Farm Structures
FACTSHEET

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SMALL SCALE ON–FARM COLD STORAGES

This factsheet outlines the basic principles of planning and designing an on-farm cold storage structure. It provided worksheets to allow you to calculate your own refrigeration requirements. Some comparative costs are provided to assist in equipment purchasing decisions.

INTRODUCTION

When fruits and vegetables are harvested, they are cut off from their source of water and nutrition and soon start to deteriorate. They lose weight, texture, flavor, nutritive value and appeal. In other words, they lose quality and potential storage life. Both time and temperature are important factors in post-harvest product deterioration

Cooling the harvested product controls the rate of quality loss by slowing the rate of living, which is called *respiration*. The warmer the temperature, the faster the deterioration and the shorter the storage life; conversely, the cooler the temperature, the slower the deterioration and the longer the storage life. The more quickly the product is cooled, the longer it will remain marketable. There is a rule of thumb for perishable crops; every hour lost before cooling to storage temperature results in a loss of approximately one day of shelf life.

The greatest need to cool occurs immediately after harvest. This also coincides with the greatest load required for refrigeration equipment. The produce is usually warm when it is harvested; that warmth, called field heat, must be removed. At high temperatures the produce respires more quickly and therefore loses its quality more quickly. A cooler or cold storage must be able to handle the peak demand or rapid deterioration will occur.

For example, freshly harvested broccoli has a potential shelf life of 25 days when cooled immediately and stored at 32ºF. However, when subjected to 12 hours at 70º F before storage, one half of its storage life is lost and it will only keep for 12 days when placed in the same 32 º F storage. It is the cumulative effects of all the temperature treatments after harvest that determines the storage life.

C O N T E N T S

1. STORAGE CONDITIONS

Short-term
Long-term
Frozen storage

Refrigerated storages may be divided into three general categories, namely:

Short-term where the product is chilled and held at some temperature above it's freezing point.

Long-term where the product is conditioned prior to entering the storage or the conditions in the storage room are altered.

Frozen Storage where the product is frozen at temperatures well below freezing.

The optimum storage conditions for a product depend on the nature of the product, the length of time of storage and whether or not the product is prepackaged. Appendix table A, *storage requirements and properties of fruits and vegetables*, provides information on the actual freezing temperature of a product, the optimum short and long-term storage temperatures, as well as the optimum relative humidity needed to maintain product quality.

One of the chief causes of the deterioration of unpacked fresh foods is the loss of moisture from the surface of the product by evaporation into the surrounding air. This process is called desiccation or dehydration. Minimum moisture losses are experienced when the humidity in the storage space is maintained at a high level with low air velocity. Unfortunately, these conditions are difficult to attain and are conducive to rapid mold growth. Good air circulation is required around the produce to achieve adequate cooling.

The relative humidities stated in Appendix table A provide appropriate levels for maintaining product quality. Most fruits and vegetables should be stored at relative humidities of between 85% and 95%. The best way to maintain high humidities in a cold storage is to use large evaporator coils. A temperature differential (TD) between the refrigerant coil inlet and coil exhaust temperature of approximately 8° F or lower will maintain a high relative humidity.

For optimum storage conditions, separate storage facilities would be required for most products; however, this is usually not economically feasible. A compromise is usually struck whereby a storage temperature slightly above the optimum for some of the products is prescribed so that damage to crops that are sensitive to low temperatures is avoided. There is one other problem associated with mixed storage and that is the transfer and absorption of flavors and odors. For instance, potatoes are one of the worst offenders for imparting off flavours to other products such as fruits.

2. COOLING METHODS

Hydro cooling
Contact icing
Vacuum cooling
Forced-air cooling
Room cooling

Rapid cooling of a perishable crop is one of the most important aspects of retaining quality and prolonging storage life. Various methods may be used, including such processes as hydro cooling, contact icing, vacuum cooling, forced air cooling and room cooling.

Hydro cooling is simply the use of cold-water spray or the direct immersion of produce in cold water to quickly lower the temperatures. It is most commonly used for such products as sweet corn, asparagus and celery.

Contact icing employs the spreading of crushed ice over the produce and is particularly advisable for products that lose moisture rapidly. Products such as lettuce, bunched carrots and radishes lend themselves well to this process.

Vacuum cooling involves a process whereby air is sucked out of a chamber where produce is being cooled. It is the evaporation of the water from the produce surface that actually does the cooling. Vacuum cooling is primarily used in areas where large volumes of lettuce, celery and other leafy crops are grown. This method is not normally used for small, on-farm situations.

Forced-air cooling involves forcing cold air into containers and through the products themselves. This technique is successfully used to rapidly precool strawberries and raspberries for shipment to fresh markets or for storage in a cooler. It has also been used for cherries, asparagus, mushrooms, broccoli and corn.

Room cooling by placing produce into a refrigerated room is another form of cooling. Cold air passes around the containers but is not directly forced through the produce. Cooling rates are much slower than other methods listed above; however, this method is far better than no cooling at all. Furthermore, the room cooler can be used for holding crops prior to shipment or direct sales.

The economics of various treatments must be assessed prior to spending money to achieve optimum cooling rates. Sometimes a combination of methods is the best choice.

3. PLANNING AN ON-FARM COLD STORAGE

There are a number of questions to ask yourself when planning an on-farm, refrigerated cold storage structure. Some of these questions are:

- How big of a refrigeration machine will be required?
- What kind of refrigeration is best?
- What kind of access is required?
- How should it be constructed?
- How big does it have to be?
- Where should it be built?
- How much will it cost?
- Will it pay off?

Many of these questions can only be answered by you, the grower. For example, the size of your facility will depend on how you propose to use the facility. The requirements for holding and shipping are different than those for roadside sales.

On-farm cold storages can be either free standing, that is, in a building of their own, or built into an existing structure. It is of prime importance that the facility be located on a site that is well drained and easily accessible for moving produce in and out of the structure. If large volumes are anticipated, truck loading ramps and docks should be incorporated into the design. Additional space may be required for receiving, grading, processing and packing. It has been stated that a normal operation will expand facilities as many as four times in any generation; therefore, expansion capabilities should be planned for in the initial layout.

The exact dimensions of the structure should take into account container sizes and stacking arrangements that will allow for easy movement of the produce, as well as, provide the required space for proper cold air circulation. The door width and ceiling height must be sized to fit forklifts, if they will be used, and stack heights, as well as provide ceiling space for air circulation.

The layout or floor plan of the building will, of course, involve the location of doors. They should be located so as to minimize the space that is wasted for access by handling equipment. But in general, efficiency in handling is very important since produce may be going in and out in great quantities. The cold-air loss by opening large doors must be considered. If frequent access is required for removal of small quantities, a small door should be constructed either in the larger door or at another location. Canvas, plastic, or rubber curtains have been used, in both large and small doors, to minimize airflows when a door is opened.

