GENERAL STORAGE OF FRUITS AND VEGETABLES

CPS
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This leaflet outlines Canada Plan Service (CPS) information and plans on storages for horticultural crops. It also discusses in some detail the planning and design of commercial vegetable storages.

PLANS AVAILABLE

The Canada Plan Service provides plans for several wood-frame potato storages ranging in size from 1000-3500 t (1100-3850 tons). With modifications to refrigeration and air flow, smaller or larger structures can be built from these plans. Plans for a small root cellar and walk-in cooler are also available.

You can also get Agriculture Canada publication 1478, *Home Storage Room for Fruits and Vegetables.* This describes very small storages for the home or market garden. Write to Communications Branch, Agriculture Canada, Ottawa K1A OC7.

CPS also provides plans for the main structural components of commercial storages, such as walls for aircooled or refrigerated bulk storages, interior bin partition walls, CA storage walls, structural diaphragm ceilings and insulated storage doors.

Miscellaneous plans and leaflets include a small pipeframe greenhouse, calculations of greenhouse heat losses and a bedding plant cold frame.

DESIGN CONSIDERATIONS

The design of long-term storage for fruits and vegetables involves several factors.

FUNCTIONAL DESIGN For convenient handling and management of the stored produce, you must consider:

- the size and number of individual bins required;
- varieties or types of produce to be stored;
- storage layout for convenient handling;
- receiving and rough grading at harvest;
- future expansion or modification;
- utilities and services required; and
- possible washing, grading or packaging facilities.

STRUCTURAL DESIGN Climatic loads (wind and snow) and product loads (the bin wall pressure and related forces caused by piled produce) must all be allowed for. Adequate insulation, vapor barrier, structural connections, foundations and reinforcement are also needed.

ENVIRONMENTAL CONTROL Here, temperature, humidity, refrigeration, ventilation air, condensation and related control equipment are concerns. For the special case of fruit kept in a controlled atmosphere (CA), the oxygen and carbon dioxide content of the storage must be closely regulated. This requires highly specialized modern technology.

In general, any type of building can be a good storage if it is structurally adequate, well insulated and meets the functional needs. Environmental control, including a good insulation system, is the key.

STORAGE TYPES

Two general types of storages are bulk storage and palletized storage. Some buildings can be adapted to either type.

Storages can be further classified according to their purpose: the produce to be stored, or whether it should be refrigerated or air-cooled. Size may range from small home facilities to large commercial structures. This leaflet deals with large commercial storages, although the same principles apply to smaller structures. Freezers are yet another type of storage; plans are not now available from the CPS.

BULK STORAGE The produce is piled in room-sized bins, which exerts forces that must be resisted by the building's walls. These forces are large and should not be underestimated in the building design. Ventilation is accomplished by circulating conditioned air through the produce from a duct system placed under the pile.

Bulk storage is generally less costly. It is most commonly used for crops that can be handled in bulk and piled deep, such as turnips, potatoes and onions (see Table 1). Other crops such as beets, carrots and parsnips can also be kept in shallow piles, though for reasons of handling and management these are more often stored and transported in pallet bins.

PALLET BIN STORAGE The crop is placed in boxes or pallet bins which in turn are stacked in storage rooms. The crop does not exert pressure on the walls, and the building need only be designed for climatic loads.

Pallet storage is used for crops that bruise easily or cannot be piled (for example, cabbages, parsnips, carrots and most fruits and greenhouse crops). Pallets permit storage of different varieties or types of crops, and crops from several growers in the same room. Bins can be selectively marketed, and problem bins can be emptied with less danger of widespread spoilage. It is the preferred storage for warehouses and plants where produce turnover is frequent.

Ventilation air at controlled temperature and humidity is circulated between rows of pallet bins. Bins are handled and stacked by fork-lifts and pallet dumping equipment. Note that fumes from gasoline or propane-powered pallet movers can seriously affect flavor of some vegetables; battery-powered equipment is recommended.

STORAGE SIZE

In planning total storage requirements, the grower has a choice of the size and number of rooms and bins. Storages vary from one large room to multiple-bin structures.

As a general rule, smaller bins are preferred. Smaller batches of produce are easier to manage for harvesting, marketing and temperature regulation. There is less risk if one bin spoils. However, the advantages of smaller bins have to be weighed against the lower cost of one or more large bins.

Marketing and handling requirements of the crop have the greatest influence on storage selection. Some specific examples illustrate this principle.

Market-garden or variety crop growers will need different storages for different groups of produce (Table 2). If just one group is grown, two or four bins improve harvest management by permitting each bin to be filled in less time. Long-term storage quality is improved by emptying bins one at a time.

Potato storages can be large one-room structures holding from 2000-5000 t (2200-5500 tons) or more, depending on variety and end-use. Seed growers will probably need smaller bins to separate varieties and reduce spoilage risk. Process potatoes sometimes require warming, or conditioning, before marketing. This is easier with smaller rooms storing about 500 t (550 tons) each with its own ventilation system.

