On-Farm Cold Storage Facilities

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Rural Energy Program
Biological Systems Engineering

Agenda
• Types of Storage Facilities
• Refrigeration Systems
• Environmental Conditions
• Material Handling
  • Containers
  • Logistics – Traffic Control
  • Material Handling equipment
• Planning
• Economics
• Storage Grants

Crop Storage Parameters
• Type of Storage
  • Crop Volumes
  • Bulk Storage
  • Containers
• Length of Storage
  • Short – up to 60 days
  • Long – 3-12 months
• Crop Compatibility
  • Temperature
  • Humidity
  • Ethylene
  • Odor
• Investment

Root Cellars
• Energy Efficient
  • Use ground temperature
  • Outside air for cooling
  • Temperature subject to ambient temp
• Vent warm air / respiration gases ?
• Little/no electrical energy use (fans)
• Not suitable for removing harvest heat
  • Slow transfer of heat
• Access for material handling??
  • Can’t afford to hand carry crops in and out

Source: http://www.kk.org/streetuse/redneck_root_cellar.jpg
Modern Root Cellar Concept

- Earth Contact basement
  - Average ground temperature – 49°F
- Why not under-ground?
  - Cost of ceiling / roof
  - Office/living 2nd Floor
- Fork Truck Accessible
- $36,000 (2001)

Food Farm, Wrenshall, MN

Potatoes
- Bulk Bins
- 42-45°F

Winter Squash on racks
- 50°F

Carrots
- Pallets / Bins
- 35-38°F

Staging Area

Modern Root Cellar Concept

- Outside air cooling
  - Outside air used when
    - Cooling is needed &
    - Outside air colder than inside temperature
  - Computer controlled
    - Fans and Dampers
  - Mixing Fans & heaters

More information at http://smfarm.cfans.umn.edu/rootcellar.htm

Refrigerators

- Self contained
- Great for smaller quantities
- No humidity control
- No planned air exchange
- Space efficiency?
  - Do containers fit shelving?
- Solid doors more energy efficient than glass
- Limited capacity to remove field heat
- Cost effective for small grower / short term storage

Walk-in / Drive-in Coolers

- Workhorse of industry
- Rule of thumb
  - 2.5 to 3 cu. ft. of cooler volume per bushel
  - 1.24 cu ft / bushel – 50% utilization
- Modular or built-in-place
- Features:
  - Lockable door
  - Washable interior
  - Floor drain
  - Well insulated walls
  - Temperature control
  - Insulated floor
  - Self closing door

Source: http://www.selectappliance.com/exec/ce-product/tl_g20000

Source: http://www.webstaurantstore.com/nor-lake-walk-in-cooler-6-x-12-x-6-7-indoor/596KLB612.html
Walk-in / Drive-in Coolers

- Manufactured panels
  - Modular tongue/groove panels
  - Walls and Roof
  - 2" to 12" thick
- Insulation
  - Closed Cell Foam
    - 4" minimum (R-25) – 6" better (R-38)
    - Urethane or Polystyrene
  - Vapor barriers
- Installation
  - Easy to assemble
  - Locking cams
  - Ceiling or floor to wall
  - Cam locks or bolts
  - Caulk all seams

Built-in-place Cooler

- Insulated walls –
  - R-25 minimum (EPACT 2005) (R-30+ recommend)
  - Fiberglass insulation **NOT** recommended
    - Wet insulation reduces insulation value
  - Foam - Polyurethane / Polystyrene
    - R-value - 4 to 6.5 per inch
    - Vapor barrier – warm side (not needed with Foam)
      - Year round storage – warm side changes
- Insulated floor
  - 1-2” foam board under concrete – 25 or 40 PSI rating foam
- Washable interior surface
  - Fiber reinforced plastic / Stainless steel / steel
- Drain – condensation / clean-up
- Cost – same as used cooler panels (labor & floor excluded)
  - 12 x 12 x 8 – $5500 w/ refrigeration

Insulation Materials

- Foam – (4” minimum – 6” better))
  - Rigid board
    - Types
      - Urethane (yellow) - R-6.25
      - Extruded Polystyrene (XPS) (pink/blue) (R-8)
      - Expanded Polystyrene (EPS) (white) (R-4)
      - Polyisocyanurate (off-white) (R-6.8)
    - Typ. Aged Insulation value – R-5
    - Tongue & groove – tape all seams
    - Offset seams if double layer
  - Foam in place – seals all edges
    - Urethane / Polyisocyanurate
    - Needs sealant on inside (high moisture)
  - Cover to protect
    - Flammable – protect from heat sources
    - Steel / plastic corrugated sheeting
    - Plywood - exterior

