College of Agricultural & Life Sciences
University of Wisconsin-Madison

On-Farm Cold Storage Facilities

Scott Sanford
Distinguished Outreach Specialist
Rural Energy Program
Biological Systems Engineering

UW Extension Learning for life

North Central SARE Sustainable Agriculture Research & Education

College of Agricultural & Life Sciences University of Wisconsin-Madison

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

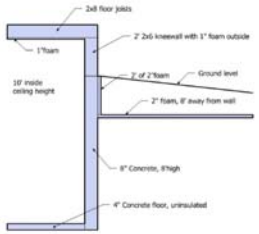
- Energy Efficient
  - Use ground temperature
  - Outside air for cooling
  - Temperature subject to ambient temp
- Vent warm air / respiration gases ??
- Little/no electrical energy use (fans)
- Not suitable for removing harvest heat
  - Slow transfer of heat
- Access for material handling??
  - Can't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

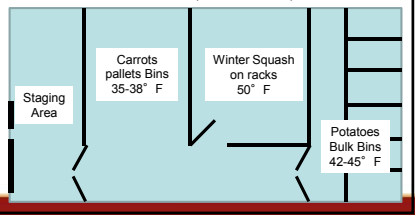
Source: http://www.kk.org/streetuse/redneck_root_cellar.jpg

Modern Root Cellar Concept

- Earth Contact basement
  - Average ground temperature – 49F
- Why not under-ground?
  - Cost of ceiling / roof
  - Office/living 2nd Floor
- Fork Truck Accessible
- $36.000 (2001)

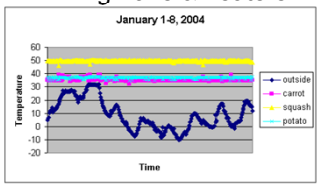
Food Farm, Wrenshall, MN





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

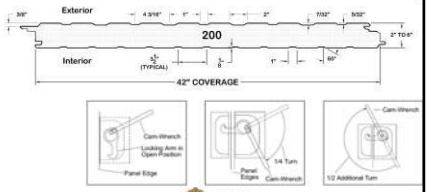
Walk-in / Drive-in Coolers

- 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

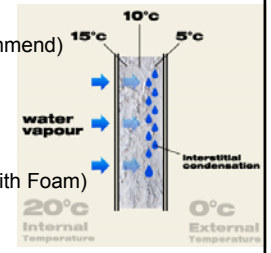


Source: http://www.kingspanpanels.us/ColdStorage/ThermalspanWall/200-Inverted-Rib.aspx

http://www.master-bilt.com/pdfs/io_manuals/walk-in_io.pdf

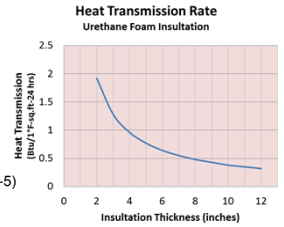
Built-in-place Cooler

- 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-5)
      - 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



Foam Thickness	R-Value
3	15
4	20
5	25
6	30
8	40
10	50
12	60

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

In-Cooler

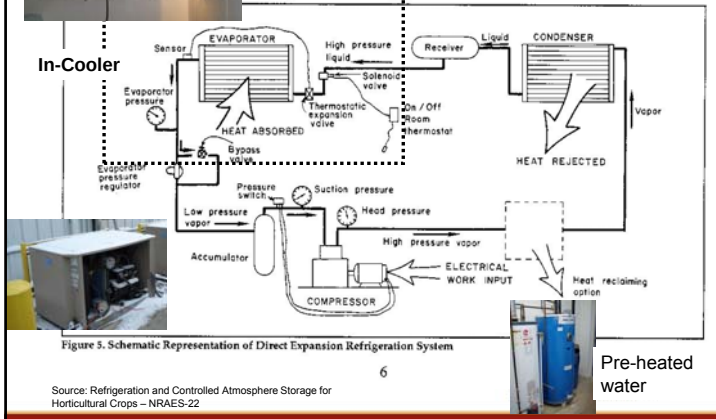


Figure 5. Schematic Representation of Direct Expansion Refrigeration System

6

Pre-heated water

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 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

College of Agricultural & Life Sciences University of Wisconsin-Madison 14

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

College of Agricultural & Life Sciences University of Wisconsin-Madison 15

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
  - ΔT x lbs x SH
  - Slow removal effect produce

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

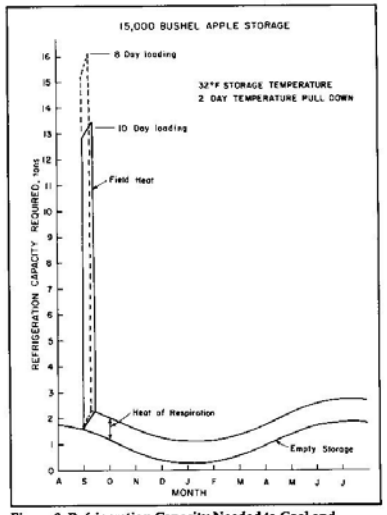


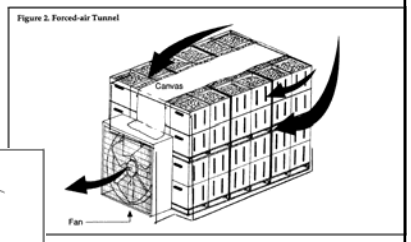
Figure 8. Refrigeration Capacity Needed to Cool and Maintain 15,000 Bushels of Apples