4. DESIGN PARAMETERS FOR COOLERS

Type of crops
Seasonal volume
Optimum temperature
Relative humidity
Crop respiration
Temperature range

A systematic approach must be taken to designing a refrigerated storage structure. Each farm operation will have varying parameters. The primary parameters include:

- The type of crops to be stored.
- The daily and seasonal volume.
- The optimum temperatures required.
- The desired relative humidity.
- The specific heat and rate of respiration of the crops.
- The ranges of temperatures.

A sample design in worksheets 1 and 2 in the Appendix (page 16-17) touches on many of the criteria required for developing a proper design. Blank columns are provided to allow you to insert your own values or information.

5. CONSTRUCTION OF STORAGE FACILITIES

The construction methods for refrigerated cold storages are similar to conventional construction techniques. The most common types of structures are:

- Steel construction, usually for large facilities.
- Masonry buildings, medium-size facilities.
- Wood frame structures smaller on-farm facilities.

It is of prime importance that the vapor barrier be placed on the exterior, or warm side of the insulation. Normal house construction has a vapor barrier toward the inside of the house whereas with refrigerated spaces, the opposite is normally true. The vapor barrier must encompass the whole storage structure and all joints must be well sealed. A vapor barrier prevents moisture from collecting within insulated spaces in walls and ceilings. The refrigerated room should be made as airtight as possible.

Insulation used in these structures can be polyurethane, Styrofoam, fiberglass batts, any other good insulation material, or any combination of the above. Polyurethane or extruded Styrofoam will not absorb moisture and would be a better choice if the cold storage were used in both summer and winter. The minimum "R" values acceptable are:

- Foundations and floors, R10
- Walls R20
- Ceilings R30

Worksheet 3 in the Appendix (page 18) calculates various "R" values for a typical structure. A blank column is provided to allow you to input your own values.

The attic areas should be well ventilated to prevent heat buildup and condensation on the underside of the roof, resulting in dripping on the ceiling insulation. The top two feet of the perimeter concrete foundation in new structures should be insulated with a rigid type of insulation board to minimize losses through this normally weak part of the insulation of the building. It is advisable to protect the wall insulation inside the storage structure from mechanical damage by installing bumper strips and/or perforated sheeting. See Appendix Figure B, *wall/foundation construction detail drawing.*

Locating the vapor barrier in a cold storage with a trussed roof is difficult. The problem is that the vapor barrier must go above the insulation to be on the **warm side**. This is normally achieved by placing the plastic vapor barrier on the underside of the ceiling; the insulation must be attached below it. If rigid insulation is used, long specialty fasteners are available to fasten the insulation to the ceiling.

If the storage structure will be used as a freezer unit, the floor must have sufficient insulation installed so that freezing of the subsoil cannot occur. Should freezing occur, a frozen bulb would likely form and eventually crack the floor. The gravel below the floor must be well drained to reduce any chance of moisture freezing under the concrete floor. A well-drained subfloor will also add insulation value to the floor of a cooler or freezer.

Should forklifts be used in the storage facility, floor construction should take into account these concentrated loads.

Special doors are required and can be bought and installed ready-made or "U-built". Ensure the manufacturer's size is determined before framing when purchasing manufactured doors. Special hinges, door openers, safety bars, sealing strips and insulation is required for the doors. Four feet by seven feet is the recommended absolute minimum door size. Larger doors will be required if forklifts will be used.

Accommodation must be made in the structure to support the evaporators, fans and other electrical equipment. Take extra precautions to minimize the number of holes in the vapor barrier and maintain airtightness.

6. HEAT LOAD OF THE REFRIGERATION FACILITY

Field heat
Heat of respiration
Conductive heat gain
Convective heat gain
Equipment heat load
Human energy load

The cooling load and refrigeration hardware required for a particular application is determined by several factors. These include:

- Field heat removal of both the products and the containers
- Respiration from the product.
- Heat gained from outside the cold room and air leakage.
- Air exchanges due to opening and closing the doors.
- Energy load from mechanical and electrical devices.
- Human occupancy load.

Heat valves are expressed in British thermal units (Btu's) and are defined as the heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Field heat represents the cooling requirement necessary to reduce the product temperature at harvest down to the safe storage level. The type of product and quantity of produce harvested each day, the harvest temperature and the final cold storage temperature all effect the field heat load. The amount of heat that it takes to raise the temperature of a product by one degree varies. The ratio of that heat to the amount of heat it takes to raise the temperature of water is called the *specific heat.*

Heat of respiration is the energy released by the product during the respiration process. Respiration heat production decreases during the cool down period after loading and then stabilizes after the storage temperature is reached.

Conductive heat gain is heat gained/lost through the building floor, walls and ceiling by conduction. Conduction gain/loss is dependent upon the temperature differences between the inside and outside of the cold room and insulating value of the floor, walls and ceiling.

Convective heat gain is heat that is transferred by convection, the mixing of outside air with the cold inside air. The smaller the room, the more of the relative volume of air is exchanged during each opening and closing of the structure. The values in Table 1 can be used as guidelines.

Table 1 **NUMBER OF AIR EXCHANGES FOR VARIOUS ROOM SIZES**

ROOM VOLUME (CUBIC FEET)	EXCHANGES PER 24 HOURS
500	26.0
1,000	17.5
2,000	12.0
3,000	9.5
4,000	8.2
5,000	7.2
6,000	6.5
8,000	5.5
10,000	4.9
20,000	3.5
30,000	2.7
50,000	2.0

Equipment heat load is the energy gained from equipment operating in the room. This includes fan motors, light fixtures, defrost equipment, as well as forklift motors. (4250 Btu/HP for motors under ½ HP, 3700 Btu/HP for larger motors and 3.41 Btu/watt for light fixtures).

Human energy load is the amount of energy expended by the number of workers in the room for certain time periods within a 24-hour period. (Average of 950 Btu/worker-hour).

An example worksheet in the Appendix (page 20) calculates the heat load of a cold storage structure with a particular product. Worksheet 4 (page 19) is provided to allow you to input your own values.

Having calculated the total refrigeration load required for the storage structure and the product loads in a 24-hour period, a few additional considerations must be addressed. The refrigeration unit cannot work for 24 hours continuously. Time allowances must be given for the evaporators to be defrosted. A normal time of 16 hours out of 24 hours is standard practice. The refrigeration capacity is therefore based on 16 hours of operation.

