On-Farm Cold Storage Planning, Design, Management

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Agenda

- Types of Storage Facilities
- Refrigeration Systems
- Environmental Conditions
- Material Handling
- 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
Type of storage facilities

- Root cellars
- Refrigerators
- Walk-in coolers
- Drive-in coolers

Source: http://energysmartideas.com/blog/category/root-cellars/

Source: http://www.tyloon.com/images/content/business/gallery/37.jpg

Source: http://www.manchesterwholesale.com/cooler.htm
Root Cellar 1843

- Typical inside temperature within a few degrees of ground temperature
- No temperature or humidity control
- Often labor intensive to move crops in and out

Source: http://www.stonestructures.org/html/root_cellars.html#Putnam
Root Cellars

- 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
- Access for material handling??
  - Can’t afford to hand carry crops in and out
- Drainage very important

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

- Fruit and Vegetable Storage plans – North Dakota, 1933 – 22 ft x 38 ft

Best for:
- Potatoes
- Short term root crop storage
Modern Root Cellar Concept

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

Source: http://www.selectappliance.com/exec/ce-product/tl_g20000
Walk-in / Drive-in Coolers Features

- Polyurethane insulated panels
- Insulated floor
- Cleanable material
- Lockable door latch
- Thermometer & light switch
- Refrigeration system
- Electric Vaporizer evaporates condensed water
- Environmental Controller
- Self closing door with gasket

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

- Insulation
  - Closed Cell Foam
    - 4” minimum (R-25) – 6” better (R-38)
  - Vapor barriers

- Installation
  - Easy to assemble
  - Locking cams

- Refrigeration system size
  - Field heat & cooler heat loss
  - Summer or Fall/winter use

Built-in-place Cooler

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

- 1-2" foam insulation
- Washable interior surface
- 5"+ foam insulation R-25 min.
- 1-2" foam insulation
- Floor Drain
- 2 x 6 or 2 x 8 walls
- Condenser
- Evaporator
- Rubber roof membrane (if outside)
- 1/2" plywood Exterior
- Thermal Break 1-2" foam insulation

Refer to span table for ceiling joist size
Insulation Materials

- Foam – (4” minimum – 6” better)
  - Types
    - Urethane (yellow)
    - Expanded Polystyrene (pink/blue)
  - Insulation value – R-4 to R-6.5 (5)
  - Foam in place – seals all edges
  - Rigid Board
    - Tongue & groove – tape all seams
    - Double layer with offset seams
  - Cover to protect
    - Steel / plastic corrugated sheeting
    - Fiberglass board
  - Flammable – protect from heat sources
  - No vapor barrier needed

<table>
<thead>
<tr>
<th>Foam Thickness</th>
<th>R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>19</td>
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<tr>
<td>4</td>
<td>25</td>
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<tr>
<td>5</td>
<td>31</td>
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<tr>
<td>6</td>
<td>38</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
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<tr>
<td>12</td>
<td>75</td>
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</table>
Ceiling Joist Spacing

- Assumptions
  - 50 psf combined live and dead load
  - 24 inch spacing
  - Lumber grade #2 or better SPF

<table>
<thead>
<tr>
<th>Span</th>
<th>Width (ft)</th>
<th>Joist Size (nominal)</th>
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<td>8</td>
<td></td>
<td>2 x 6</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>2 x 8</td>
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<tr>
<td>12</td>
<td></td>
<td>2 x 10</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>2 x 10</td>
</tr>
</tbody>
</table>
Vapor Barriers

- Located on warm side of wall
- Warm side changes summer to winter

Figure 4. Vapor Barrier Location and Methods of Ventilating Attics

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

Source: http://www.portablecoldstorage.com/
Controlled Atmosphere Storage (CA)

- Suppresses metabolic activity (ripening)
- Gas tight room
- Modify gases in air (78% N₂, 21% O₂ & 0.03% CO₂)
  - Low Oxygen (< 8%)
  - Elevated Carbon Dioxide (>1%)
  - Reduced temperatures
- Commercial use – Crops
  - Apples & pears
  - Cabbage
  - Nuts, kiwifruit, persimmon, pomegranate
  - Used during long distance transportation
    - Asparagus, broccoli, cane berries, figs, lettuce, muskmelons, strawberry, sweet corn, fresh cut fruits
Refrigeration System
– Direct Expansion