Self-contained units

- Truck/Trailer Reefer
  - Higher Heat losses/gain
    - 2.25" to 3" foam
  - Smaller refrigeration system
    - Designed to maintain the temperature of product
  - Air flow may not be ideal
  - Access for Material Handling

Source: http://www.portablecoldstorage.com/
Refrigeration System – Direct Expansion

Evaporator Fan motors
- Can be higher cost to operate than compressors
  - Run to promote air mixing
  - Evaporator Fan Controller
    - Reduces fan speed when compressor not running
- PSC – Permanent Split Capacitor (old)
  - Full load efficiency – 50-60%
  - Lower efficiency at lower speeds
- EC – Electronically Commutated (new)
  - Efficiency - 65 – 80%
  - Typically 30-50% energy savings

Types of Refrigerants
- New systems – R404a
- Used Systems
  - Avoid
    - R-12 - restricted sales (ban as of Jan 1, 2015)
    - R22 - Jan 1, 2010 ban the use in new equipment
      - Production creases Jan 2020
      - Can use a replacement refrigerant for existing equipment
  - Acceptable Refrigerants
    - R134a – restricted sales (March 2004)
    - R404a
    - It is illegal to intentionally release any refrigerant

Refrigeration Sizing
- Field heat removal
- Heat of respiration
- Conduction heat gain / loss
- Infiltration heat gain / loss
  - Air exchange (opening of door)
  - Leaks – door, seams
- Equipment heat gain
  - Lights, fans, fork truck
Refrigeration Requirement

• Field heat Removal
  • Largest component
  • Short duration
  • Smaller for Fall harvested crops
  • $\Delta T \times \text{lbs} \times \text{SH}$
  • Slow removal effect produce

Factors - field heat removal rate

• Type of packaging / container
  • Solid sides/bottom versus slotted
• Low Refrigeration Capacity
• Air flow rate
• Reduction in quality if field heat is not removed rapidly enough.
  • Wilting
  • Ripening
  • Spoilage
  • Shortened self-life

Precooling

• Hydro-cooling – Water bath
• Forced air cooling
• Ice Pack
• Vacuum Cooling

Respiration Rates (Btu/ton/day)

<table>
<thead>
<tr>
<th>Commodity</th>
<th>32 °F</th>
<th>40 °F</th>
<th>60 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>660</td>
<td>1320</td>
<td>3190</td>
</tr>
<tr>
<td>Asparagus</td>
<td>11,770</td>
<td>21,010</td>
<td>53,570</td>
</tr>
<tr>
<td>Snap Beans</td>
<td>4400</td>
<td>7700</td>
<td>20,460</td>
</tr>
<tr>
<td>Beets – topped</td>
<td>1320</td>
<td>2090</td>
<td>4400</td>
</tr>
<tr>
<td>Broccoli</td>
<td>4400</td>
<td>7590</td>
<td>38,170</td>
</tr>
<tr>
<td>Cabbage</td>
<td>1100</td>
<td>2310</td>
<td>5720</td>
</tr>
<tr>
<td>Carrots - topped</td>
<td>3300</td>
<td>4290</td>
<td>8800</td>
</tr>
<tr>
<td>Leaf lettuce</td>
<td>5060</td>
<td>6490</td>
<td>13,750</td>
</tr>
<tr>
<td>Peas - unshelled</td>
<td>8470</td>
<td>14,410</td>
<td>41,910</td>
</tr>
<tr>
<td>Peppers, sweet</td>
<td>2200</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td>1320</td>
<td>1980</td>
<td></td>
</tr>
<tr>
<td>Squash, summer</td>
<td>2750</td>
<td>3630</td>
<td>18,150</td>
</tr>
<tr>
<td>Sweet potatoes (cured)</td>
<td></td>
<td></td>
<td>4840</td>
</tr>
</tbody>
</table>

Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22
Refrigeration Sizing

- **Total refrigeration requirement**
  - Use maximum (worst case) values for each
  \[ Q_t = Q_{FH} + Q_{resp} + Q_{cond} + Q_{infil} + Q_{Equip} \]

- **Capacity of refrigeration system**
  \[ \text{Capacity} = Q_t \times SF \times DF \]
  - **SF** = service factor, typically 1.1 to 1.2
  - **DF** = defrost factor, typically 1.1 to 1.2