In the example heat load calculation (page 20), the refrigeration load was calculated to be 172,900 Btu per 24 hours, and since this capacity must be achieved in a 16-hour period, the refrigeration rate will be 10,800 Btu/hr. A frequently used term in describing the refrigeration machine capacity is to state the capacity in terms of "tons" of refrigeration. A one-ton refrigeration machine is capable of 12,000 Btu/hr. Therefore, in our example, we would probably select a one-ton refrigeration machine.

7. EVAPORATOR DESIGN

Emphasis must be given to the design or capacity of the evaporators to operate at low temperature differences and provide the relatively high humidities required for the storage of most small fruits and vegetables. A relative humidity of 80%-90% at 32^0F means that the coil temperature difference (TD) between the refrigerant inlet and exhaust side of the evaporator coils should be less than 8^0F. The storeroom airstream TD across the evaporator would be one half of the evaporator coil TD. Table 2 shows the effect the TDs and relative humidity that can be maintained naturally.

Blower or forced-air evaporators have a heat transfer rate of approximately 4 BTU/ft^2/^{0}F TD/hr. To transfer the calculated heat load in our example in Section 6, the following surface area would be required in the evaporator:

$$\text{Surface area} = \frac{10{,}800 \text{ Btu/hr}}{4 \text{ Btu.ft}^2\text{/hr/°F} \times 8\text{°F TD}} = 338 \text{ ft}^2$$

Relatively speaking, this is a fairly large evaporator for a one-ton refrigeration system; however, it should be noted that produce quality will be maintained and weight losses will be minimized. Each evaporator, and it's associated design and fans, has a specific performance capability.

Table 2 TEMPERATURE DIFFERENCES AND ACHIEVABLE RELATIVE HUMIDITIES[1]

TD[2] IN °F	MINIMUM RELATIVE HUMIDITY (%) AT VARIOUS STORAGE ROOM TEMPERATURES		
	32° F	35° F	38° F
2	95.8	96.1	96.1
4	91.2	92.3	92.4
6	87.1	88.7	88.8
8	83.0	84.7	85.3
10	79.0	80.0	82.0

1. Evaporator coil temperature difference.
2. Relative humidities based on the assumption that evaporator coil TD is twice that of the airstream TD across evaporators.

8. REFRIGERATION CYCLE

Continuous refrigeration in small applications is usually accomplished by the vapor compression system, more commonly known as the simple compression cycle, as illustrated in Appendix Figure A, *schematic of refrigeration system.* There are two pressures existing in the compression system: the evaporating or low pressure, and the condensing or high pressure. The refrigerant acts as a transportation medium to move heat from the evaporator to the condenser or from inside of the room to outside of the room. The change of state from liquid to vapor and back to liquid allows the refrigerant to absorb heat at low temperatures, and discharge large quantities of heat at high temperatures very efficiently.

The basic cycle operates as follows:

High-pressure liquid refrigerant is fed from the receiver through the liquid line and through the filter dryers to the metering device, separating the high-pressure side of the system from the low-pressure evaporator. A thermostatic expansion valve controls the feed of the liquid refrigerant to the evaporator and, by means of an orifice, reduces the pressure of the refrigerant to the evaporating or low side pressure.

The reduction of pressure on the liquid refrigerant causes it to boil or vaporize until the refrigerant is at the saturation temperature corresponding to its pressure. As the low-temperature refrigerant passes through the evaporator coil, heat flows through the walls of the evaporator tubing and fins to the refrigerant causing the boiling action to continue until the refrigerant is completely vaporized.

The expansion valve regulating the flow through the evaporator is necessary to maintain a preset temperature difference between the evaporating refrigerant and the vapor leaving the evaporator. As the temperature of the gas leaving the evaporator varies, the expansion valve power element bulb senses its temperature and acts to modulate the feed through the expansion valve as required.

The refrigerant vapor leaving the evaporator travels through the suction line and accumulator and then on to the compressor inlet. The compressor takes the low-pressure vapor and compresses it, increasing both the pressure and temperature. The hot, high-pressure gas is forced out of the compressor discharge valve and into the condenser.

As the high-pressure gas passes through the condenser, it is usually cooled by a fan and fin-type condenser surface. As the temperature of the refrigerant vapor reaches the saturation temperature corresponding to the high pressure on the condenser, the vapor condenses into a liquid and flows back to the receiver to repeat the cycle.

9. DEFROST SYSTEMS

Hot gas
Reverse cycle
Electric heater

Evaporators operating in rooms colder than 36°F will have to be defrosted. Defrosting is usually done automatically at a preset time and for a certain time frame. Regardless of the defrost system used, it should always be operated to remove all the ice from the evaporator coils. Maximum air distribution and rapid cooling are obtained only when the coil is free of ice. Partially melted ice may refreeze and collapse evaporator tubes, and deforms fins, tubes, and electric defrost heating elements. The defrost system should never be left on longer than needed because heat will be added to the cold storage room. Although there are several defrosting methods, the hot gas, reverse cycle and electric heater systems are the most commonly used for smaller cooling systems.

In a **hot gas system**, hot refrigerant vapor is pumped directly through the evaporator tubing. The system has a refrigerant line running directly from the compressor discharge line up to the evaporator. This line is opened and closed by a solenoid shut-off valve. At the predetermined time, the time clock stops the evaporator fans and hot compressed vapor rushes along the suction line. To keep the defrost water from freezing in the drain pan and tube, part of the hot gas defrost line is installed under the drain pan and drainpipe.

The **reverse cycle system** defrosts evaporators by reversing the flow of the refrigerant. This causes the evaporator to become the condenser and the condenser to become the evaporator. A four-way valve allows for the reversal of refrigerant flow. A bypass valve is required at the thermal expansion valve; as well, an additional expansion valve is required in front of the reversing cycle line in front of the condenser. The liquid receiver is specially designed to permit the reverse flow of vapor to travel over the reverse liquid in the receiver. It does not return the vapor to the condenser.

The **electric heater system** uses heating coils that are installed in or around the evaporator or within the refrigerant passages to furnish heat. A timer stops the refrigeration unit, closes the liquid line and pumps the refrigerant out of the evaporator. The blowers and electric heaters are turned on. The heaters quickly melt the frost from the evaporator and the water drains away. When the evaporators are warm enough to ensure that all the frost is gone, a thermostat on the evaporator returns the system to normal operation. This system is probably the cheapest and most fail-proof system to install; however, it is a little more expensive to operate from an energy-input point of view. For short-term small structures, this is probably the best system to use.

10. OPERATION AND MAINTENANCE

The purpose of refrigerated storage is to extend the period of marketable quality of perishable, seasonal products. To achieve this, the produce must be of top quality as deterioration begins as soon as a crop is harvested. Products should be picked in the morning to reduce the “field heat”. Produce should be placed in the cold storage as soon as possible after harvesting, preferably within one hour. To keep field heat to a minimum, containers should be kept or stored in the shade or cool areas.