Figure 5. Schematic Representation of Direct Expansion Refrigeration System

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

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

- Field heat removal
  - Typically largest heat load
  - Cooler loading rate (lbs of product / hour)
  - Removal Rate limited by:
    - crop surface area
    - Product Thermal properties
      - (Specific Heat – Btu/lb-F)
    - Air/water temperature
  - Using a precoolor reduces cooling needs

- Heat load calculation
  - $Q_1 = \text{Field heat removal rate, Btu/24 hrs}$
  - $M = \text{mass of product cooled per 24 hrs, lbs}$
  - $C = \text{Specific heat of product, Btu/lb°F}$
  - $\Delta T = \text{Temperature drop of product in 24 hrs, °F}$

$$Q_1 = MCD\Delta T$$
Refrigeration Requirement

- Field heat removal
  - Largest component
  - Short duration
  - Smaller for fall harvested crops

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

Figure 8. Refrigeration Capacity Needed to Cool and Maintain 15,000 Bushels of Apples
Factors affecting field heat removal

- 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
Pre-Coolers for field heat removal

- Hydro –
  - Water bath or shower
  - Disease / pathogen transmission

Source: USDA Agricultural Handbook Number 66, 2004
Pre-Coolers for field heat removal

- Dedicated Cooling Room – too slow
  - Plenum wall
- Forced air cooling

Source: USDA Agricultural Handbook Number 66, 2004
Precooling Produce – Gast & Flores, MF-1002, Kansas State U, 1991
Air Precooling
Pre-coolers for field heat removal

- Ice pack
- Vacuum cooling –
  - causes rapid evaporation of water

Reference: Li, Changying, Precooling Fruits and Vegetables in Georgia, C-1004, 12 pgs, University of Georgia Extension, 2011

Source: USDA Agricultural Handbook Number 66, 2004
Refrigeration Sizing

- **Heat of Respiration**
  - Varies with crop and temperature
  - Higher storage temperature increases respiration

\[ Q_2 = MK \]

- **Equation**
  - \( Q_2 \) = respiration heat load, Btu/24 hrs
  - \( M \) = Mass of product cooled per 24 hrs, tons
  - \( K \) = rate of respiration heat production, Btu/24 hours-ton
    - Affected by storage temperature
# Heat of respiration table

Table 6. Heat of Respiration and Specific Heat of Fresh Fruits and Vegetables When Stored at Various Temperatures

