long-term contact with water. Although no produce would normally come into contact with it, the lumber must be treated with an approved nontoxic material. Information on the toxicity of treated lumber should be obtained from the building materials supplier. Additional information is available in Extension publication AG-99-1, *Pressure-Treated Southern Pine: Some Questions and Answers*.

During construction, the interface between the underside of the sill plate and the floor must be sealed to prevent the movement of water. This is easily done by completely coating the underside of the sill plate with a heavy layer of suitable sealant before securing it to the foundation pad with anchor bolts. The sill plate **must** be adequately secured to the floor to prevent the building from moving off the foundation in a high wind.

Although the plan shows a treated 4-by-4-inch bumper guard adjacent to the sill plate, a 4-by-6-inch guard is recommended (Figure 2). This essential component serves two important purposes. First, it protects the walls from being damaged by movement of loaded produce pallets and lift trucks. It also ensures that a suitable air gap is maintained between the produce and the walls.

Figure 2. Bumper guard

Insulation. Thermal energy always flows from warm objects to cold ones. All materials, even good conductors like metals, offer some resistance to the flow of heat. Insulation, however, is any material that offers high resistance to the flow of energy. Hundreds of different materials have been used at one time or another for thermal insulation. Since selecting the proper insulation is one of the most important building decisions you will make, it is important that the material be not only cost effective but also correct for the job. The characteristics of insulation materials differ considerably. Suitability for a particular application, not cost, should be the deciding factor in choosing a material. Some of the important characteristics that should be considered are the product s R-value, its cost, and the effects of moisture on it.

R-Value. A measure of an insulation s resistance to the movement of heat is its R-value. The R (for resistance) number, is always associated with a thickness; the higher the R-value, the higher the resistance and the better the insulating properties of the material. The R-value can be given in terms of a 1-inch-thick layer or in terms of the total thickness of the material.

The total resistance to the flow of heat through any insulated wall is simply the sum of the resistances of the individual components. That is, in addition to the thermal resistance of the insulation, the inside and outside sheathing, layers of paint, and even the thin layer of air next to the surface contribute to the wall s overall thermal resistance. Although they are highly weather resistant and require little upkeep, metal sheathing materials are very poor insulators. When specifying building materials, be sure to select those with the best combination of economic value and thermal resistance. The R-values of common building materials are listed in Table 3.

Table 3. Insulation R-Values for Common Building Materials

	R-Value	
Material	**1 inch thick**	**Full thickness of material**
Batt and Blanket Insulation		
Glass wool, mineral wool, or fiberglass	3.50	
Fill-Type Insulation		
Cellulose	3.50	
Glass or mineral wool	2.50-3.00	
Vermiculite	2.20	
Wood shavings or sawdust	2.22	
Rigid Insulation		
Plain expanded extruded polystyrene	5.00	
Expanded rubber	4.55	
Expanded polystyrene molded beads	3.57	
Aged expanded polyurethane	6.25	

Glass fiber	4.00	
Polyisocyranuate	8.00	
Wood or cane fiber board	2.50	
Foamed-in-Place Insulation		
Sprayed expanded urethane	6.25	
Urea-formaldehyde	4.20-5.50	
Building Materials		
Solid concrete	0.08	
8-inch concrete block, open core		1.11
8-inch lightweight concrete block, open core		2.00
8-inch concrete block with vermiculite in core		5.03
Lumber, fir or pine	1.25	
Metal siding		<0.01
3/8-inch plywood	1.25	0.47
1/2-inch plywood	1.25	0.62
Masonite particleboard	1.06	
25/32-inch insulated sheathing		2.06
1/2-inch Sheetrock		0.45
1/2-inch wood lapsiding		0.81

Cost. The cost of insulation varies considerably with the type, whether expressed in dollars per square foot per inch of thickness or dollars per square foot per unit of thermal resistance (R). For example, even though the R-value per inch of polyisocyranuate (Table 3) is more than twice that of loose-fill cellulose, the cellulose may actually be less expensive in terms of insulating value per dollar.

Of the insulation materials commonly used for refrigerated rooms, loose-fill cellulose is usually the least costly, followed by batts and blankets, then various foam sheet materials, and finally sprayed or foamed-in-place materials, which are the most expensive. Sprayed-on and foamed-in-place insulations have the added advantage of sealing an otherwise leaky structure and thereby greatly reducing infiltration. Sprayed-on foam also significantly reduces labor and material costs because an interior panel wall is not required. Certain types of foam insulation may constitute a fire hazard if carelessly handled, and care should therefore be exercised. Check local fire and building codes. In selecting any insulation material, carefully consider the cost associated with installation and any additional material costs.

Effects of Moisture. In most types of insulation the flow of heat energy is impeded by small cells of trapped air distributed throughout the material. When the insulation absorbs moisture, the air is replaced by water and the insulating value is greatly reduced. For this reason, insulation should be kept dry at all times.

With the exception of most plastic foam insulations, which are essentially waterproof, all insulation materials must be used with a suitable vapor barrier. A 4-mil polyethylene sheet is normally installed on the warm side (outside) of the insulation, the opposite of the normal practice for house construction. This placement prevents the formation of condensation on and within the insulating material. The vapor barrier sheet must be continuous from floor to ceiling. Where two sheets join, they should overlap 12 inches and be positively sealed (for example, with duct tape).