The distribution of the produce in the cold storage is important so that good cold air circulation around it is achieved. This means that products should be stacked away from walls on pallets and should not be stacked to the ceiling. Spaces should also be left between stacks and pallets. Some recommended clearances are as follows:

- Wall 8-12 inches
- Ceiling 24+inches
- Between pallets 4-5 inches

When warm produce is brought in to the storage with existing cooled produce, place the warm produce close to the return duct or area closest to the evaporator so that the warm produce heat is not passed over the already cooled produce.

To keep the air exchanges to a minimum, the cold storage should be accessed only when absolutely necessary. Light fixtures should be of low wattage.

The refrigeration equipment should be maintained at optimum operating conditions. At the start of the season, ensure that the condenser is clean, the oil level and refrigerant levels are up to recommended levels, the evaporator is clean and check that the defrost pan and outlet pipe are clean. Ensure that the compressor has been serviced.

It is advisable to run the refrigeration system a couple of days before produce is introduced to ensure the system is working properly and all materials in the room are cooled down. All thermostats should be checked by immersing them in a bucket of ice water. Note that at least two thermometers of good quality should be used.

Should servicing of the refrigeration be required, a qualified refrigeration technician should be contacted to do the work.

During the operating season, check that the defrost cycle is working properly and no serious frost or ice buildup occurs on the evaporator. Periodically, check the pan drainpipe to ensure that the defrost water can escape.

Only approved, special door hardware should be installed on the door to permit easy egress. Prior to locking any such facility, a thorough check of the room should be made to ensure no one will be trapped inside.

11. COMPARATIVE COSTS OF REFRIGERATED STORAGES

A. Structural Costs

A number of construction techniques can be used to build cold storage facilities. The home-built units will usually be the cheapest. Next would be the modular insulated panel construction whereby assembly of the prefabricated units can be done by the owner, with vapor barriers and sheeting being installed by the owner.. Certain companies will supply a fully fabricated “cold storage box” with all the trimmings. These units will usually be the most expensive but will require the least time input from the owner. Some comparative costs are given in Table 3. (Prices are in Canadian dollars for the autumn of 1993.)

B. Refrigeration Unit Costs

Before establishing the cost of a unit, accurate calculations, as outlined previously, should be done to determine the heat load. Alternately, the approximate relative size of the unit can be obtained from Table 5. Both room size and product load will determine the refrigeration capacity required. Remember, refrigeration capacity should not be determined by room size alone.

The cost of various capacities to achieve 8°F is given in Table 4 in Canadian dollars for the autumn of 1993.

12. DISPLAY CASES

The principal function of any kind of display fixture is to display the product or commodity as attractively as possible. This is not necessarily compatible with providing the optimum storage conditions for the product being displayed. Hence the storage life of a product in a display fixture is usually reduced compared to storing the product in a properly designed storage facility.

TABLE 3 STRUCTURAL COSTS			
ROOM SIZE	**HOME BUILT**	**PREFAB PANELS**	**COMPLETE BOX**
8x8x8	1,800	2,500	4,900
10x10x8	2,400	3,500	5,900
12x12x8	2,900	4,200	7,400
16x16x8	4,200	6,100	10,200

TABLE 4 REFRIGERATION UNIT COSTS		
POWER INPUT IN HP	**CAPACITY OF UNIT IN BTU/HR**	**AVERAGE INSTALLED COST IN $**
0.50	4,000	1,800
0.75	6,000	2,650
1.00	9,000	3,000
1.50	12,000	4,450
2.00	18,000	5,400
3.00	30,000	7,200
4.00	40,000	9,000
5.00	50,000	10,600

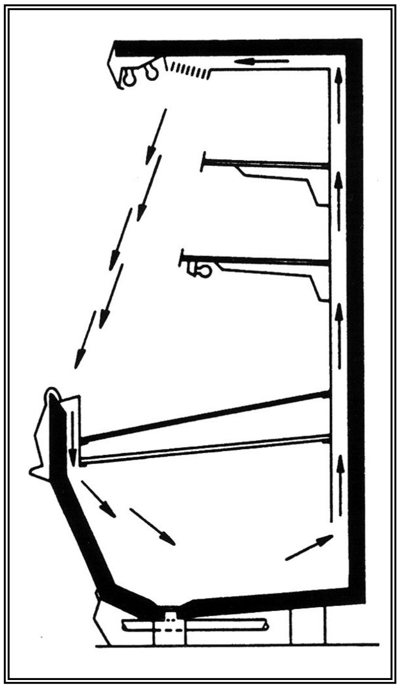
TABLE 5 APPROXIMATE HEAT LOAD FOR VARIOUS ROOM SIZES[1]				
PRODUCT LOAD (LB/DAY)	**HEAT LOAD (BTU/HR) FOR VARIOUS ROOM SIZES**			
	8x8x8	**10x10x8**	**12x12x8**	**16x16x8**
500	5,500	6,800		
1,000	7,400	8,600	9,100	
1,500	9,200	10,300	10,800	13,000
2,000	11,000	12,300	12,800	15,000
3,000		16,000	16,500	18,700
4,000			20,200	22,400
5,000				26,100

1. These heat loads should be used only as a guide. They are based on the product and temperature difference used in the example worksheet on page 20.

Display fixtures are of two general types: the self-service type from which the customer serves himself directly and secondly, the service case from which an attendant serves the customer. The self-service cases are either the open (see Figure 1) or closed types (see Figure 2) with the open type being the most predominant in supermarkets. On-farm direct marketers may choose the closed types to reduce the energy loads required to keep the open types going. In high-volume product flow-through operations, the open style may be more appealing to the customer as no sliding or swinging door can interfere with the customer handling or picking out the desired product.

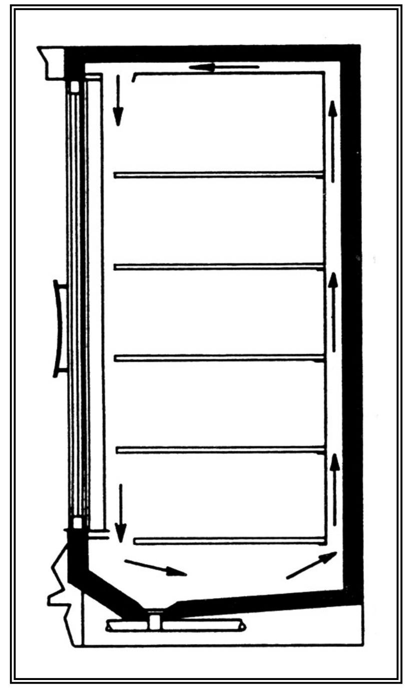
The closed service type of fixture provides for visual displays of the product for the customer but an attendant takes the product out of the display/storage case, usually from the rear of the fixture. These cases are frequently used for fresh deli meats or exposed-unwrapped sensitive products such as fresh bean salads, cut fruit pies, etc. Other closed-type units can be accessed by the customer by opening swinging,

Figure 1



Multi-deck Display cooler

Figure 2



Reach-in glassed-door freezer or cooler

sliding doors or curtains. These units are frequently used for soft drinks, dairy products, eggs, floral arrangements and other prepackaged goods.