<table>
<thead>
<tr>
<th>Commodity</th>
<th>32°F</th>
<th>40°F</th>
<th>60°F</th>
<th>70°F</th>
<th>80°F</th>
<th>Specific Heat Btu / 10°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples, summer</td>
<td>660-1,320</td>
<td>1,100-2,420</td>
<td>3,960-6,620</td>
<td>4,400-9,020</td>
<td>—</td>
<td>.87</td>
</tr>
<tr>
<td>Apples, fall</td>
<td>440-880</td>
<td>1,100-1,540</td>
<td>1,980-4,400</td>
<td>3,300-5,500</td>
<td>—</td>
<td>.97</td>
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<tr>
<td>Apricots</td>
<td>1,100-1,320</td>
<td>1,320-1,980</td>
<td>4,620-7,480</td>
<td>6,360-11,440</td>
<td>—</td>
<td>.88</td>
</tr>
<tr>
<td>Artichokes, globe</td>
<td>3,360-9,900</td>
<td>5,720-13,320</td>
<td>16,720-31,900</td>
<td>29,700-51,260</td>
<td>31,900-66,000</td>
<td>.87</td>
</tr>
<tr>
<td>Asparagus</td>
<td>5,940-17,620</td>
<td>12,100-29,920</td>
<td>35,200-71,940</td>
<td>60,500-110,000</td>
<td>110,000-132,000</td>
<td>.94</td>
</tr>
<tr>
<td>Avocados</td>
<td>—</td>
<td>4,400-6,800</td>
<td>13,640-34,540</td>
<td>16,280-76,340</td>
<td>25,980-64,160</td>
<td>.81</td>
</tr>
<tr>
<td>Bananas, green</td>
<td>—</td>
<td>—</td>
<td>4,620-5,060</td>
<td>7,260-7,700</td>
<td>—</td>
<td>.81</td>
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<tr>
<td>Bananas, ripening</td>
<td>—</td>
<td>—</td>
<td>5,500-16,500</td>
<td>7,260-31,240</td>
<td>11,000-53,900</td>
<td>—</td>
</tr>
<tr>
<td>Beans, lima</td>
<td>2,200-6,800</td>
<td>4,400-7,920</td>
<td>22,000-27,500</td>
<td>28,260-39,380</td>
<td>—</td>
<td>.73</td>
</tr>
<tr>
<td>Beans, snap</td>
<td>4,400</td>
<td>7,700</td>
<td>20,480</td>
<td>26,600</td>
<td>42,480</td>
<td>.91</td>
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<tr>
<td>Bean sprouts</td>
<td>4,820-6,500</td>
<td>9,240</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>.91</td>
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<tr>
<td>Beets, topped</td>
<td>1,100-1,540</td>
<td>1,980-2,200</td>
<td>3,740-5,060</td>
<td>—</td>
<td>—</td>
<td>.90</td>
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<tr>
<td>Beets, with leaves</td>
<td>2,420</td>
<td>3,080</td>
<td>5,500</td>
<td>6,800</td>
<td>—</td>
<td>—</td>
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<tr>
<td>Berries:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blackberries</td>
<td>3,960-4,400</td>
<td>6,620-9,020</td>
<td>16,500</td>
<td>34,100</td>
<td>—</td>
<td>.88</td>
</tr>
<tr>
<td>Blueberries</td>
<td>440-2,200</td>
<td>1,980-2,840</td>
<td>7,480-13,840</td>
<td>11,440-19,140</td>
<td>17,160-27,280</td>
<td>.86</td>
</tr>
<tr>
<td>Cranberries</td>
<td>—</td>
<td>860-1,100</td>
<td>—</td>
<td>2,420-3,960</td>
<td>—</td>
<td>.90</td>
</tr>
<tr>
<td>Gooseberries</td>
<td>1,100-1,540</td>
<td>1,780-3,520</td>
<td>5,940-15,180</td>
<td>9,020-23,100</td>
<td>—</td>
<td>.91</td>
</tr>
<tr>
<td>Raspberries</td>
<td>3,960-5,500</td>
<td>6,820-8,580</td>
<td>18,040-22,220</td>
<td>—</td>
<td>—</td>
<td>.86</td>
</tr>
<tr>
<td>Strawberries</td>
<td>2,840-2,960</td>
<td>3,520-5,060</td>
<td>15,520-20,240</td>
<td>22,440-43,120</td>
<td>37,180-46,420</td>
<td>.92</td>
</tr>
<tr>
<td>Broccoli</td>
<td>4,180-4,620</td>
<td>7,040-8,140</td>
<td>35,420-40,920</td>
<td>61,180-70,400</td>
<td>—</td>
<td>.92</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td>2,200-6,600</td>
<td>4,840-10,560</td>
<td>14,092-29,920</td>
<td>18,920-41,800</td>
<td>—</td>
<td>.86</td>
</tr>
<tr>
<td>Cabbage</td>
<td>880-1,320</td>
<td>1,980-2,840</td>
<td>4,400-7,040</td>
<td>6,160-10,780</td>
<td>10,780-13,860</td>
<td>.94</td>
</tr>
<tr>
<td>Carrots, topped</td>
<td>2,200-4,400</td>
<td>2,680-5,720</td>
<td>5,720-11,880</td>
<td>10,120-20,900</td>
<td>—</td>
<td>.91</td>
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<tr>
<td>Carrots, bunched</td>
<td>3,960-7,700</td>
<td>5,500-11,220</td>
<td>12,100-23,320</td>
<td>19,140-26,620</td>
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<tr>
<td>Cauliflower</td>
<td>3,520-4,180</td>
<td>4,180-4,840</td>
<td>9,460-10,780</td>
<td>16,500-18,920</td>
<td>18,480-30,300</td>
<td>.93</td>
</tr>
</tbody>
</table>

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

- Conductive Heat Gain
  - Temperature difference across cooler walls, ceiling, floors
  - Insulation value of walls, ceiling, floors
  - Total surface area

\[ Q_3 = 24 \frac{A(T_o - T_i)}{R} \]

- Heat Gain (loss) Equation
  - \( Q_3 \) = conductive heat gain (loss), Btu/24 hrs
  - \( A \) = area of floor, wall or ceiling, ft\(^2\)
  - \( T_o \) = Outside temperature, °F
  - \( T_i \) = Inside temperature, °F
  - \( R \) = R-value of respective component (hr ft\(^2\) °F)/Btu
  - Each component (wall, ceiling, floor) is calculated separately then added together
Refrigeration Sizing

- Convection Heat Gain
  - Heat gain (loss) from outside entering cold storage environment
  - Opening of door / planned venting

\[ Q_4 = (h_o - h_i)V \frac{N}{13.5} \]