Doors and Other Hardware Items. The door is a critical part of a cooling facility. Improperly built or maintained doors can waste large quantities of energy. Doors should have as much insulation as the walls and should be well weather stripped to reduce the infiltration of warm air. Door gaskets should always provide a good seal.

Door seals can be checked by inserting a thin sheet of paper between the door and the seal area and then closing the door. The seal is acceptable only if resistance is felt when the paper is pulled out. Remember that a large single sliding or swinging door is much easier to keep tight than a set of double swinging doors.

All large doors have a tendency to sag over time unless they are diagonally braced and well supported. Use only the best grade of hinges and latches. Be sure that the door can be opened from the inside. Plastic strip curtains are often added to reduce energy loss when the door must remain open for long periods. These curtains allow free entry and exit by people, produce, and fork trucks but block the mixing of inside and outside air, which can waste a substantial amount of energy. Although there are many acceptable designs, three door section details that have been proven in actual use are shown in Figure 3.

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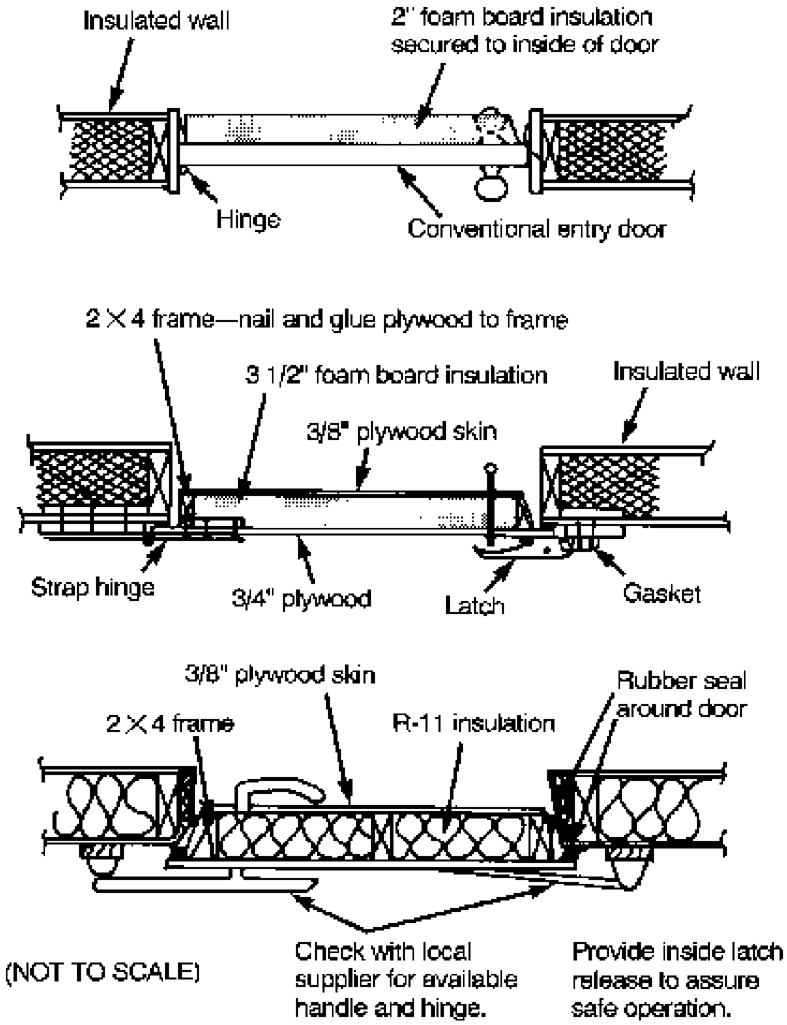

Figure 3. Three acceptable door designs.

Calculating the Heat Load

The optimal storage temperature must be continuously maintained to obtain the full benefit of cold storage. To make sure the storage room can be kept at the desired temperature, calculate the required refrigeration capacity using the most severe conditions expected during operation. These conditions include the mean maximum outside temperature, the maximum amount of produce cooled each day, and the maximum temperature of the produce to be cooled. The total amount of heat that the refrigeration system must remove from the cooling room is called the *heat load*. If the refrigeration system can be thought of as a heat pump, the refrigerated room can be thought of as a boat leaking in several places with an occasional wave splashing over the side. The leaks and splashes of heat entering a cooling room come from several sources:

- **Heat Conduction** - heat entering through the insulated walls, ceiling, and floor;
- **Field Heat** - heat extracted from the produce as it cools to the storage temperature;

- **Heat of Respiration** - heat generated by the produce as a natural by-product of its respiration;
- **Service Load** - heat from lights, equipment, people, and warm, moist air entering through cracks or through the door when opened.

Example. The following example illustrates the method for calculating the amount of refrigeration needed to operate a cold storage facility.

Two thousand bushels of summer apples are loaded into a storage room 23 feet square and 14 feet high (inside dimensions) at the rate of 200 bushels per day. The walls have an insulation value of R-16, the ceiling a value of R-20, and the floor a value of R-11. The cold storage room will be operated at 32 F during August when the mean maximum temperature is 80 F. The average maximum temperature for all 12 months for locations throughout North Carolina can be obtained from Table 4.