Bulk storage size can be estimated from bulk density data (Table 1). Plan your storage for above-average yield and future expansion, or changes such as an added grading room, loading shed or refrigeration system. Consider that it is not usually feasible to fill storages full depth right to the doors unless heavy doors or bulkhead systems are in place. At least 0.5 m (2 ft) clearance is required over a pile for operation of the piling equipment; however, about 1.5 m (5 ft) is preferred for inspection (unless special walkways are provided).

Palletized storage capacity is determined by laying out the required number of bins in layers and rows. Stacking height is often determined by stacking equipment limits, usually four to six layers high. The most efficient room size provides for precise rows of bins, with about 150 mm (6 in.) air space between bins and along walls.

STRUCTURAL DESIGN

Pallet storages need only be designed for wind and snow loads; however, consider whether there is a possibility of changing to bulk storage in the future. Highest floor loads are caused by fork-lift wheels.

Bulk storages, in addition to climatic loads, must also withstand the pressure of piled vegetables against walls. Pay particular attention to wall stud strength, top and bottom wall connections, foundation side forces, and forces on the roof system caused by wall pressure.

Good design information is available on potato bin pressure, but not for most other crops. It is recommended that bulk vegetable storage walls be designed for potatoes; though other crops exert less pressure, the storage may some day be used for potatoes.

In engineering terms, potato storage wall systems can be designed on the basis of a granular product with "equivalent fluid density" of 2.1 kN/M^3 (13 lb/cu ft). Bending moments and wall forces are calculated accordingly.

OTHER CONSTRUCTION NOTES Most storages have high humidity and controlled temperature. Whether storages are wood frame, steel or concrete, they must be moisture resistant and extremely well insulated. Vapor barriers must be properly located and airtight to be effective. CPS leaflet 6330 deals with storage insulation in detail.

Whatever the construction type, you should:

- insulate the foundation, preferably on the exterior;
- pay particular attention to thermal bridges (cold spots) in otherwise good wall or roof systems that cause serious condensation problems (solid studs, steel purlins and beams, and discontinuous insulation at foundations or plates are the most common problem areas);
- ensure durability and ease of sanitizing;
- use CCA-treated wood, because of high humidity, for all sills and any wood to be covered in polyurethane insulation. Extending CCA-treatment to all the covered wall framing adds a measure of insurance that will greatly increase the expected life of the building at moderate extra cost.

ENVIRONMENTAL CONTROL

Environmental control means the control of air temperature, humidity and airflow. For some special applications, you may also have to consider the proportion of gases (0_2 and $C0_2$) in the storage. Proper conditions are critical for quality long-term storage. Table 2 lists the recommended storage conditions for common fruits and vegetables.

From Table 2 it is evident that there are groups of produce having similar storage requirements. These will keep well together. Except for very short terms, it is not advisable to mix different groups in one storage.

Storages may be either air-cooled or refrigerated, or both. In air-cooled storage, temperature is controlled by blending cold, outdoor air into the ventilation system. During most of the storage season this requires outdoor temperatures below storage temperature for all but short periods. In general this applies to potato, onion and squash storages and some short-term cold storages.

Ventilation is the movement of conditioned air around or through the vegetables to remove heat, maintain uniform conditions and control humidity or condensation. This involves air flow rates and patterns, temperature controls, fans and ducts. Table 1 gives the recommended range of ventilation rates for vegetables.

In bulk storage, air is circulated through the pile by a fan and duct system. Temperature is usually controlled by a system of thermostats that operate dampers to blend cold outside air with recirculated inside air. Controls should include a proportioning thermostat, a low-limit safety thermostat, an outside temperature sensor (to prevent entry of outside air that is too warm), a timer and damper control motors.

Design an air handling and distribution system that adheres to sound engineering principles. Ducts should be free of obstructions and be adequately sized. Under-pile ducts are spaced 2.4-3.6 m (8-12 ft) apart. Storages requiring high humidity should include a high-capacity humidifier in the system.

Simpler, low-cost ventilation systems, suitable for shorter term or smaller storages, can use fans and ducts without automatic controls to circulate air through the pile. Manually operated doors and vents can bring in outside air for cooling. Small amounts of vegetables store well in shallow piles on slatted floors that allow natural air movement through the pile.

Refrigeration to about $O^{o}C$ is required for very long-term storage, for early fall storage, and for most cold crop storage. The two most common systems use cooling coils and air-washing. Each has advantages and shortcomings. Cooling coils may be either direct expansion or chilled cooling fluid types.