- Heat Gain Equation
  - \( Q_4 \) = Convective heat gain, Btu / 24 hr
  - \( H_o \) = enthalpy (heat content) of outside air, Btu/lb.
  - \( H_i \) = enthalpy (heat content) of inside air, Btu/lb.
  - \( V \) = volume of empty cold storage, cubic feet
  - \( N \) = number of air changes per 24 hrs
  - 13.5 – an average value for the specific volume of outside air, cu ft / lb.
# Average Air Changes Per 24 HR. For Storage Rooms Due to Door Openings and Infiltration

<table>
<thead>
<tr>
<th>Volume cu. ft.</th>
<th>Air Changes per 24 hr.</th>
<th>Volume cu. ft.</th>
<th>Air Changes per 24 hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Above 32 F</td>
<td>Below 32 F</td>
<td>Above 32 F</td>
</tr>
<tr>
<td>200</td>
<td>44.0</td>
<td>33.5</td>
<td>6,000</td>
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<tr>
<td>300</td>
<td>34.5</td>
<td>26.2</td>
<td>8,000</td>
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<tr>
<td>400</td>
<td>29.5</td>
<td>22.5</td>
<td>10,000</td>
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<tr>
<td>500</td>
<td>26.0</td>
<td>20.0</td>
<td>15,000</td>
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<tr>
<td>600</td>
<td>23.0</td>
<td>18.0</td>
<td>20,000</td>
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<tr>
<td>800</td>
<td>20.0</td>
<td>15.3</td>
<td>25,000</td>
</tr>
<tr>
<td>1,000</td>
<td>17.5</td>
<td>13.5</td>
<td>30,000</td>
</tr>
<tr>
<td>1,500</td>
<td>14.0</td>
<td>11.0</td>
<td>40,000</td>
</tr>
<tr>
<td>2,000</td>
<td>12.0</td>
<td>9.3</td>
<td>50,000</td>
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<tr>
<td>3,000</td>
<td>9.5</td>
<td>7.4</td>
<td>75,000</td>
</tr>
<tr>
<td>4,000</td>
<td>8.2</td>
<td>6.3</td>
<td>100,000</td>
</tr>
<tr>
<td>5,000</td>
<td>7.2</td>
<td>5.6</td>
<td></td>
</tr>
</tbody>
</table>

Note: For heavy usage multiply the above values by 2.

Source: http://www.industrialcontrolsonline.com/training/online/refrigeration-load-sizing-walk-coolers-freezers-other-boxes
Refrigeration Sizing

- In-cooler Equipment Heat Load
  - Lights, Motors
  - Heaters / Defroster
  - Fork truck
  - People

\[ Q_5 = (kW \times 3430) \times tl + (Hp \times 2545) \times tm \]

- Equation heat gain
  - \( Q_5 \) = heat produced by equipment, Btu/24 hrs
  - kWh = kilowatt total for electric lights
  - Hp = horsepower total for motors
  - tl, tm = total hours of operation per day for lights and motors, respectively.
Refrigeration Sizing

- Total refrigeration requirement
  - Use maximum (worth case) values for each
    \[ Q_t = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 \]

- Capacity of refrigeration system
  \[ \text{Capacity} = Q_t \times SF \times DF / (16 \text{ to } 24 \text{ hrs}) \]
  - 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
## Compressor Capacity Recommendation for Small Coolers

<table>
<thead>
<tr>
<th>Dimensions (feet)</th>
<th>Volume (cubic feet)</th>
<th>Cooling Load (Btu/hr)</th>
<th>Compressor Size (Hp²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6x6x9</td>
<td>324</td>
<td>2,800</td>
<td>0.50</td>
</tr>
<tr>
<td>6x12x9</td>
<td>648</td>
<td>4,500</td>
<td>0.75</td>
</tr>
<tr>
<td>8x8x9</td>
<td>576</td>
<td>4,100</td>
<td>0.75</td>
</tr>
<tr>
<td>8x12x9</td>
<td>864</td>
<td>5,500</td>
<td>0.75</td>
</tr>
<tr>
<td>8x16x9</td>
<td>1152</td>
<td>7,100</td>
<td>1.00</td>
</tr>
<tr>
<td>10x10x9</td>
<td>900</td>
<td>5,600</td>
<td>0.75</td>
</tr>
<tr>
<td>10x15x9</td>
<td>1350</td>
<td>7,900</td>
<td>1.50</td>
</tr>
<tr>
<td>12x12x9</td>
<td>1296</td>
<td>7,700</td>
<td>1.00</td>
</tr>
<tr>
<td>12x20x9</td>
<td>2160</td>
<td>9,800</td>
<td>1.50</td>
</tr>
<tr>
<td>20x20x9</td>
<td>3600</td>
<td>15,800</td>
<td>3.00</td>
</tr>
</tbody>
</table>

¹Based on Prefabricated cooler data with R-30 box insulation, 35°F inside and 90°F outside temperature.
²Nearest fractional horsepower matched to cooling load times a service factor of 1.5.