Table 4. Average Monthly Maximum Dry-Bulb Temperatures for Various North Carolina Cities

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Asheboro	48	51	58	69	76	81	84	84	78	69	59	50
Asheville	48	51	58	69	76	81	84	84	78	69	59	50
Banner Elk	42	44	51	61	68	74	76	76	71	62	52	45
Elizabeth City	51	53	61	71	78	84	88	87	82	72	63	55
Franklin	50	53	61	71	78	83	86	85	80	72	61	53
Gastonia	52	56	64	74	81	87	90	89	83	73	63	54
Laurinburg	55	59	67	77	83	89	91	91	86	76	67	58
Mount Airy	48	52	61	72	79	85	88	87	81	71	60	51
New Bern	54	57	64	74	80	85	88	88	83	74	66	57
Oxford	50	53	62	73	80	86	89	88	82	72	62	53
Smithfield	53	56	64	75	82	88	91	90	85	74	65	56
Southport	56	57	63	72	79	84	87	87	83	75	67	59

Note: Select the city that best approximates the climate of your location.

1. **Heat Conduction.** Heat is conducted into the cooling room through the walls, ceiling, and floor. The amount of heat flowing through these surfaces is a function of their thermal resistance (R-value), their area, and the temperature difference between one side and the other.

   The walls have an R-value of 16 and an area of 4 X (23 X 14) or 1,288 square feet. The temperature difference between the inside and outside is 80 F - 32 F, or 48 F. The heat conduction, HC, through the walls is found by multiplying the area of the walls by the temperature difference and dividing the product by the R-value.

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              Wall area (sq ft) X Temp. Difference (F)
HC (Btu/hr) = ----------------------------------------
                       R-value (sq ft F/Btu)

              1,288 sq ft X 48 F
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$$= \frac{}{16\ \text{sq ft F/Btu}}$$

$$= 3{,}864\ \text{Btu/hr}$$

Heat conducted through the ceiling is calculated using the same equation. However, since the ceiling usually has a more direct exposure to sunlight and hence a higher temperature, more insulation is installed in it, and the temperature difference in the calculation is increased by 10 F (that is, 80 F + 10 F = 90 F). If applicable, the installation of an attic fan will reduce the temperature considerably, but the cost of the fan and the electricity to run it should be weighed against the saving in heat conduction.

$$1{,}534\ \text{Btu/hr} = \frac{529\ \text{sq ft} \times 58\ \text{F}}{20}$$

Heat conducted through the floor is also calculated with this equation. However, since the ground has an average year-round temperature of approximately 55 F in most parts of North Carolina, less insulation is put in the floor, and the temperature differential used in the equation is decreased to 23 F.

$$1{,}106\ \text{Btu/hr} = \frac{529\ \text{sq ft} \times (55\ \text{F} - 32\ \text{F})}{11}$$

The total amount of heat conducted through the walls, ceiling, and floor is the sum of these three calculated values:

$$\underset{\text{(walls)}}{3{,}864\ \text{Btu/hr}} + \underset{\text{(ceiling)}}{1{,}534\ \text{Btu/hr}} + \underset{\text{(floor)}}{1{,}106\ \text{Btu/hr}} = \underset{\text{(total)}}{6{,}504\ \text{Btu/hr}}$$

2. **Field Heat.** The second source of heat is the warm produce brought into the cooling facility. The heat energy it contains is called *field heat*. The amount of field heat is usually calculated from the mean maximum monthly temperature in this example, 80 F. The apples are to be cooled from a field temperature of 80 F to the optimum cold storage temperature of 32 F within 24 hours.

   Field heat, FH, is the product of the specific heat, SH, of the crop (the amount of heat energy it holds per degree), the difference, DT, between the field temperature and the storage temperature, and the weight, W, of the produce.

   $$\text{FH (Btu/hr)} = \text{SH (Btu/lb/F)} \times \text{DT (F)} \times \text{W (lb)}$$

   The specific heat of water is 1 Btu per pound per degree Fahrenheit. Since fruits and vegetables are mostly water, their individual specific heat is directly related to their water content and can for practical purposes be estimated as 1. For actual specific heat values, see Table 5. For this example, we will use the actual value of 0.87. This means that 0.87 Btu of heat must be removed to cool 1 pound of apples 1 F.

Table 5. Specific Heat and Heat of Respiration for Horticultural Crops Grown in North Carolina

Commodity	Specific Heat (Btu/lb/F)	Respiration Cool	Respiration Warm
		(Btu/lb/hour)	
Apples, summer	0.87	0.018	0.340
Apples, fall	0.87	0.012	0.240
Asparagus	0.94	0.245	2.523
Beans, butter	0.73	0.123	0.716
Beans, string	0.91	0.161	0.885
Beets, topped	0.90	0.028	0.092
Blueberries	0.86	0.028	0.748
Brambles	0.87	0.092	0.711
Broccoli	0.92	0.092	1.376
Cabbage	0.94	0.023	0.257
Cantaloupes	0.94	0.025	0.305
Cucumbers	0.97	0.119	0.170
Grapes	0.86	0.014	0.179
Green onions	0.91	0.096	0.704
Leafy greens	0.90	0.100	1.034
Okra	0.92	0.257	1.583
Peaches	0.91	0.023	0.466
Peas, garden	0.79	0.177	1.651
Peas, field	0.73	0.160	1.554
Peppers	0.94	0.046	0.252
Potatoes	0.84	0.028	0.055
Squash	0.95	0.161	0.751
Strawberries	0.92	0.069	0.872
Sweet corn	0.79	0.186	1.644
Sweetpotatoes	0.75	0.064	0.100
Tomatoes, mature green	0.94	0.030	0.197
Tomatoes, ripening	0.95	0.067	0.188
Turnips	0.93	0.034	0.130
Watermelons	0.94	0.034	0.110