Fruit and produce open display units are of the multi-deck or single deck configuration (see Figure 3). These units will have some additional features to enhance the products and their shelf life. These include sprayers, either automatic misters or hand held spray guns for wetting the produce, night covers, sliding or stationary mirrors to enhance the display and other special features.

Reach-in or display refrigeration units are usually available in either medium or low temperature ranges. The medium temperature units hold the product temperatures at close to 38°F (3.5 °C) suitable for most produce, dairy products, fresh meats, eggs, beverages, etc. The low temperature units should be set to 0°F (-18 °C) for frozen foods and -5 °F (-20.5 °C) for ice cream.

Open display units, whether medium or low temperature, work on the principle of creating a cold curtain across the open section of the display case. Either gravity or forced air circulation can create this cold curtain. In the case of gravity systems, the cold air supplied by the evaporator from the refrigeration machine is located at the top and cold air is dropped to a suction intake at the bottom of the front of the unit. Forced air circulation systems forces air across the evaporator and distribute the cold air across the front of the unit to create the cold curtain. Cold air is also forced through the various shelves if the unit is so equipped.

The majority of display units are self-contained, meaning that the total refrigeration machines, including compressor, condenser and evaporator, are an integral part of the whole unit. Some questions to keep in mind when purchasing either a new or used unit are:

- What is the capacity of the unit in terms of product loading and is the unit able to maintain a specific product temperature?
- Does the unit have adequate strength to accommodate the volume or weight that is to be cooled and displayed?
- Is the unit easily cleaned and are the cleaning surfaces durable enough to withstand discolouring and etching by commonly used cleaning compounds?
- Are the exterior and interior surfaces strong enough to resist denting, scratching and abrasion? In descending order of costs, common surfaces include stainless steel, porcelain enamel on steel, aluminum and synthetic enamel on steel.
- Is it visually important to match the new unit with existing equipment?

- Is the unit to be located against a wall or is it free standing as a display island (see Figure 4)? If
- free standing, can power be easily supplied to the unit and has the need for defrost drainage and cleaning drains been addressed?

- As any refrigeration unit gives off heat during the condensing portion of the refrigeration cycle, is there adequate ventilation around the unit to disperse the heat being developed?

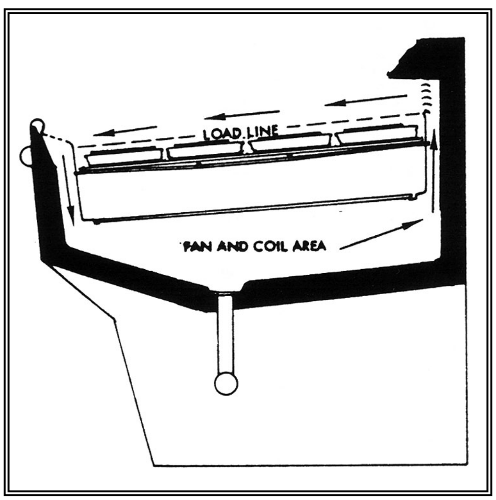
Manufacturers of display coolers specify their units as either low temperature (freezer) or medium temperature (cooler) units. The size is rated by the interior volume capacity in cubic feet. Additional information includes the horsepower of the compressor and the weight and overall dimensions of the unit.

Prices are very variable and depend on the layout of the units, the finishes, the number of shelves, whether open or closed and many other aspects.

- Smaller cooler units: $150-300 per cubic ft
- Larger cooler units: $110-250 per cubic ft
- Small freezers: $300-450 per cubic ft
- Larger freezers: $200-350 per cubic ft

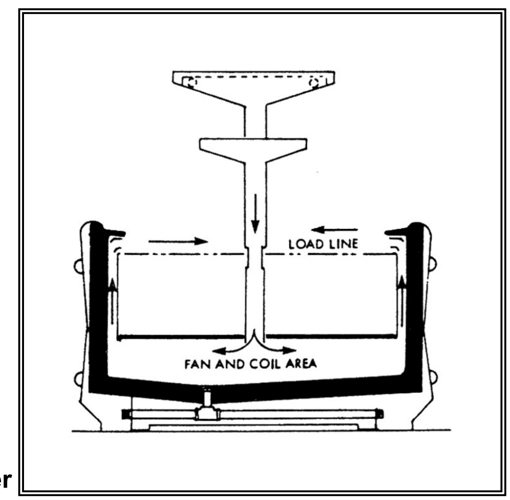
Most on-farm direct marketers should probably shop around and try and locate either secondhand or refurbished used equipment. Prices should be less than 50% of new equipment. There are numerous companies listed in the Yellow Pages TM of local phone books under "Refrigeration Equipment – Commercial" that will supply both quotations and types of equipment available. Many companies will also have secondhand equipment available or may know where equipment can be located.

Figure 3



Single-deck Display cooler

Figure 4



Island-type display freezer

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RESOURCE MANAGEMENT BRANCH
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APPENDIX - TABLE A