Though detailed design of refrigeration systems is beyond the scope of this leaflet, remember to design refrigeration capacity to handle the necessary loads. The system must be able to handle:

- field heat from the produce (this is often the largest cooling load);
- respiration heat of stored fruits or vegetables;
- heat gain through walls, ceiling and floor of the storage structure;
- mechanical heat load from lights and motors; and
- warm air infiltration.

When these cooling loads are taken into account, typical refrigeration capacity for vegetable storages should be:

- cold crops 120-150 W/t (9000-11250 BTU/(ton.day)
- potatoes 35-40 W/t (2 600-3 000 BTU/(ton.day)

Refrigeration systems *must* operate effectively at high humidity, near-freezing conditions. This requires a large coil area with a relatively high air flow of 200-250 L/(kW.s) (1500-1900 cfm/ton of refrigeration). Defrost cycles are required for low-temperature systems.

In planning both refrigerated and air-cooled pallet storages, the refrigerated or cooled air must flow from the coldest to the warmest produce (usually from back to front). Design both storage loading and the cooling system accordingly. That way, heat removed from warmer produce does not reheat vegetables that were previously cooled. Condensation caused by warmer, moist air striking cold produce is also prevented.

Refrigeration design will vary with the crops stored, harvesting conditions, storage management, size of storage and type of refrigeration equipment selected. Each storage should be designed for its specific requirements.

MANAGEMENT

To get the best results from most storages:

- harvest crops at the right stage of maturity;
- grow varieties that are known to store well;
- pre-cool cold storage crops before storage and/or try to harvest under cool conditions (such as early morning);
- pre-grade to remove diseased or damaged produce;
- handle produce carefully to avoid damage;
- dampen earth floors of storages ahead of time;
- try to harvest frost-damaged, water-soaked or other spoil-susceptible crops last, if these are to be stored, then segregate them in storage and market them as soon as possible.

TABLE 1 TECHNICAL DATA FOR SELECTED VEGETABLES

Produce	Bulk density[a]		Pile depth[b]		Heat of respiration[c] W/t			Ventilation[d]	
	kg/m^3	(lb/cu ft)	m	(ft)	0^oC	5^oC	16^oC	L/s.t	(cfm/ton)
Beets	700	44	3.0-4.0	10-14	10-15	25-30		20-30	40-60
Cabbage	500	31	2.0-3.0	6-10	10-12	25-30	70-100	20-30	40-60
Carrots	550	34	3.0-4.0	10-14	10-13	17-20	60-80	20-30	40-60
Parsnips	550	34	2.5-3.6	8-12	10-20	16-40	60-80	20-30	40-60
Potatoes	670	42	4.2-6.0	14-20		8-12	16-30	6-10	12-20
Pumpkins and squash	600	37	0.6-1.0	10-12				15-20	30-40
Rutabagas and turnips	600	37	3.0-3.6	10-12	6-8	10-15	25-40	15-25	
Onions	650	41	3.0-3.6	--	8-10	10-12		35-40[e] 10-12[f]	70-80[e] 20-25[f]

a Bulk density varies 5-10% depending on variety and size.

b Use pile depth as an approximate guide in planning storage requirements. This will vary with variety, storage time, handling and marketing procedures.

c Heat of respiration given is for sound, healthy, mature produce. Respiration increases greatly for immature or damaged crops. It is usually greatest at harvest and varies with variety. To convert from W/t to BTU/(ton.day), multiply W/t times 74.5.

d Use higher rates where ventilation air is also airflow through cooling coils for good coil performance.

e Curing

f Storing

TABLE 1 STORAGE CONDITIONS FOR SELECTED FRUITS AND VEGETABLES

Storage	Produce[a]	Temperature (°C)	Relative humidity (%)	Storage period (months)
Fruits[b]	Apples	0-1	90-95	Varies up to 12 months; highly variety dependant
Cold and humid	Beets Cabbages[c] Carrots Parsnips Radishes Turnips	0-1	95+	4-6 2-6 4-6 2-5 0.5-3 4-6
Cool and humid	Potatoes[d] - seed - table - process	 4-5 5-7 7-10	90-95	5-10
Cool and less humid	Squash[e] Marrow[e] Pumpkins	10-13	70-75	4-6 4-6 2-4
Cold and dry	Onions[f] – cured	0-3	70-75	4-8

a Most produce, particularly cabbage and potato, reacts to light; store in dark conditions.

b Commercial storage of apples involves controlled-atmosphere (CA) technology. Do not store vegetables and apples together because apples give off ethylene which causes off-flavors in carrots, parsnips and other vegetables.

c Cabbage storage quality and time is highly variety dependent.

d Potatoes are normally cured 2 to 3 weeks at 10-15°C (50-59°F) and high then cooled slowly to storage temperature.

e Squash and marrow should be well ripened; cure at 30°C (86°F) then reduce temperature.

f Onions are either field, or cured in storage at 32-36°C (89-97°F) with high air flow before long-term storage.