Although a bushel of apples weighs about 45 pounds, we will assume a weight of 50 pounds to take into account the weight of the container, which must also be cooled. The amount of field heat that must be removed is:

0.87 Btu/lb X (80 F - 32 F) X 200 bu X 50 lb/bu = 417,600 Btu

Since the apples are to be cooled to 32 F in one day, the hourly field heat load is 417,600 Btu divided by 24 hours, or 17,400 Btu per hour.

3. **Heat of Respiration.** The third source of heat is the respiration of the crop itself. Horticultural crops are alive and give off heat as they respire. The amount of heat produced depends on the temperature, the crop, and the conditions and treatment the crop has received. The heat of respiration at various temperatures for horticultural crops grown in North Carolina is given in Table 5. The amount of heat given off approximately doubles for each 18 F increase in temperature. Therefore, less refrigeration is required to remove the heat of respiration when produce is cool than when it is warm.

   On the last day of harvest, the storage facility will contain 1,800 bushels of cool apples and 200 bushels of field- warm apples. At this time the respiration heat load generated by the stored crop will be the largest. Table 5 shows that field-warm summer apples produce about 0.340 Btu per pound per hour, whereas properly cooled summer apples produce only 0.018 Btu per pound per hour. Thus field-warm apples pro-duce nearly 19 times as much heat by respiration as do cool apples. Since the freshly harvested (warm) apples will be cooled to their proper storage temperature within one day, the heat of respiration used in the calculation will be the average of the values. The average is:

   $$\frac{0.340 + 0.018}{2} = 0.179 \text{ Btu/lb/hr}$$

   The weight, W, of the 1,800 bushels of cool apples is approximately:

   $$W = 1{,}800 \text{ bu} \times 50 \text{ lb/bu} = 90{,}000 \text{ lb}$$

   The heat of respiration of the cool apples, HRc, is:

   $$\begin{aligned} HRc &= 90{,}000 \text{ lb} \times 0.018 \text{ Btu/lb/hr} \\ &= 1{,}620 \text{ Btu/hr} \end{aligned}$$

   The weight, W, of the 200 bushels of warm apples is approximately:

   $$W = 200 \text{ bu} \times 50 \text{ lb/bu} = 10{,}000 \text{ lb}$$

   The average respiration rate, as given previously, is 0.179 Btu per pound per hour. Therefore the heat of respiration for the warm apples, HRw, is:

   $$\begin{aligned} HRw &= 10{,}000 \text{ lb} \times 0.179 \text{ Btu/hr} \\ &= 1{,}790 \text{ Btu/hr} \end{aligned}$$

   To obtain the total heat of respiration, HRt, we add the value for cool and warm apples:

   $$\begin{aligned} HRt &= 1{,}620 \text{ Btu/hr} + 1{,}790 \text{ Btu/hr} \\ &= 3{,}410 \text{ Btu/hr} \end{aligned}$$

4. **Service Load.** The fourth source of heat comprises a number of miscellaneous items and is called the *service load*. It includes heat given off by equipment such as lights and fans and by people working in the storage room, heat brought into the storage area by warm

air when the door is opened, and heat that enters by air infiltration past faulty door gaskets and through other cracks. The amount of heat contributed by these sources is usually very difficult to deter-mine accurately. Service load is therefore dealt with collectively and estimated to equal 10 percent of the heat from the other three sources: conductance, field heat, and heat of respiration. The service load, SL, is therefore:

5.
$$\begin{aligned} SL &= 0.10 \times (6{,}504 + 17{,}400 + 3{,}410 \text{ Btu/hr}) \\ &= 2{,}731 \text{ Btu/hr} \end{aligned}$$

The total heat load is the sum from all four sources, as shown in Table 6.

Table 6. Total Heat Load for Example Cooling Facility

1.	**Heat conductance**		
	Walls	3,864	
	Ceiling	1,534	
	Floor	1,106	6,504 Btu/hr
2.	**Field heat**		
	200 bushels per day at 80 F		17,400 Btu/hr
3.	**Heat of respiration**		
	200 bushels warm apples	1,790	
	1,800 bushels cold apples	1,620	3,410 Btu/hr
	Subtotal		27,314 Btu/hr
4.	**Service load**		
	10% of subtotal		2,731 Btu/hr
	Total heat load		**30,045 Btu/hr**

The approximate proportion of the total heat load contributed by each of the four sources is:

Heat conduction	21.6 percent
Field heat.	57.9 percent
Heat of respiration . .	11.3 percent
Service load.	9.1 percent

Sizing the Refrigeration System

As discussed previously, refrigeration systems are rated by how much heat they will move or displace in a given length of time. The standard unit of rating is the ton. Since 1 ton of refrigeration equals 288,000 Btu per 24 hours, or 12,000 Btu per hour, the refrigeration capacity, RC, for a unit that would just handle the heat load in the previous example *under the conditions described* would be:

$$RC = \frac{30{,}061 \text{ Btu/hr}}{12{,}000 \text{ Btu/hr ton}}$$

$$= 2.51 \text{ tons}$$

A 2.51-ton refrigeration unit would need to run continuously to keep the temperature in this storage facility at 32 F under the conditions listed above. If the conditions used in this calculation were changed, a 2.51-ton unit could be either too large or too small to maintain the desired storage temperature. The capacity needed to maintain a temperature of 32 F would increase if:

- The refrigeration system were to run only part of the day,
- More than 200 bushels of fruit were stored every day,
- The building were larger,
- The incoming fruit were warmer than 80 F,
- The outside temperature were higher than 80 F,
- The amount of fruit in storage were greater.