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

- CoolBot™ Controller
  - Over-rides standard window air conditioner controls
  - Cooling capacity less than rating at lower temps
  - Maybe lower capacity than require for field heat removal
  - Multiply units may be needed

- All-in One Refrigeration units
  - Plug and Play – no Refrigeration tech needed
  - Higher / known capacity
  - Circulating fan
  - Roof top or side-mount / inside or outside
  - Warranty
Refrigeration System

- **Compressors**
  - Reciprocating compressors – older technology
  - Scroll Compressors
    - 15-20% higher efficiency
    - Cost about the same
    - Energy Efficiency Grants available??

- **Maintenance**
  - Clean Condenser units – 1 to 2X per year
    - Degreaser and rinse
  - Annual Service
    - Check refrigerant level
    - Check for leaks, operation of fans, thermostatic control
Environmental Controls

- Temperature
- Humidification
- Respiration gases
- Fresh air / outside air
- Internal Air circulation
- Refrigeration
  - Defrost

Source: http://www.bartinst.com/GREENHOUSE/ghk12x2c.html
Temperature Ranges for crops

- **Cold & Wet**
  - Beets, cabbage, carrots, turnips, parsnips
  - 32F & RH 95%+

- **Cold & Dry**
  - Onions / Garlic - 32F & RH 65-70%

- **Cool & Wet**
  - Potatoes - 40-50F & RH 95%

- **Warm & Dry**
  - Winter Squash - 50-55F & RH 50-70%
  - Sweet Potatoes - 55-60F & RH 80-85%
### Table 1. Fruits & Vegetables that require cold, moist conditions

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Temperature (°F)</th>
<th>Relative Humidity (%)</th>
<th>Length of Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asparagus</td>
<td>32-36</td>
<td>95</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Apples</td>
<td>32</td>
<td>95</td>
<td>2-6 months</td>
</tr>
<tr>
<td>Beets</td>
<td>32</td>
<td>95</td>
<td>3-5 months</td>
</tr>
<tr>
<td>Broccoli</td>
<td>32</td>
<td>95</td>
<td>10-14 days</td>
</tr>
<tr>
<td>Brussels Sprouts</td>
<td>32</td>
<td>95</td>
<td>4-6 weeks</td>
</tr>
<tr>
<td>Cabbage, Early</td>
<td>32</td>
<td>95</td>
<td>1-2 months</td>
</tr>
<tr>
<td>Cabbage, Late</td>
<td>32</td>
<td>95</td>
<td>3-4 months</td>
</tr>
<tr>
<td>Cabbage, Chinese</td>
<td>32</td>
<td>95</td>
<td>3-6 weeks</td>
</tr>
<tr>
<td>Carrots, mature</td>
<td>32</td>
<td>95</td>
<td>4-5 months</td>
</tr>
<tr>
<td>Carrots, immature</td>
<td>32</td>
<td>95</td>
<td>4-6 weeks</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>32</td>
<td>95</td>
<td>2-4 weeks</td>
</tr>
<tr>
<td>Celeriac</td>
<td>32</td>
<td>95</td>
<td>3-4 months</td>
</tr>
<tr>
<td>Celery</td>
<td>32</td>
<td>95</td>
<td>2-3 months</td>
</tr>
<tr>
<td>Collards</td>
<td>32</td>
<td>95</td>
<td>4-5 weeks</td>
</tr>
<tr>
<td>Corn, sweet</td>
<td>32</td>
<td>95</td>
<td>2-6 days</td>
</tr>
<tr>
<td>Endive, Escarole</td>
<td>32</td>
<td>95</td>
<td>6-8 days</td>
</tr>
<tr>
<td>Grapes</td>
<td>32</td>
<td>95</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Kale</td>
<td>32</td>
<td>95</td>
<td>1-2 months</td>
</tr>
<tr>
<td>Leeks, green</td>
<td>32</td>
<td>95</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Lettuce</td>
<td>32</td>
<td>95</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Parsley</td>
<td>32</td>
<td>95</td>
<td>2-6 months</td>
</tr>
<tr>
<td>Parsnips</td>
<td>32</td>
<td>95</td>
<td>2-6 months</td>
</tr>
<tr>
<td>Pears</td>
<td>32</td>
<td>95</td>
<td>2-7 months</td>
</tr>
<tr>
<td>Peas, green</td>
<td>32</td>
<td>95</td>
<td>1-3 weeks</td>
</tr>
<tr>
<td>Potatoes, early</td>
<td>50</td>
<td>90</td>
<td>3-4 months</td>
</tr>
<tr>
<td>Potatoes, late</td>
<td>39</td>
<td>90</td>
<td>4-9 months</td>
</tr>
<tr>
<td>Radishes, spring</td>
<td>32</td>
<td>95</td>
<td>1-2 weeks</td>
</tr>
<tr>
<td>Radishes, winter</td>
<td>32</td>
<td>95</td>
<td>2-4 months</td>
</tr>
<tr>
<td>Rhubarb</td>
<td>32</td>
<td>95</td>
<td>2-4 weeks</td>
</tr>
<tr>
<td>Rutabagas</td>
<td>32</td>
<td>95</td>
<td>2-4 months</td>
</tr>
<tr>
<td>Spinach</td>
<td>32</td>
<td>95</td>
<td>1-2 weeks</td>
</tr>
</tbody>
</table>