  - One ton of Refrigeration = cooling based on melting 2000 lbs of ice in 24 hrs
  - 288,000 Btu/24 hrs or 12,000 Btu/hr

Typical Refrigeration Capacity

Refrigeration capacity needs to be sized for your conditions

<table>
<thead>
<tr>
<th>Cooler size (w x d x h)</th>
<th>Room volume (ft³)</th>
<th>+ 32°F Typ Load¹ (Btu/hr)</th>
<th>+ 32°F Heavy load² (Btu/hr)</th>
<th>+ 40°F Typ Load¹ (Btu/hr)</th>
<th>+ 40°F Heavy load² (Btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 x 10 x 8</td>
<td>640</td>
<td>6/700</td>
<td>8/900</td>
<td>9/1000</td>
<td>10/1100</td>
</tr>
<tr>
<td>8 x 10 x 10</td>
<td>7,120</td>
<td>7/1200</td>
<td>9/1600</td>
<td>10/2000</td>
<td>11/2400</td>
</tr>
<tr>
<td>10 x 14 x 9.5</td>
<td>13,920</td>
<td>10/1600</td>
<td>12/2400</td>
<td>13/2800</td>
<td>14/3200</td>
</tr>
<tr>
<td>12 x 18 x 10</td>
<td>18,720</td>
<td>13/2400</td>
<td>15/3600</td>
<td>16/4200</td>
<td>17/4800</td>
</tr>
<tr>
<td>14 x 24 x 10</td>
<td>36,000</td>
<td>23/4800</td>
<td>25/7200</td>
<td>26/9000</td>
<td>28/10800</td>
</tr>
<tr>
<td>16 x 30 x 10</td>
<td>48,000</td>
<td>33/7200</td>
<td>35/10800</td>
<td>36/13600</td>
<td>38/16400</td>
</tr>
<tr>
<td>20 x 40 x 10</td>
<td>80,000</td>
<td>53/13600</td>
<td>55/20800</td>
<td>57/27200</td>
<td>59/33600</td>
</tr>
</tbody>
</table>

¹ Typical load assumes 2 lb of product per cubic foot (ft³) of cooler volume entering per day at 50°F and cooled to cooler set-point temperature in 24 hrs; 25% of volume with carrots for respiration load, 93°F outside temperature; R-value of walls and ceiling are R = 25; uninsulated floor at 55°F; average air exchange rate - less than 3 openings per hour; internal loads of 1 HP per 16,000 ft², lighting at 1 W/ft²; 1 person load per 25,000 ft²; 16 hr run time; plus a 10% safety factor.

² Heavy load assumes twice the air exchange rate: 4 openings per hr or more, 3 lb of produce per ft³ of cooler volume, otherwise the same conditions as typical load.

Small Refrigeration Systems

- **CoolBot™ Controller**
  - Over-rides standard window air conditioner controls
  - Cooling capacity less at lower temps than AC rating
  - Maybe lower capacity than require for field heat removal
  - Cannot reach 32-33°F – Best above 35°F
  - Some brands of AC units don’t run in cold weather
  - Multiply units may be needed for larger loads
  - AC unit - $600-$700 / Controller - $300

Small Refrigeration Systems

- **Self-Contained Refrigeration unit**
  - Condenser, compressor & evaporator – one unit
  - Plug and Play – no Refrigeration tech needed
  - Higher / known capacity @ rate temperature
  - Circulating fan
  - Roof top or side-mount
  - Inside or outside
  - $1600 - $3800

Temperature Ranges for Crops

- Cold & Very Humid - 32F & RH 95-99%
  - Beets, cabbage, carrots, parsnips, celeriac
- Cold & Humid - 32F & RH 90-95%
  - Apples, pears, turnips, Jerusalem Artichokes
- Cold & Dry - 32F & RH 65-70%
  - Onions / Garlic
- Cool & Wet - 40-50F & RH 95%
  - Potatoes
- Warm & Dry
  - Winter Squash - 50-55F & RH 50-70%
  - Sweet Potatoes - 55-60F & RH 80-85%

Temperature & Storage length

### Table 1: Cold & Humid

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Storage time (months)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>2-4, 3-12 CA</td>
<td></td>
</tr>
<tr>
<td>Horseradish</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Jerusalem Artichokes</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Pears</td>
<td>2-3, 0-8 CA</td>
<td></td>
</tr>
<tr>
<td>Turnips</td>
<td>4-5</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2: Cold and Very Humid

