On-Farm Cold Storage Facilities

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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
- 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
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

Source: http://www.selectappliance.com/exec.ce-product/tl_g20000
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.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
  - Fiberglass / plastic / 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)
  - Types
    - Urethane (yellow)
    - Expanded Polystyrene (pink/blue)
  - Insulation value – R-4 to R-6.5
  - 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:

<table>
<thead>
<tr>
<th>Foam Thickness</th>
<th>R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>19</td>
</tr>
<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>
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<tr>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
</tr>
<tr>
<td>12</td>
<td>75</td>
</tr>
</tbody>
</table>
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

Figure 5. Schematic Representation of Direct Expansion Refrigeration System

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

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

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

- Hydro-cooling – Water bath
- Forced air cooling
- Ice Pack
- Vacuum Cooling
## 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>50°F</th>
<th>60°F</th>
<th>70°F</th>
<th>80°F</th>
<th>Specific Heat Dtu / lb°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples, summer</td>
<td>660-1,520</td>
<td>1,100-2,420</td>
<td>3,960-6,820</td>
<td>4,400-9,020</td>
<td>—</td>
<td>—</td>
<td>.87</td>
</tr>
<tr>
<td>Apples, fall</td>
<td>440-680</td>
<td>1,100-1,540</td>
<td>1,960-4,400</td>
<td>3,300-5,520</td>
<td>—</td>
<td>—</td>
<td>.87</td>
</tr>
<tr>
<td>Apricots</td>
<td>1,100-1,320</td>
<td>1,320-1,980</td>
<td>4,620-7,480</td>
<td>6,380-11,440</td>
<td>—</td>
<td>—</td>
<td>.88</td>
</tr>
<tr>
<td>Artichokes, globe</td>
<td>3,300-9,900</td>
<td>5,720-13,320</td>
<td>16,720-31,900</td>
<td>29,700-51,260</td>
<td>31,800-66,000</td>
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<td>.87</td>
</tr>
<tr>
<td>Asparagus</td>
<td>5,940-17,600</td>
<td>12,100-29,320</td>
<td>35,200-71,940</td>
<td>60,500-110,000</td>
<td>110,000-192,000</td>
<td>—</td>
<td>.94</td>
</tr>
<tr>
<td>Avocados</td>
<td>—</td>
<td>4,400-6,600</td>
<td>13,640-34,540</td>
<td>16,280-37,140</td>
<td>25,960-54,160</td>
<td>—</td>
<td>.91</td>
</tr>
<tr>
<td>Bananas, green</td>
<td>—</td>
<td>—</td>
<td>4,600-5,060</td>
<td>7,260-7,700</td>
<td>—</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>11,000-53,000</td>
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</tr>
<tr>
<td>Beans, lima</td>
<td>2,200-6,600</td>
<td>4,400-7,920</td>
<td>22,000-27,500</td>
<td>29,260-39,980</td>
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<td>.79</td>
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<tr>
<td>Beans, snap</td>
<td>4,400</td>
<td>7,700</td>
<td>20,450</td>
<td>26,600</td>
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<tr>
<td>Bean sprouts</td>
<td>4,620-5,500</td>
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<td>—</td>
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</tr>
<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>—</td>
<td>.90</td>
</tr>
<tr>
<td>Beets, with leaves</td>
<td>2,420</td>
<td>3,060</td>
<td>5,500</td>
<td>8,600</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Berries:</td>
<td></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>15,500</td>
<td>34,100</td>
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<td>.88</td>
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<tr>
<td>Blueberries</td>
<td>440-2,200</td>
<td>1,580-2,640</td>
<td>7,480-13,340</td>
<td>11,440-18,140</td>
<td>17,160-27,230</td>
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<td>.65</td>
</tr>
<tr>
<td>Cranberries</td>
<td>—</td>
<td>880-1,100</td>
<td>—</td>
<td>2,420-3,960</td>
<td>—</td>
<td>—</td>
<td>.90</td>
</tr>
<tr>
<td>Gooseberries</td>
<td>1,100-1,540</td>
<td>1,760-3,520</td>
<td>5,940-15,180</td>
<td>9,020-23,100</td>
<td>—</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>
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<td>.76</td>
</tr>
<tr>
<td>Strawberries</td>
<td>2,640-3,960</td>
<td>3,520-5,060</td>
<td>15,820-20,240</td>
<td>22,440-45,120</td>
<td>37,180-46,240</td>
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<tr>
<td>Broccoli</td>
<td>4,180-4,620</td>
<td>7,040-8,140</td>
<td>35,420-49,920</td>
<td>61,160-70,400</td>
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<td>—</td>
<td>.92</td>
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<tr>
<td>Brussels sprouts</td>
<td>2,200-6,600</td>
<td>4,840-10,560</td>
<td>14,060-29,620</td>
<td>18,920-41,800</td>
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<td>—</td>
<td>.88</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>
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<td>.94</td>
</tr>
<tr>
<td>Carrots, topped</td>
<td>2,250-4,400</td>
<td>2,860-5,720</td>
<td>5,720-11,880</td>
<td>10,120-20,900</td>
<td>—</td>
<td>—</td>
<td>.91</td>
</tr>
<tr>
<td>Carrots, bunched</td>
<td>3,360-7,700</td>
<td>5,500-11,220</td>
<td>12,100-23,220</td>
<td>19,140-36,620</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cauliflower</td>
<td>3,520-4,180</td>
<td>4,180-4,840</td>
<td>9,460-10,750</td>
<td>15,500-18,920</td>
<td>18,480-30,800</td>
<td>—</td>
<td>.93</td>
</tr>
</tbody>
</table>