For example, if harvesting were increased to 400 bushels of apples per day, the total heat load would increase to nearly 51,000 Btu per hour. A 4 1/4-ton unit running continuously would be required to maintain a storage temperature of 32 F under these conditions.

In practice, it is advisable in selecting a refrigeration system to add reserve capacity to the calculated rating as a protection against overloads. Of particular interest is the fact that refrigeration systems, for reasons to be discussed later, are operated for a total of only 16 to 20 hours per day. The total capacity of the system must be increased, therefore, to compensate for the "off time." For example, if the system described in the example were to operate for only 16 hours per day, it would need to be 24/16, or 1.5 times as large--that is, 3.77 tons instead of 2.51 tons.

Furthermore, it is good practice to increase the capacity of the system by a chilling rate factor. The rate at which heat is removed from the produce is not constant during the cycle but is greatest at the beginning. If the capacity of the system is not sufficient to overcome the thermal inertia of the produce, cooling time may increase above the specified limits for the product. To compensate, a chilling rate factor of 1.5 is applied to most fresh fruits and vegetables. This factor is applied in addition to the on-time factor. Thus the actual refrigeration system capacity, RC, required for the example facility would be:

```
RC = 2.51 X 1.5 X 1.5 = 5.65 tons
```

Reducing the Refrigeration Load

In the example, field heat accounts for 58.9 percent of the total heat load. Once field heat has been removed from the crop, much less refrigeration capacity is required to maintain the storage temperature. While 5.65 tons of refrigeration are needed to cool the apples in the example, about 2 1/2 tons are needed to maintain a constant temperature after they have reached 32 F. Therefore, anything that can be done to lower the temperature of the crop brought into the storage facility will significantly reduce the initial heat load, thus reducing the cost of the refrigeration equipment needed and the electrical energy to operate it.

Harvesting early or late in the day or even at night helps reduce refrigeration cost. Some large growers of highly perishable crops have started harvesting "under the lights" to reduce cooling costs and preserve quality. Although not usable for all crops, hydrocooling is an effective way to remove the first 20 to 30 degrees of heat quickly, lessening the load on the system. Even cooling with well water is a very energy efficient method of precooling produce before it is placed in the cooling room. Note, however, that some types of produce are sensitive to wetting, which encourages the growth of microorganisms.

If the 200 bushels of apples in the example facility were cooled just 20 F before entering the cooling room, the total heat load would be reduced to about 22,080 Btu per hour, or 26 percent. In this case, only 4.14 tons of refrigeration would be required instead of 5.65. Table 7 shows the calculations involved.

Table 7. Total Heat Load at a Field Temperature of 60 F

1. Heat conductance	6,504 Btu/hr
2. Field heat	10,158 Btu/hr
3. Heat of respiration	3,410 Btu/hr
Subtotal	20,072 Btu/hr
4. Service load	2,007 Btu/hr
Total heat load	**22,079 Btu/hr**

Although doubling the insulation value in the walls, ceiling, and floor would reduce the heat conductance by one-half from 6,504 to 3,252 Btu per hour, the percentage reduction of the total heat load would be small. The only way to reduce the heat load substantially is to start the refrigeration cooling process with fruit as cool as possible.

A computer program that greatly simplifies the calculation of refrigeration unit size is available from the North Carolina Agricultural Extension Service. For additional information, write to Extension Agricultural Engineering, Campus Box 7625, North Carolina State University, Raleigh, NC 27695-7625.

Other Factors to Consider in a Cooling Facility

Condensation and Humidity. The cooling coils of the refrigeration system (Figure 4) must be colder than the air in the room if the air is to be cooled. The larger the temperature difference, the greater the rate of heat transfer and the smaller (and less expensive) the cooling coils. However, the colder the coil surface, the more water vapor from the air will condense on the coils, either as a liquid or as ice. Evaporator coil condensation represents wasted refrigeration capacity and should be minimized. Allowing hot, humid air to enter the cooling room is particularly costly because the refrigeration system must not only cool the air but also condense the additional water vapor.