### Table 2. Vegetables that require cool, moist conditions

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Temperature (°F)</th>
<th>Relative Humidity (%)</th>
<th>Length of Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beans, snap</td>
<td>40-50</td>
<td>95</td>
<td>7-10 days</td>
</tr>
<tr>
<td>Cucumbers</td>
<td>45-50</td>
<td>95</td>
<td>10-14 days</td>
</tr>
<tr>
<td>Eggplant</td>
<td>45-50</td>
<td>90</td>
<td>1 week</td>
</tr>
<tr>
<td>Carrots, ripe</td>
<td>40</td>
<td>90</td>
<td>15 days</td>
</tr>
<tr>
<td>Watermelon</td>
<td>40-50</td>
<td>80-95</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Peppers, sweet</td>
<td>45-50</td>
<td>95</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Potatoes, early</td>
<td>50</td>
<td>90</td>
<td>1-3 weeks</td>
</tr>
<tr>
<td>Potatoes, late</td>
<td>40</td>
<td>90</td>
<td>4-9 months</td>
</tr>
<tr>
<td>Tomatoes, green</td>
<td>50-70</td>
<td>90</td>
<td>1-3 weeks</td>
</tr>
<tr>
<td>Tomatoes, ripe</td>
<td>45-50</td>
<td>90</td>
<td>4-7 days</td>
</tr>
</tbody>
</table>

### Table 3. Vegetables that require cool dry conditions

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Temperature (°F)</th>
<th>Relative Humidity (%)</th>
<th>Length of Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garlic</td>
<td>32</td>
<td>65-70</td>
<td>6-7 months</td>
</tr>
<tr>
<td>Onions</td>
<td>32</td>
<td>65-70</td>
<td>6-7 months</td>
</tr>
</tbody>
</table>

### Table 4. Vegetables that require warm dry conditions

<table>
<thead>
<tr>
<th>Vegetable</th>
<th>Temperature (°F)</th>
<th>Relative Humidity (%)</th>
<th>Length of Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peppers, hot</td>
<td>50</td>
<td>60-70</td>
<td>6 months</td>
</tr>
<tr>
<td>Pumpkins</td>
<td>50-55</td>
<td>70-75</td>
<td>2-3 months</td>
</tr>
<tr>
<td>Squash, winter</td>
<td>50-55</td>
<td>50-60</td>
<td>2-6 months</td>
</tr>
<tr>
<td>Sweet Potato</td>
<td>55-60</td>
<td>80-85</td>
<td>4-6 months</td>
</tr>
<tr>
<td>Products</td>
<td>Effects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apples or Pears with</td>
<td>Ethylene from apples and pears damages or causes off flavors in vegetables. Potatoes cause &quot;earthy&quot; flavor in fruit. Potatoes are injured by cold temperatures. High humidity causes root growth in onions. Ethylene causes bitterness in carrots.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Celery with Onions or Carrots</td>
<td>Odor transfer occurs between products.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meat Eggs Dairy with</td>
<td>Fruit flavors are taken up by the meat, eggs, and dairy products.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leafy Greens and Flowers with</td>
<td>Ethylene produced by the fruit crops damages greens and flowers.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucumbers Peppers and Green Squash with</td>
<td>Ethylene from tomatoes, apples, and pears causes loss of green color. This is aggravated by storage temperatures of 45-50°F which are too warm for apples and pears.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Modified from Hardenburg et. al. (1986).
Humidity control