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

- Total refrigeration requirement
  - Use maximum (worth 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
## 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

- **Self-Contained Refrigeration unit**
  - Condenser, compressor & evaporator – one unit
  - Plug and Play – no Refrigeration tech needed
  - Higher / known capacity
  - Circulating fan
  - Roof top or side-mount
  - Inside or outside
  - Warranty
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>90</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>3-5 weeks</td>
</tr>
<tr>
<td>Cabbage, Early</td>
<td>32</td>
<td>95</td>
<td>3-6 weeks</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>1-2 months</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>Celery</td>
<td>32</td>
<td>95</td>
<td>3-4 months</td>
</tr>
<tr>
<td>Collards</td>
<td>32</td>
<td>95</td>
<td>2-3 months</td>
</tr>
<tr>
<td>Corn, sweet</td>
<td>32</td>
<td>95</td>
<td>10-14 days</td>
</tr>
<tr>
<td>Endive, Escarole</td>
<td>32</td>
<td>95</td>
<td>3-6 weeks</td>
</tr>
<tr>
<td>Grapes</td>
<td>32</td>
<td>95</td>
<td>4-6 weeks</td>
</tr>
<tr>
<td>Kale</td>
<td>32</td>
<td>95</td>
<td>10-14 days</td>
</tr>
<tr>
<td>Leeks, green</td>
<td>32</td>
<td>95</td>
<td>1-3 months</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>1-2 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>1-3 weeks</td>
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<tr>
<td>Potatoes, late</td>
<td>39</td>
<td>90</td>
<td>4-9 months</td>
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<tr>
<td>Radishes, spring</td>
<td>32</td>
<td>95</td>
<td>3-4 weeks</td>
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<tr>
<td>Radishes, winter</td>
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<td>95</td>
<td>2-4 months</td>
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<tr>
<td>Rhubarb</td>
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<td>95</td>
<td>2-4 weeks</td>
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<tr>
<td>Rutabagas</td>
<td>32</td>
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<td>2-4 months</td>
</tr>
<tr>
<td>Spinach</td>
<td>32</td>
<td>95</td>
<td>10-14 days</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>Cantaloupe</td>
<td>40</td>
<td>95</td>
<td>15 days</td>
</tr>
<tr>
<td>Watermelon</td>
<td>40-50</td>
<td>80-85</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>60-65</td>
<td>6 months</td>
</tr>
<tr>
<td>Pumpkins</td>
<td>50-85</td>
<td>70-75</td>
<td>2-3 months</td>
</tr>
<tr>
<td>Squash, winter</td>
<td>50-85</td>
<td>50-90</td>
<td>2-6 months</td>
</tr>
<tr>
<td>Sweet Potato</td>
<td>55-60</td>
<td>50-85</td>
<td>4-6 months</td>
</tr>
</tbody>
</table>
### Table 2.3 Products which are incompatible in long-term storage.