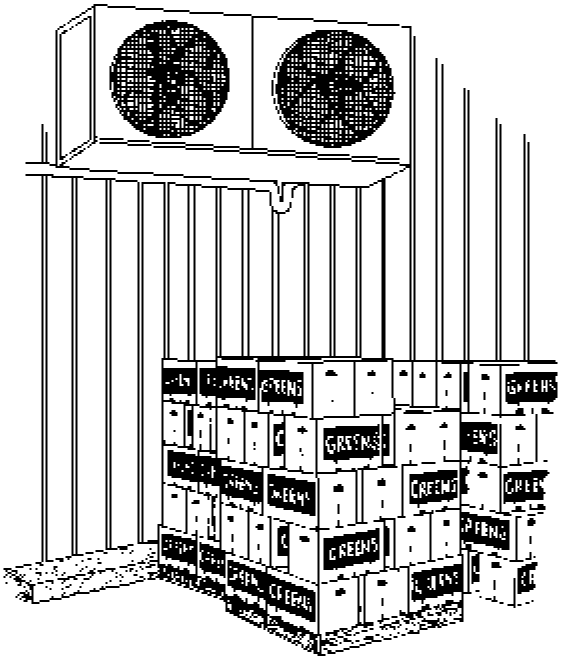

Figure 4. Evaporator coils inside a cooling room.

Besides substantially reducing the energy efficiency of the system, condensation of water reduces the relative humidity of the air. Since the optimum storage humidity for most produce is 90 percent or greater, either moisture must be added with a humidifier or the difference between the air and coil temperatures must be minimized. The temperature difference can be reduced by increasing the size of the coils enough that the air-to-coil temperature differential is 5 F or less. Not all refrigeration contractors are aware of the special needs of produce cooling, so when purchasing a system be sure to specify a 5 F maximum air-to-coil differential. The system will be slightly more expensive, but the benefits will soon pay for the difference in cost. Table 8 lists the recommended maximum coil-to-air temperature differential for various relative humidities.

Table 8. Maximum Evaporator Design Temperature Differential

Desired Relative Humidity (percent)	Design Temperature Differential (F)
98	5
95	8
92	9
90	10
88	11
86	12
84	13
82	14

80	15
76	16
70	18

If the cooling room temperature is below 36 F, the coil temperature must be below freezing, and ice will therefore accumulate on the coil surface. The ice acts as an insulator, greatly reducing the coil's capacity to absorb heat from the air. This ice must be removed periodically by some type of defrosting mechanism, such as electrical resistance heaters, a warm water spray, or the momentary reversing of the refrigerant flow. If the refrigeration system has sufficient capacity, it may be allowed to remain off for 6 to 8 hours to let the ice melt naturally without adding supplemental heat. Mechanisms designed specifically to aid de-frosting introduce heat into the room to melt evaporator ice, thus adding to the total cooling load. The amount of heat added, although small, should be taken into account when calculating refrigeration unit size.

Sanitation and Maintenance. It is essential that storage rooms and containers be clean and sanitary. All accumulations of condensation water should be piped outside. Clean all storage rooms thoroughly before filling them. If molds are found growing inside the room, disinfect the surfaces with a 0.25 percent solution of sodium hypochlorite (1 gallon of household chlorine bleach in 20 gallons of water) applied with a high-pressure washer. Allow the room surfaces to air dry for several days. Refrigeration coils, fans, and ducts should be inspected and cleaned regularly. Refrigeration coils in particular can become clogged with dust and dirt, substantially decreasing their thermal efficiency.

Temperature Control. In controlling a cooling facility, the most important temperature is that of the produce, not the air. Measuring the air temperature will not correctly indicate produce temperature because the heat of respiration *always* raises the temperature of the produce above that of the surrounding air. Put thermometers and thermostat sensing elements into the produce or at least into the produce container. Directly measuring the temperature of the pulp (interior of the product) is the only accurate way to determine the produce temperature. It is good practice to use several pulp thermometers in various locations to obtain an accurate temperature reading. Thermostats and wet-bulb thermometers should be recalibrated from time to time with an accurate mercury thermometer. Humidistats can be checked for accuracy with a sling psychrometer. If possible, avoid positioning the sensing elements of controllers on the exterior walls or ceiling. Typical temperature controllers are shown in Figure 5.

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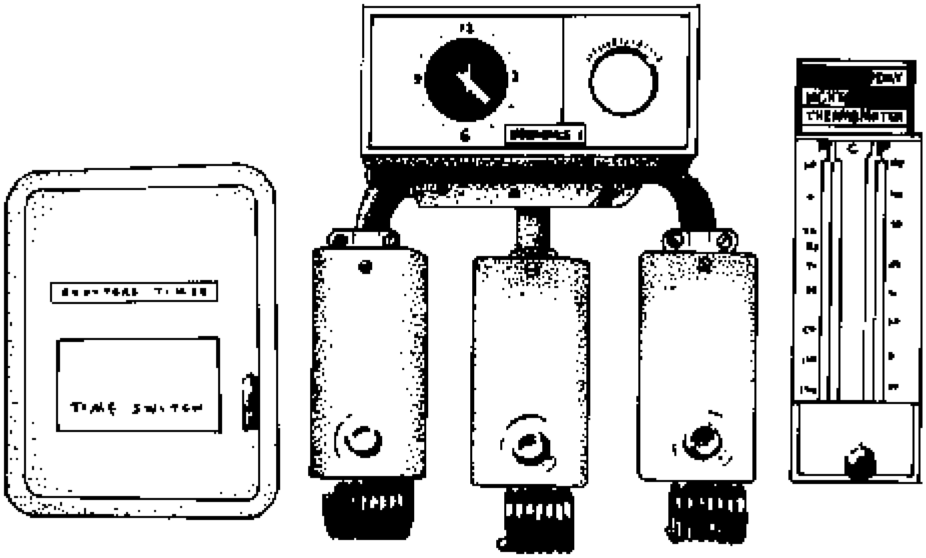


Figure 5. Temperature controllers.