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Storage time (months)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beets</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Broccoli</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Cabbage</td>
<td>0-4</td>
<td></td>
</tr>
<tr>
<td>Carrots</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Chillies</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Leeks</td>
<td>1-2</td>
<td></td>
</tr>
<tr>
<td>Parsnips</td>
<td>4-6</td>
<td></td>
</tr>
<tr>
<td>Radish</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Rutabagas</td>
<td>4-6</td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Cold and Dry

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Storage time (months)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garlic</td>
<td>5-8</td>
<td></td>
</tr>
<tr>
<td>Onions (sweet)</td>
<td>1-3</td>
<td></td>
</tr>
<tr>
<td>Onions (pungent)</td>
<td>6-9</td>
<td></td>
</tr>
<tr>
<td>Shallots</td>
<td>6-10</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4: Specialty conditions

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Storage time (months)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes, late crop</td>
<td>2-12</td>
<td></td>
</tr>
<tr>
<td>Sweet Potatoes</td>
<td>4-9</td>
<td></td>
</tr>
<tr>
<td>Dry Beans</td>
<td>6-10</td>
<td></td>
</tr>
<tr>
<td>Acorn, Butternut, Hubbard</td>
<td>2-3</td>
<td></td>
</tr>
</tbody>
</table>

Humidity control

- Add moisture to air to reduce crop moisture loss
- Evaporative cooler pad
- Centrifugal Atomizer
  - Fixed or variable rate
  - ~ $300 - $1700
- Ultrasonic Humidifier
- Micro-Climate
  - Pack in
    - Plastic bag
    - Damp sand / sawdust

Source: [Gellert Company](http://ivi-air.com/)

Modified from Hardenburg et. al. (1986).
**Humidistat**
- Accuracy range
  - Range to 99%
  - Accuracy - 3-4% or less
  - Resolution – 1% or less
  - Smallest display digit
  - Accuracy decreases >90%
- Remote sensor desirable
- Locate in air flow
- Enclosure designed for wet environment
- Cost $140 - $500

**Humidity Control**
- Refrigeration dehumidifies air
- Low temp drop → large evaporator surface area

<table>
<thead>
<tr>
<th>Temperature Drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Across Evaporator</td>
</tr>
<tr>
<td>-1° F</td>
</tr>
<tr>
<td>-2° F</td>
</tr>
<tr>
<td>-3° F</td>
</tr>
<tr>
<td>-4° F</td>
</tr>
<tr>
<td>-5° F</td>
</tr>
<tr>
<td>-10° F</td>
</tr>
<tr>
<td>-15° F</td>
</tr>
</tbody>
</table>

1 Calculated from Psychrometric Tables
2 Actual Airstream temperature drop between inlet and outlet. The coil TD will be approximately twice this value.

**Outdoor air to reduce refrigeration**
- Exchange air
- Controls
  - Manual
  - Automatic
    - Temperature
    - Time of day
- Disadvantage
  - Loss of humidity
  - Colder air is dryer
Cold storage – clearances & air flow pattern

- Nothing stacked above bottom of evaporator
- Wall clearance allows air to cool product
- Space under and between containers

Air Flow with Plenum Wall

- Horizontal slots in plenum wall
- Bins stacked tight
- 2-way fork slot – air duct
- Use for Force-Air pre-cooling
- Humidification in plenum

Bins

- Materials:
  - Wood – heavier, absorb moisture, repairable
  - Plastic – FDA approved, easily sanitized, repairable
- Rated for loading
- Stackable (without lid)
- Covers/lids available
- Vented / solid sides / bottom
  - Minimum 8-11% of bottom open
- Handle with Fork Truck or Pallet Jack
- Fit standard racking
- Sized to fit cooler dimensions

Racking

- Allows better access to individual containers
- Better ventilation and cooling
- Keep containers off floor
- Wire shelving – better air flow
- Rolling racks for small walk-ins
Material Handling Equipment

- Pallet Jacks
- Pallet Lift
  - Need smooth level hard surface
  - Narrower aisle than needed for fork truck
- Fork Truck
- Skid Steer w/ Pallet Forks

Traffic & Material Flow

- Room to maneuver
- Type material handling equipment
- Access without moving many things
- Order of use
  - First in, First out
  - Last in, First out
- Pedestrian and vehicle paths separated
- Convenient to packaging & processing area

Rules of Thumb

- 2.5 to 3 cu. ft. of cooler volume per bushel
  - 1.24 cu ft / bushel – 50% utilization
- 4-6” between side walls and containers
- 8-10” between end walls and containers
- 12-18” between of overhead space

Layout Issues

- Wide or length in-efficient for container size
- Door location doesn’t allow maximum number of containers
**Layout Issues**
- Door location / sized for bins
- Allows last bin to go straight in.