<table>
<thead>
<tr>
<th>Products</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples or Pears</td>
<td>Ethylene from apples and pears damages or causes off flavors in vegetables.</td>
</tr>
<tr>
<td>or Pears</td>
<td>Potatoes cause &quot;earthy&quot; flavor in fruit.</td>
</tr>
<tr>
<td>with</td>
<td>Potatoes are injured by cold temperatures.</td>
</tr>
<tr>
<td>Celery</td>
<td>High humidity causes root growth in onions.</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Ethylene causes bitterness in carrots.</td>
</tr>
<tr>
<td>Carrots</td>
<td></td>
</tr>
<tr>
<td>Potatoes</td>
<td></td>
</tr>
<tr>
<td>Onions</td>
<td></td>
</tr>
<tr>
<td>Onions or Carrots</td>
<td></td>
</tr>
<tr>
<td>Meat Eggs Dairy</td>
<td>Odor transfer occurs between products.</td>
</tr>
<tr>
<td>with</td>
<td></td>
</tr>
<tr>
<td>Apples and Citrus</td>
<td>Fruit flavors are taken up by the meat, eggs, and dairy products.</td>
</tr>
<tr>
<td>Leafy Greens and Flowers</td>
<td>Ethylene produced by the fruit crops damages greens and flowers.</td>
</tr>
<tr>
<td>with</td>
<td></td>
</tr>
<tr>
<td>Apples Pears Peaches Tomatoes and Cantaloupe</td>
<td>Ethylene from tomatoes, apples, and pears causes loss of green color.</td>
</tr>
<tr>
<td>Cucumbers Peppers and Green Squash</td>
<td>This is aggravated by storage temperatures of 45-50°F which are too warm for apples and pears.</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**
Humidity Control

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

Table 3. Minimum Relative Humidity Levels\(^1\) Developed at Various Storage and Evaporator Discharge Temperatures

<table>
<thead>
<tr>
<th>Temperature Drop(^2) Across Evaporator, °F</th>
<th>Storeroom Temperature, °F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>32°</td>
</tr>
<tr>
<td>-1°</td>
<td>95.8</td>
</tr>
<tr>
<td>-2°</td>
<td>91.2</td>
</tr>
<tr>
<td>-3°</td>
<td>87.1</td>
</tr>
<tr>
<td>-4°</td>
<td>83.0</td>
</tr>
<tr>
<td>-5°</td>
<td>79.4</td>
</tr>
<tr>
<td>-10°</td>
<td>62.7</td>
</tr>
<tr>
<td>-15°</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 to reduce refrigeration

- Exchange air
- Controls
  - Manual
  - Automatic
    - Temperature
    - Time of day
- Disadvantage
  - Loss of humidity
  - Colder air is dryer

![Graphs showing temperature trends for different times and conditions](image)
Air Flow/Ventilation Patterns

Figure 12. Bulk Storage with Ceiling-Mounted Evaporator Fan
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 & Tots

- **Materials:**
  - Wood – heavier, absorb moisture, repairable
  - Plastic – FDA approved, easily sanitized, repairable?
- **Rated for loading**
- **Stackable (without lid)**
- **Vented / solid sides / bottom**
  - Minimum 8-11% of bottom open
- **Handle with Fork Truck or Pallet Jack**
- **Fit standard racking**
- **Hand holes**
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


Source: http://www.beechhandlingservices.co.uk/
http://www.prestolifts.com/stuff/contentmgr/files/
f243d69b64cf66fa30c5f6092fcb8ec/misc/pallet_stacker.jpg
Layout Issues – Door Location

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

- Allows last container to go straight in.
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
  - Temperature
- Labor
- Future Expansion

Diagram:
- Packing
- Cleaning
- Produce from Fields
- Employee space
- Storage
- Office

Diagram compartments:
- Cleaning
- Packing
- Produce from Fields
- Employee space
- Storage
- Office
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
- Short-term Storage
  - Food Bank
- Culls – Food-bank / Compost Pile
  - Food Bank
  - Compost
- Truck to Market
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) – 5 to 40%
- Labor costs (benefits)
- Markets and Pricing
  - 20% higher costs
  - Handling/storage
- Risk and rewards
  - Cash flow during normally low period
Storage Facility Capital Cost

- Multiple units may be needed if you plan to store different products
- **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)
- Electric costs to run cooler:
  - $2 to $4 per day.
  - Supplemental heating required
    - Storage units in unheated building/outside
### 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><strong>CSA</strong> (Direct Wholesale)</td>
<td><strong>Direct Wholesale</strong> CSA and (f. mkts)</td>
<td><strong>Direct Wholesale</strong> Distributor &amp; (CSA)</td>
<td><strong>Direct Wholesale</strong> (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% - 12yr
  - 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

- 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](http://www2.ca.uky.edu/agc/pubs/aen/aen96/aen96.pdf)
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