The produce temperature and the humidity must be monitored frequently during cooling and storage to prevent undercooling and chill injury. Also, maintaining the proper temperature and humidity becomes more important with increasing time in storage. For the proper cooling and storage temperature and humidities, refer to Extension publication AG-414-1, *Introduction to Proper Postharvest Cooling and Handling Methods*.

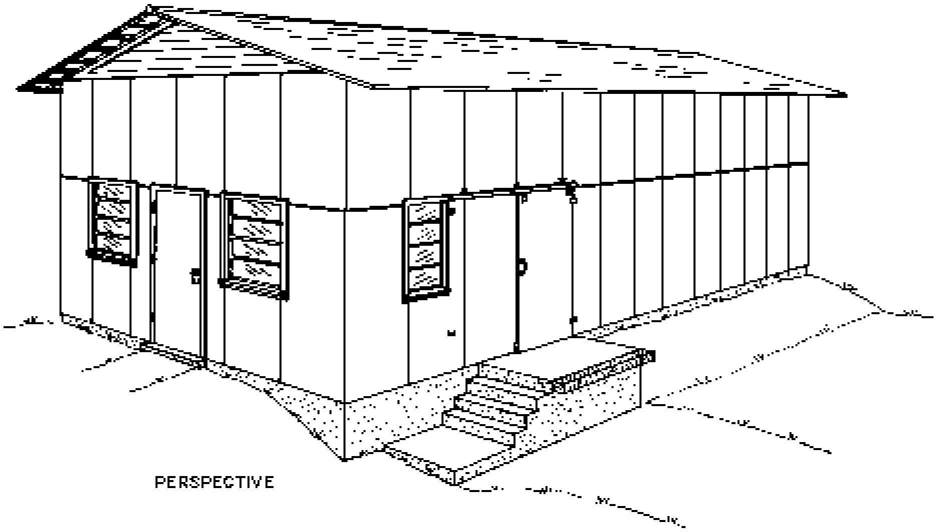
Container Design and Positioning. The movement of air inside the cooling room helps conduct heat away from the produce. Produce containers should be designed and stacked to allow sufficient air circulation to enhance the cooling rate and keep the crop at the optimum storage temperature. Evaporator coil fans may be positioned to aid air circulation inside the cooling room. For the rapid cooling required by many horticultural crops, it may be necessary to move cool air past the produce with additional fans. Fans designed and operated specifically to force cold air through produce containers can reduce cooling time by more than 80 percent if sufficient refrigeration capacity is available. For more information, refer to Extension publication AG-414-3, *Forced-Air Cooling*.

Summary

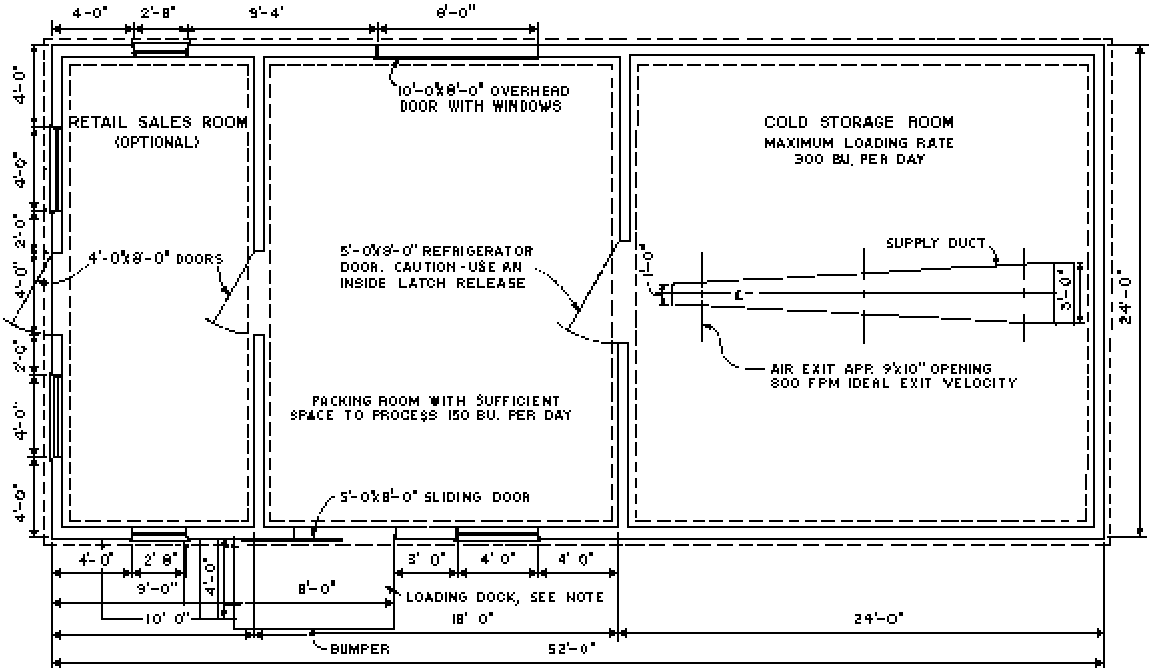
Although cooling increases production cost, it is essential to maintaining high product quality. No amount of cooling, however, will improve poor-quality produce. If you wish to have high-quality produce after cooling and storage, you must start with high-quality produce. Maintaining quality requires harvesting the crop at the correct stage of maturity; handling it with *tender, loving care*; and quickly cooling it to the proper storage temperature.