**Layout for accessibility**
- Add doors to reduce aisle space inside cooler
- Small goods and Bulk area

**Planning!!!**
- Space requirements
- Material Flow
  - Access to processing area
- Material Handling
- Utility needs
  - Water
  - Electricity
  - Drains
  - Temperature
- Labor
- Future Expansion
Flow Charts – by crop

- From Field
- Wash
- Bulk Bins
- Long-Term Storage (Oct - Feb)
  - 34°F @ 95% RH
- Packing 5# mesh bags
- Sort by size A & B
- Culls – Food-bank / Compost Pile
- Compost
- Truck to Market
- Packing 5# mesh bags
- Short-term Storage
- Food Bank
- Wash

Building Layout

- Ramp to Fields
- Loading Dock
- Cooler #1
- Cooler #2
- Cooler #3
- Belt washer
- Hydro-Cooler
- Work Alesys
- Sorting equipment
- Packing Line
- Supply Storage Racks
- Bath / Shower Room
- Lunch Rm / Employee Lockers
- Office

Economics of Storage Crops

Factors to consider:
- Cost to build and operate storage units
- Facilities and capacity to move, wash and pack heavy, bulky items during the winter
- Shrink (spoilage and grading)
- Labor costs (benefits)
- Markets and Pricing
- Risk and rewards

Storage Facility Capital Cost

- Multiple units may be needed if you plan to store different products
  - Cold and moist (root crops)
  - Cold and dry (onions, garlic)
  - Cool and dry (squash, sweet potato)
- 12 x 12 cooler:
  - $8,000-$9,000 (new)
  - $4,000-$6,000 (used)
- 20 x 30 cooler:
  - $20,000-$24,000 (new)
  - $12,000-$14,000 (used)
Costs and Pricing

• Higher Costs - Winter storage and sales
  • Add at least 20% more costs (growers’ estimates)
  • Additional handling of product.
• Charge more at winter markets,
  • Achieving positive cash flow during a normally dead time of year.
• Electric costs to run cooler:
  • $2 to $4 per day.
  • Supplemental heating required
  • Storage units in unheated building/outside

Shrinkage and Labor Costs

• Shrinkage
  • Squash and onions - 20 to 30% - spoil
  • Root crops - 3 to 10% - culls
  • Cabbage - 10 to 40% - storage disease
• Labor
  • Few hours / week – Owner/operator
  • Part-time / full-time – larger farm
Farm Storage Facility Loan Program

- Low interest financing
  - Fixed rate for 2.000% - 7yr, 2.625% - 10yr, 2.875% - 12 yr
  - Up to $500,000
  - 15% down
- Build or upgrade storage and handling facility
  - New cold storage (Used equipment not eligible)
  - Framed structure or prefabricated permanently installed
  - Permanently affix equipment – refrigeration system, lighting, controls
  - Useful life of 15 years or more
- Administered by Farm Service Agency

Summary

- Know the storage requirements for each crop
- Market within the expected storage duration
- Plan storage facilities into work flow / traffic
- Use Foam insulation!!!
- Plan for expansion
- Sanitize storage and containers between seasons
- Price produce to cover additional costs

New Publication

- On-Farm Cold Storage of Fall-Harvested Fruits and Vegetable Crops
  - Authors: Scott Sanford & John Hendrickson
  - Published by University of Wisconsin-Extension Bulletin # A4105
  - Available at [http://learningstore.uwex.edu](http://learningstore.uwex.edu)

The 84 page bulletin covers Planning, Design and Operation of coolers for storage of fruits and vegetables.

Other Resources

- Wilholt, J., Low Cost Cold Storage Room for Market Growers, AEN-96, University of Kentucky Extension, 2009 [http://www2.ca.uky.edu/agc/pubs/aen/aen96/aen96.pdf](http://www2.ca.uky.edu/agc/pubs/aen/aen96/aen96.pdf)
- Bubel, Mike & Nancy, Root Cellaring, 2nd Ed, Storey, Pownal, VT, 1991
Questions can be emailed or call to discuss.

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