STORAGE REQUIREMENTS AND PROPERTIES OF FRUITS AND VEGETABLES

PRODUCT	STORAGE TEMP Long °F	STORAGE TEMP Short °F	WATER CONTENT % (mass)	HUMIDITY % R.H.	SPECIFIC HEAT ABOVE FREEZING BTU / lb / °F	SPECIFIC HEAT BELOW FREEZING BTU / lb / °F	LATENT HEAT OF FUSION BTU / lb.	HIGHEST FREEZING POINT °F	RESPIRATION AT STORAGE TEMPERATURE BTU / lb / day
FRUITS									
Apples (fresh)	30-32	38-42	84	85-90	0.87	0.45	120.5	30.0	0.27-0.45
Apricots	31-32	40-48	85	85-90	0.88	0.46	121.9	30.0	0.56-0.63
Blackberries	31-32	42-45	85	85-95	0.88	0.46	121.9	30.6	1.71-2.53
Blueberries	30-32	35-40	82	85-95	0.86	0.45	117.6	29.1	0.26-1.15
Cherries (sweet)	31-32	40	80	80-90	0.84	0.44	114.7	28.8	0.45-0.60
Cranberries	36-40	40-45	87	85-95	0.90	0.46	124.8	30.4	0.45-0.52
Currants	31-32	40-45	85	85-95	0.88	0.46	121.9	30.2	n/a
Gooseberries	30-32	35-40	89	85-95	0.91	0.47	127.6	30.0	0.74-0.97
Grapes (vinifera)	30-32	35-40	82	80-90	0.86	0.45	117.6	28.2	0.15-0.26
Peaches (fresh)	31-32	50	89	85-90	0.91	0.47	130.5	30.4	0.41-0.71
Pears	29-31	40	83	85-90	0.86	0.45	119.0	29.1	0.30-0.74
Plums	31-32	40-45	86	80-90	0.89	0.46	123.3	30.6	0.22-0.33
Prunes	31-32	40-45	86	80-90	0.89	0.46	123.3	30.6	0.22-0.33
Raspberries	31-32	40-45	84	80-90	0.87	0.47	120.5	30.9	1.93-2.75
Strawberries	31-32	42-45	90	80-90	0.92	0.47	129.1	30.6	1.34-1.93
VEGETABLES									
Asparagus	32	40	93	85-95	0.94	0.48	133.4	30.9	3.01-8.82
Beans, snap	32-34	40-45	89	85-95	0.91	0.47	127.6	30.7	3.76-3.83
Beans, dried	36-40	50-60	11	70	0.29	0.23	n/a	n/a	n/a
Beets, roots	32-35	45-50	88	95-98	0.90	0.46	126.2	30.0	0.60-0.78
Broccoli	32-35	40-45	90	90-95	0.92	0.47	129.1	30.9	2.05-2.34
Brussels sprouts	32-35	40-45	85	90-05	0.88	0.46	121.9	30.6	1.71-2.64
Cabbage	32	45	92	90-95	0.94	0.48	132.0	30.4	0.45-1.49
Carrots (roots)	32	40-45	88	95-98	0.90	0.46	126.2	29.5	1.71
Cauliflower	32	40-45	92	85-95	0.94	0.48	132.0	30.6	1.97-2.64
Celery	31-32	45-50	94	90-95	0.95	0.48	134.8	31.1	0.78
Corn, sweet	31-32	45	74	85-95	0.79	0.42	106.1	30.9	4.65
Cucumbers	45-50	45-50	96	90-95	0.97	0.49	137.7	31.1	2.53-3.20
Eggplant	45-50	46-50	93	85-95	0.94	0.48	133.4	30.6	n/a
Garlic (dry)	32	50-60	61	65-70	0.69	0.38	87.5	30.6	0.33-1.19
Leeks	31-32	45-50	85	90-05	0.88	0.46	121.9	30.7	1.04-1.79
Lettuce (head)	32	45	95	95-98	0.96	0.49	136.3	31.6	1.00-1.86
Mushrooms	32-35	55-60	91	80-90	0.93	0.47	130.5	30.4	3.09-4.80
Onions (green)	32	50-60	89	90-95	0.91	0.47	127.6	30.4	1.15-2.46
Parsnips	32-34	34-40	79	95-98	0.83	0.44	113.3	30.4	n/a
Peas, green	32	40-45	95	85-95	0.79	0.42	106.1	30.9	3.35-5.13
Peppers (sweet)	45-50	40-45	95	90-95	0.94	0.48	132.0	30.7	1.60
Potatoes (white)	36-50	45-60	78	85-95	0.82	0.43	111.9	30.9	0.63-0.74
Pumpkins	50-55	55-60	91	70-75	0.93	0.47	130.5	30.6	n/a
Radishes	32-34	40-45	95	95-98	0.96	0.49	136.3	30.7	0.60-0.63
Rhubarb	32-34	40-45	95	90-95	0.96	0.49	136.3	30.4	0.89-1.45
Spinach	32	45-50	93	90-95	0.94	0.48	133.4	31.5	5.06
Squash (winter)	50-55	55-60	95	70-75	0.88	0.46	119.1	30.8	1.30-1.41
Tomatoes (ripe)	40-50	55-70	94	85-90	0.95	0.48	134.8	31.1	1.56
Turnip (roots)	32	40-45	92	90-95	0.94	0.47	132.0	30.0	0.97

*Use higher values for first day storage and lower values, when product is at an equilibrium state, for longer storage period.

Data largely taken from 1986 A.S.H.R.A.E. Refrigeration Handbook.

APPENDIX - TABLE B

THERMAL PROPERTIES OF SELECTED INSULATING AND BUILDING MATERIAL

Material	Insulating "R" Factor hr sq ft deg F / BTU
Insulation	
Fiberglass batts[2]	3.32/inch
Fiberglass, loose	2.55/inch
Fiberglass, board	4.00/inch
Cellular glass (Foamglas)	2.86/inch
Styrofoam, extruded	5.26/inch
Styrofoam, beadboard *	4.17/inch
Polyurethane, board	6.25/inch
Polyurethane, foamed-in-place	6.25/inch
Polyisocyanurate, board	7.04/inch
Building Materials	
Fir plywood	1.25/inch
Fiberboard sheathing1/2"	1.32
Particle board 1/2" (Aspenite)	0.92
Gypsum board (5/8")	0.56
Concrete, cast	0.11/inch
Concrete block 8"	1.11
Concrete block 12"	1.28
Glass, single pane	0.10
Air Film and Air Gaps	
Air Film, outside or warm	0.28
Air Film, inside or cold	0.17
Air gap 1 inch or greater	0.72