Many factors must be considered when planning and building a cooling facility. Among them are how it is to be used, the types and amounts of produce to be cooled and stored, and the desired refrigeration capacity. The correct size of a cooling facility cannot be determined strictly on a "square foot per acre" basis. Similarly, the capacity of the refrigeration system needed cannot be accurately determined solely on the basis of the floor area or volume of the facility. By taking the time to follow the design procedures described in this publication, you can assure yourself that the facility you build will be adequate to meet your needs under all foreseeable conditions.

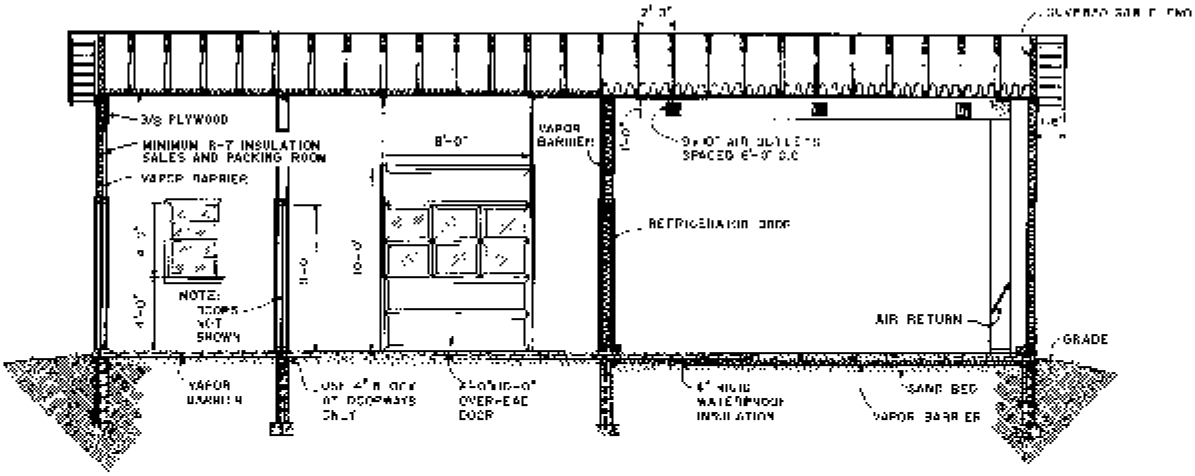
Plan 6145: Refrigerated Storage Building



PERSPECTIVE

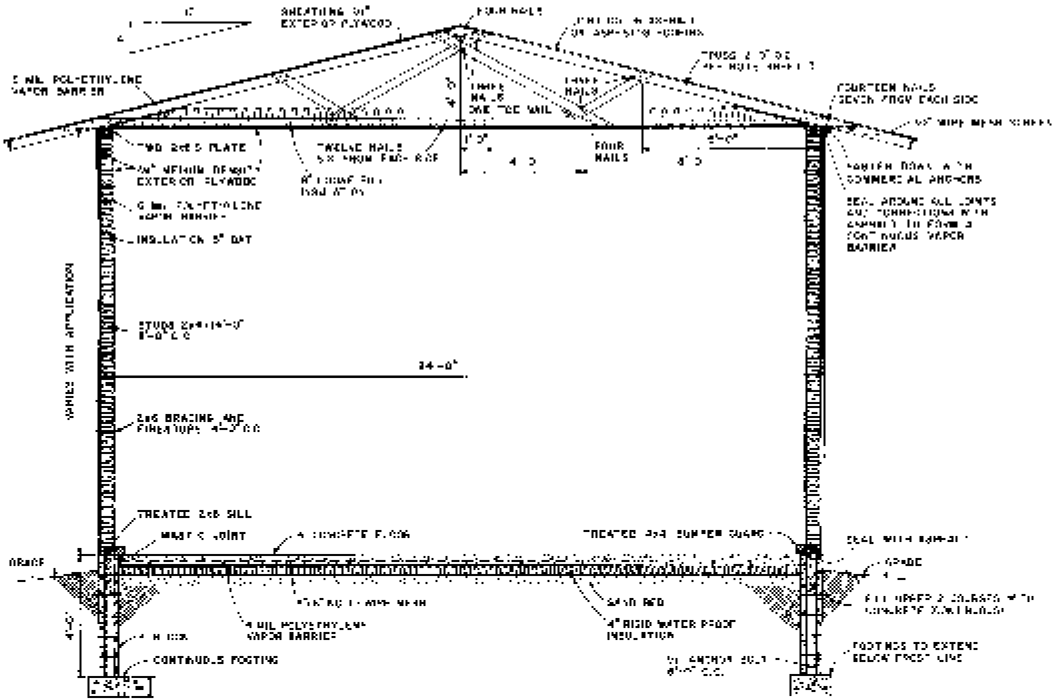


FLOOR PLAN
SCALE 1/4"=1'-0"



LONGITUDINAL SECTION

SCALE 1/4"=1'-0"



SECTION THROUGH
COLD STORAGE ROOM

SCALE 1/2"=1'-0"

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