- Add moisture to air to reduce crop moisture loss
- Evaporative cooler pad
- Atomizer
- Misting
  - No water on crops
- Pack in Plastic bag
- Pack crops in damp sand or sawdust

Source: http://ivi-air.com/
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 $130 - $500
Centrifugal Humidifier

- Utilities: Electric & Water
Humidity Control

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

<table>
<thead>
<tr>
<th>Temperature Drop²</th>
<th>Storeroom Temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Across Evaporator, °F</td>
<td>32°F</td>
</tr>
<tr>
<td>-1°F</td>
<td>95.8</td>
</tr>
<tr>
<td>-2°F</td>
<td>91.2</td>
</tr>
<tr>
<td>-3°F</td>
<td>87.1</td>
</tr>
<tr>
<td>-4°F</td>
<td>83.0</td>
</tr>
<tr>
<td>-5°F</td>
<td>79.4</td>
</tr>
<tr>
<td>-10°F</td>
<td>62.7</td>
</tr>
<tr>
<td>-15°F</td>
<td>49.3</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.

Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22
Outdoor Air Cooling

- Fall - use cool night air to reduce refrigeration
- Exchange air
- Controls
  - Manual
  - Automatic
    - Temperature
    - Time of day
- Disadvantage
  - Loss of humidity
  - Colder air is dryer
Outside Air Cooling
Food Farm, Wrenshall, MN

August 1-9, 2002

November 1-9, 2002

January 1-8, 2004

April 2002
Air Flow/Ventilation Patterns

Figure 12: Bulk Storage with Ceiling-Mounted Evaporator Fan
Cold storage
– wall & ceiling clearance

- 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
Air Flow/Ventilation

- Poly tube ventilation
  - Aids in air distribution
  - Helps control condensation
  - Distribute fresh air
- Horizontal Flow fans
  - Keeps air circulating when refrigeration is not running
  - Can use Evaporator fans
- Add Heat
Air Flow Capacity

- Field heat removal / Precooling
  - 100 cfm* per ton of product

- Long Term storage
  - 10-40 cfm per ton of product
    - Crop dependent
  - Use only enough air flow to maintain uniform temperature in storage
    - Typically 1°F difference
  - Variable speed controlled fans to adjust air flow

* Cubic Feet per minute
Lighting

- Wiring must meet National Electric Code
  - Wet environment – Conduit
  - Vapor-proof fixtures
  - 10 foot candles minimum
  - 50 foot candles for inspection/sorting

- Lamp Types
  - T8 fluorescent – Ok
  - LED Tube light - Best
Material Handling

- Bulk
- Pallet Containers
- Tot Boxes
- Racking
- Material Handling equipment
- Traffic flow
Pallet Bins

- Materials:
  - Wood – repairable, heavier, absorb moisture
  - Plastic – FDA approved plastic, easily sanitized
- Rated for loading
- Stackable
- Covers available
- Vented sides / bottom
  - Minimum 8-11% of bottom open
- Handle with Fork Truck or Pallet Jack
- Fit standard racking
Small storage bins

- Stackable
- Plastic – easy to sanitize
- Wood - Repairable
- Durable
- Vented or solid sides
- Vented or drain holes in bottom
- Hand holes
- Lids – micro-environments
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

Source: http://ervojic.hr/images/uploads/paletni-regali-velika.jpg
http://www.ancostorage.co.uk/acatalog/Kwick_Rack.html
http://www.martforcarts.com/carts/3.html
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 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
Layout Issues

- Door location doesn’t allow maximum number of containers
Layout Issues

- Door location
- Allows last container to go straight in.
Layout for accessibility

- Aisle Space inside cooler expensive
- Going up cheaper than bigger foot print
Layout for accessibility

- Add doors to reduce aisle space inside cooler
Layout for accessibility

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

- Add doors to reduce aisle space inside cooler
- Small goods and Bulk area

Third Door for First in – First Out
Layout for accessibility

- Small quantities / fragile goods / packed produces
Planning!!