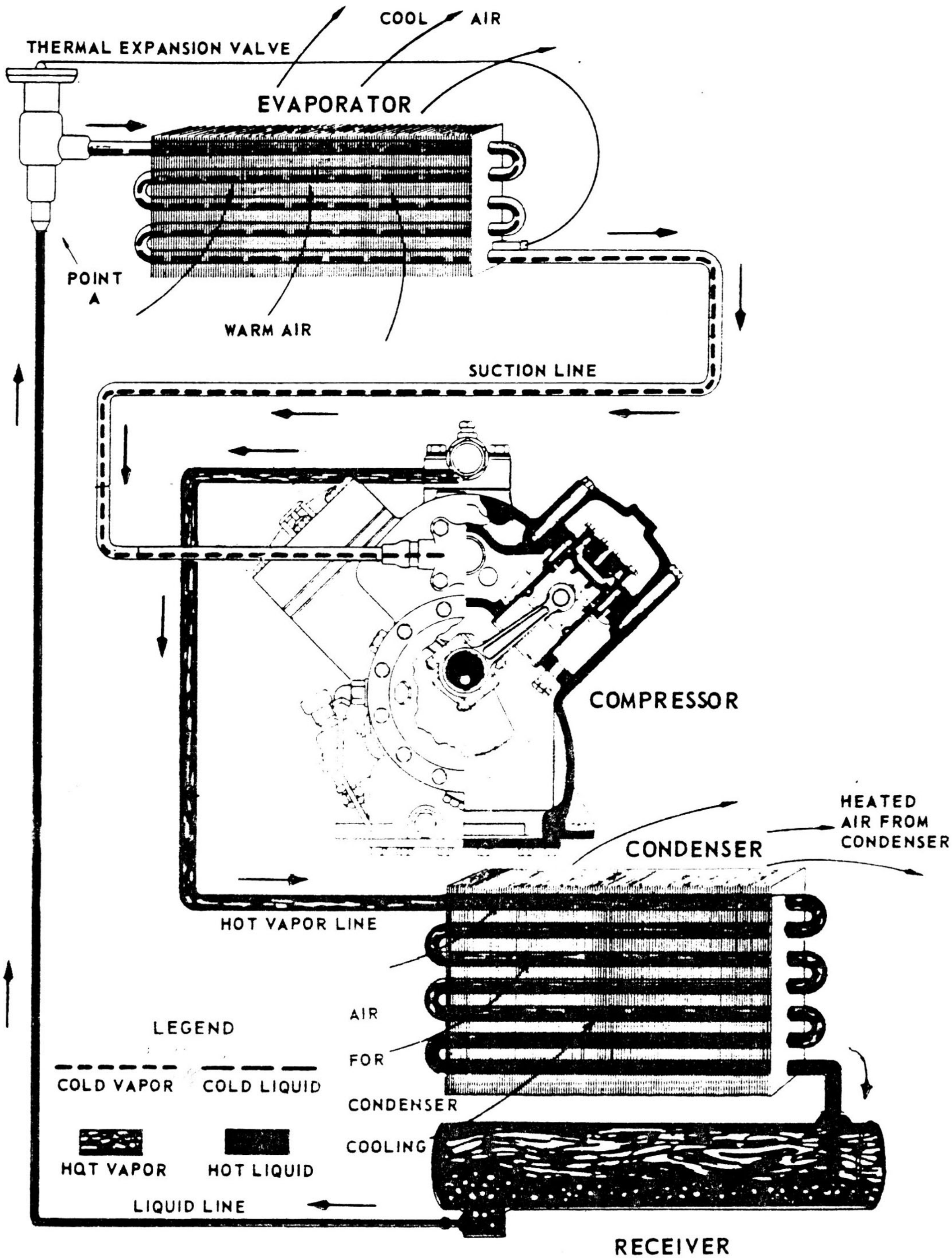
* Density of 1.5 lb/cu ft

Metric Conversion Factors: hr sq ft deg F / BTU x 0.276 = sq m deg K / W

Extracted from:
Agricultural Engineering Extension Bulletin 448
Cornell University, Ithaca, New York 14853

APPENDIX - Figure A

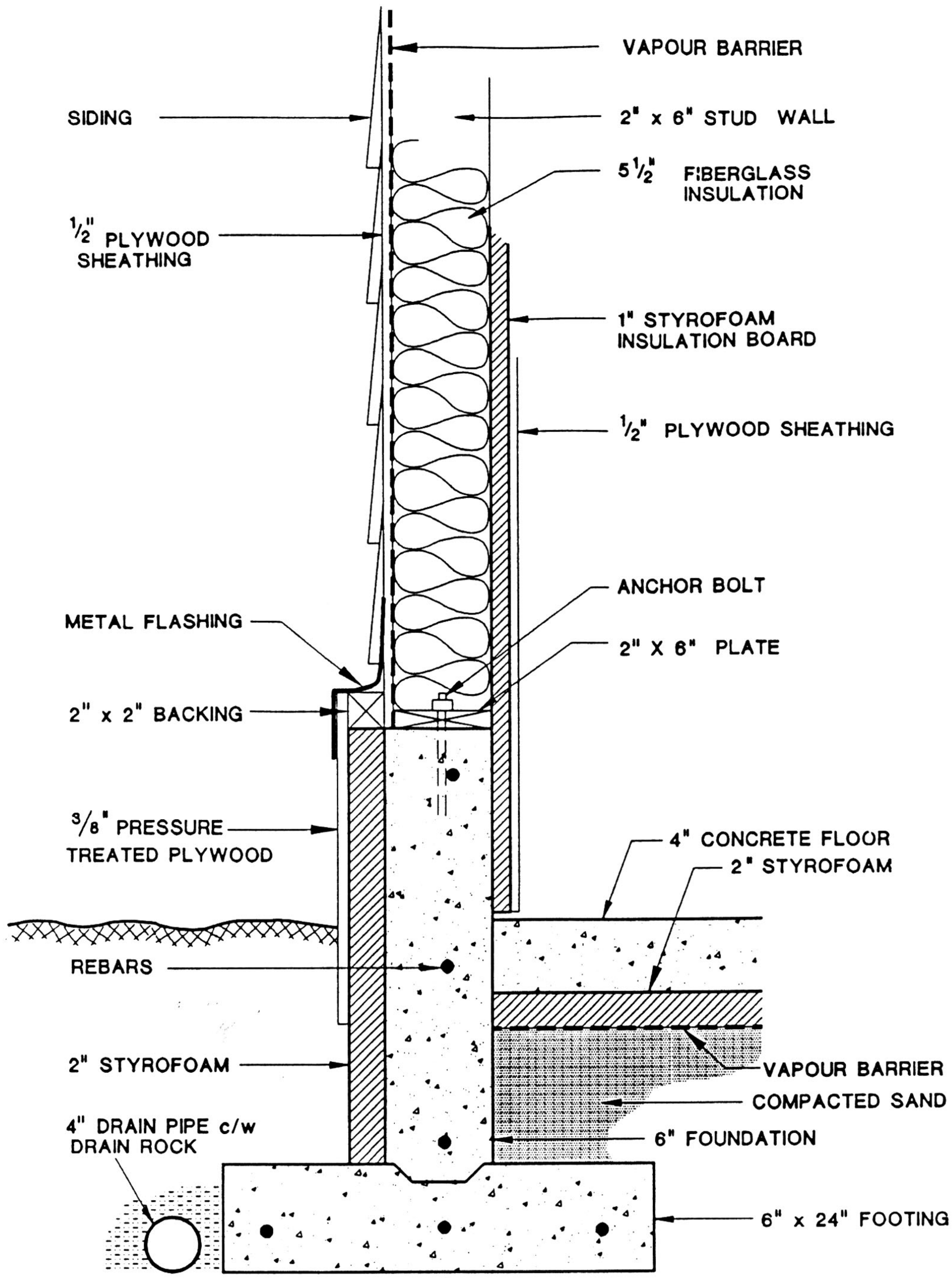
SCHEMATIC OF REFRIGERATION SYSTEM



A serviceable commercial system with air-cooled condenser, thermostatic expansion valve and V-type compressor. (Carrier Air Conditioning Group, United Technologies Corp.)