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

From Field — Wash — Bulk Bins — Long-Term Storage

- 34°F @ 95% RH

- Packing 5# mesh bags

- Sort by size A & B

- Culls – Food-bank / Compost Pile

- Food Bank

- Compost

Truck to Market

Short-term Storage
Building Layout

- Ramp to Fields
- Loading Dock
- Lunch Rm / Employee Lockers
- Bath / Shower Room
- Office
- Work Alleys
- Belt washer
- Hydro-Cooler
- Sorting equipment
- Packing Line
- Supply Storage Racks
- Cooler #1
- Cooler Access Alley
- Cooler #2
- Cooler #3
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, swt potato)

- **12 x 12 cooler:**
  - $8,000-$9000 (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.
  - Storage units in unheated building/outside during winter require supplemental heating!
## Utility Cost Estimates

### Madison, WI (12’ x 12’ x 9’)

<table>
<thead>
<tr>
<th>Heating (Btu/mo)</th>
<th>kWh/mo</th>
<th>Heat cost</th>
<th>Refrigeration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating (Btu/mo)</td>
<td>kWh/mo</td>
<td>Cooling (Btu/mo)</td>
<td>kWh/mo</td>
</tr>
<tr>
<td>January</td>
<td>220606</td>
<td>68</td>
<td>935570</td>
</tr>
<tr>
<td>February</td>
<td>107586</td>
<td>33</td>
<td>998719</td>
</tr>
<tr>
<td>March</td>
<td>0</td>
<td>0</td>
<td>1396363</td>
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<tr>
<td>April</td>
<td>0</td>
<td>0</td>
<td>1888260</td>
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<tr>
<td>May</td>
<td>0</td>
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<td>2487550</td>
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<td>June</td>
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<td>2768388</td>
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<td>July</td>
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<td>August</td>
<td>0</td>
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<td>2821733</td>
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<tr>
<td>September</td>
<td>0</td>
<td>0</td>
<td>2491730</td>
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<td>October</td>
<td>0</td>
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<td>November</td>
<td>0</td>
<td>0</td>
<td>1538737</td>
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<tr>
<td>December</td>
<td>115122</td>
<td>36</td>
<td>1090925</td>
</tr>
<tr>
<td>Yearly heat loss</td>
<td>443313</td>
<td>137</td>
<td>23659027</td>
</tr>
</tbody>
</table>

| Est. Yearly Electric Use | 6089 kWh |
| Est. Yearly Electric Cost | $609    |
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
## Storage Crop Case Studies

<table>
<thead>
<tr>
<th></th>
<th>Farm A</th>
<th>Farm B</th>
<th>Farm C</th>
<th>Farm D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cubic Feet of Storage Space</strong></td>
<td>812</td>
<td>6,000</td>
<td>17,374</td>
<td>22,400</td>
</tr>
<tr>
<td><strong>Crops</strong></td>
<td>Roots, Alliums, Squash, Cabbage, Sweet Potatoes</td>
<td>Roots, Alliums, Squash, Cabbage</td>
<td>Roots, Cabbage, Alliums, Squash, Sweet Potatoes</td>
<td>Cabbage, Carrots, Butternut</td>
</tr>
<tr>
<td><strong>Winter Labor</strong></td>
<td>Owner (2-4 hrs / wk)</td>
<td>Owner + 1 part-time (30 hrs / wk)</td>
<td>Owner + 5.5 (80-90 hrs / wk)</td>
<td>Owner + 8 (280 hrs / wk)</td>
</tr>
<tr>
<td><strong>Markets</strong></td>
<td>CSA (Direct Wholesale)</td>
<td>Direct Wholesale CSA and (f. mkts)</td>
<td>Direct Wholesale Distributor &amp; (CSA)</td>
<td>Direct Wholesale (CSA)</td>
</tr>
<tr>
<td><strong>Gross Sales</strong></td>
<td>$14,400</td>
<td>$85,000</td>
<td>$136,000</td>
<td>$250,000</td>
</tr>
<tr>
<td><strong>Gross / cubic ft</strong></td>
<td>$18</td>
<td>$14</td>
<td>$8</td>
<td>$11</td>
</tr>
</tbody>
</table>
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
Resources

  http://learningstore.uwex.edu/Assets/pdfs/A3823.pdf
  http://www.gardening.cornell.edu/factsheets/vegetables/storage.pdf
- Fruit & Vegetable Post Harvest & Storage Information – Website with data sheets on crops from Ambarella to Zinnia.  
  http://www.postharvest.com.au/Produce_Information.htm
- Wilhoit, 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
- Bubel, Mike & Nancy, Root Cellaring, 2nd Ed, Storey, Pownal, VT, 1991
Questions??

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