APPENDIX - Figure B

WALL / FOUNDATION CONSTRUCTION DETAIL



APPENDIX

Worksheet 1 – DESIGN PARAMETERS

ITEM	EXAMPLE	YOUR FARM
Crop to be grown for cooling or storing	Strawberries	
Acreage of crop	4.0 acres	
Annual production rate	7 ton/acre	
Harvesting period	May 20-June	
Peak daily production	3,200 lb/day	
Peak daily production requiring cooling	1,600 lb/day	
Maximum field crop temperature	90^oF	
Optimum storage temperature	32^oF	
Temperature differential between field	58^oF	
Highest freezing point	$30.6\ ^oF$	
Optimum relative humidity	85% - 95%	
Specific heat of crop (BTU/lb/ ^oF/day)	0.92	
Respiration heat of crop (BTU/lb/day)	1.93	

APPENDIX

Worksheet 2 - STORAGE SIZE

ITEM	EXAMPLE	YOUR FARM
Crop crate size	12” x 16” x 4”	
Weight of product per crate	10 lb	
Total weight of crate plus product	11 lb	
Height of stacking of crates	48”	
Produce weight per stack	120 lb	
Volume per stack	5.33 cu ft	
Number of stacks in cooler	14 stacks	
Space between stacks for air flow	6” – 8”	
Floor area required	42 sq ft	
Cooler size (inside) - length - width - height - floor area - room volume	 9 ft 8 ft $7^{1}/_{2}$ ft 72 sq ft 540 cu ft	 ____________ ____________ ____________ ____________ ____________
Cooler size (outside) - length - width - height	 10 ft 9 ft 8 ft	 _________ _________ _________

Note: A square or close to square room is most economical in that surface areas per total volume are minimized. This will reduce heat losses and reduce construction costs. Adequate space must be provided in the room for the evaporator unit as well as for maneuverability of the produce in the cooler.

APPENDIX

Worksheet 3 - CALCULATING INSULATION FACTORS

Based on the actual construction, an "R" value (insulation factor) is calculated using the values found in Appendix Table B, Thermal Properties of Selected Insulating and Building Materials.

ITEM	EXAMPLE	YOUR FARM
FLOOR AND FOUNDATION		
• 2-inch rigid insulation	10.52	____________
• 4-inch concrete (6" foundation)	0.44	____________
• inside air	0.17	____________
Total "R" value for floor	**11.13**	____________
WALLS		
• outside air	0.28	____________
• sheet metal cladding	0.00	____________
• 51/2-inch fibreglass	18.26	____________
• 1-inch rigid insulation	5.26	____________
• 1/2-inch plywood	0.63	____________
• inside air	0.17	____________
Total "R" value for walls	**24.60**	____________
CEILING		
• outside air	0.28	____________
• 51/2-inch fibreglass	18.26	____________
• 2-inch rigid insulation	10.52	____________
• 1/2-inch plywood	0.63	____________
• inside air	0.17	____________
Total "R" value for ceiling	**29.86**	____________

Note: Fibreglass batts must be left in their expanded form to gain the optimum value. Any seriously compressed material will reduce the calculated "R" value.

APPENDIX

Worksheet 4 - HEAT LOAD CALCULATION *

ITEM	YOUR FARM - BTU / DAY
1. **Field Heat** _____ lb berries + _____ lb crates _____ lb x _____ Btu / lb deg F day x _____ deg F	
2. **Heat of Respiration** (very variable) _____ lb x _____ Btu / lb day	
3. **Conductive Heat** (heat leakage) Walls = _____ sq ft x _____ deg F x 24 hr / _____ hr sq ft deg F per Btu day Ceiling = _____ sq ft x _____ deg F x 24 hr / _____ hr sq ft deg F per Btu day Floor = _____ sq ft x _____ deg F x 24 hr / _____ hr sq ft deg F per Btu day	
4. **Convective Heat** (air exchanges) _____ cu ft x _____ exchanges / day x 2 Btu / cu ft	
5. **Equipment Heat Load** _____ x _____ HP fans x _____ Btu / HP – hr x 24 hr / day _____ x _____ watt lights x _____hr / day x 3.41 Btu / watt – hr	
6. **Human Energy Load** _____ person x _____ hr / day x 950 Btu / worker – hr	
TOTAL CONTINUOUS HEAT LOAD	**= _________ BTU / 24 hr**
REFRIGERATION CAPACITY BASED ON DEFROST TIMES = _____ BTU / 24 hr ÷ _____ hrs	= _________ **BTU / hr**

* *Refer to "**Example Heat Load Calculation**" on Page 20*

APPENDIX

EXAMPLE HEAT LOAD CALCULATION

ITEM	YOUR FARM - BTU / DAY
1. **Field Heat** 1600 lb berries + 160 lb crates 1760 lb x 0.92 Btu / lb deg F day x 58 deg F	= 93,900
2. **Heat of Respiration** (very variable) 1600 lb x 1.93 Btu / lb day	= 3,100
3. **Conductive Heat** (heat leakage) Walls = 304 sq ft x 58 deg F x 24 hr / 24.60 hr sq ft deg F per Btu day Ceiling = 90 sq ft x 58 deg F x 24 hr / 29.86 hr sq ft deg F per Btu day Floor = 90 sq ft x 13 deg F x 24 hr / 11.13 hr sq ft deg F per Btu day	= 17,700 = 4,200 = 2,500
4. **Convective Heat** (air exchanges) 540 cu ft x 25 exchanges / day x 2 Btu / cu ft	= 27,000
5. **Equipment Heat Load** 2/10 x 1 HP fans x 4250 Btu / HP – hr x 24 hr / day 2 x 40 watt lights x 8 hr / day x 3.41 Btu / watt – hr	= 20,400 = 2,200
6. **Human Energy Load** 1 person x 2 hr / day x 950 Btu / worker – hr	= 1,900
TOTAL CONTINUOUS HEAT LOAD	= 172,900 **BTU / 24 hr**
REFRIGERATION CAPACITY **BASED ON DEFROST TIMES** = 172,900 **BTU / 24 hr** ÷ 16 **hrs**	= 10,800 **BTU / hr**