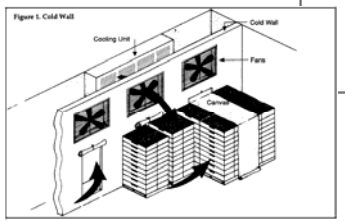
Factors - field heat removal rate

- 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)

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

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 size for your conditions

Cooler size (w x l x h)	Room volume (ft^3)	+ 32ºF		+ 40ºF	
		Typical load[1] (Btu/hr)	Heavy load[2] (Btu/hr)	Typical load[1] (Btu/hr)	Heavy load[2] (Btu/hr)
8 x 10 x 8	640	6710	8700	5570	7080
10 x 14 x 8	1,120	8910	11860	7100	9280
14 x 16 x 10	2,240	13920	18740	10690	14110
18 x 20 x 10	3,600	19600	26570	14660	19480
20 x 24 x 10	4,800	24430	33190	18020	23970
20 x 40 x 10	8,000	36530	49250	26270	34550

[1] Typical load assumes 2 lb of product per cubic foot (ft^3) of cooler volume entering per day at 50ºF and cooled to cooler set-point temperature in 24 hrs; 25% of volume with carrots for respiration load, 95ºF outside temperature; R-value of walls and ceiling are R = 25; uninsulated floor at 55ºF; average air exchange rate – less than 3 openings per hour; internal loads of 1 HP per 16,000 ft^3; lighting at 1 W/ft^2; 1 person load per 25,000 ft^3; 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 ft^3 of cooler volume, otherwise the same conditions as typical load.

Adapted from Quick Load Calculations, Heatcraft Refrigeration Products, www.heatcraftrpd.com/PDF/MQuick Load Calculations.pdf

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 32-33F – Best above 35F
  - 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
32 to 36F, 90-95% RH

Commodity	Typ. Storage time (months)
Apples	2-4 air 3-12 CA
Horseradish	8-10
Jerusalem Artichoke	12
Pears	2-5 air 8-9 CA
Turnips	4-5

Table 2: Cold and Very Humid
32 to 36F, 95-98% RH

Commodity	Typ. Storage time (months)
Beets	4-6
Brussels Sprouts	1
Cabbage	5- 6
Carrots	5-9
Celeriac	6-8
Leeks	2-3
Parsnips	4-6
Radish	1-2
Rutabagas	4-6

Table 3: Cold and Dry
32 to 35 @ 60-70% RH

Commodity	Typ. Storage time (months)
Garlic	5-8
Onions (sweet)	1-3
Onions (pungent)	6-9
Shallots	6-10

Table 4: Specialty conditions

Commodity	Typ. Storage time (months)
40 – 50F @ 95-99% RH	
Potatoes, late crop	2-12
55 to 59F @ 85-95% RH	
Sweet Potatoes	4-7
40-50F @ 40-50% RH	
Dry Beans	6-10
50-55F @ 50-75% RH	
Winter Squash & Pumpkins (Acorn, Buttercup, Butternut, Hubbard)	2-3

Table 2.3 Products which are incompatible in long-term storage.

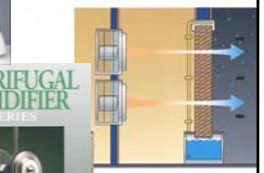
Products			Effects
Apples or Pears	with	Celery Cabbage Carrots Potatoes Onions	Ethylene from apples and pears damages or causes off flavors in vegetables. Potatoes cause "earthy" flavor in fruit. Potatoes are injured by cold temperatures. High humidity causes root growth in onions. Ethylene causes bitterness in carrots.
Celery	with	Onions or Carrots	Odor transfer occurs between products.
Meat Eggs Dairy	with	Apples and Citrus	Fruit flavors are taken up by the meat, eggs, and dairy products.
Leafy Greens and Flowers	with	Apples Pears Peaches Tomatoes and Cantaloupe	Ethylene produced by the fruit crops damages greens and flowers.
Cucumbers Peppers and Green Squash	with	Tomatoes Apples Pears	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.

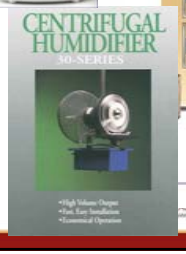
Modified from Hardenburg et. al. (1986).

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


Gellert Company





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 $140 - $500

Humidity Control

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

Minimum Relative Humidity Levels[1] Developed at various Storage and Evaporator Discharge Temperatures

Temperature Drop[2]	Storeroom Temperature, ° F		
Across Evaporator, ° F	32° F	35° F	38° F
-1° F	95.8	96.1	96.1
-2° F	91.2	92.3	92.4
-3° F	87.1	88.7	88.8
-4° F	83.0	84.7	85.3
-5° F	79.4	80.9	82.0
-10° F	62.7	64.1	65.3
-15° F	49.3	50.5	49.4

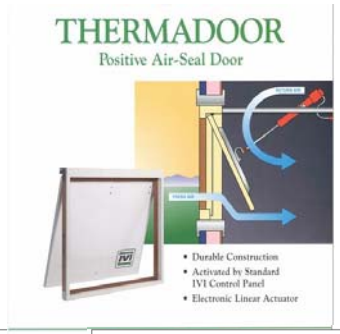
[1] Calculated from Psychrometric Tables

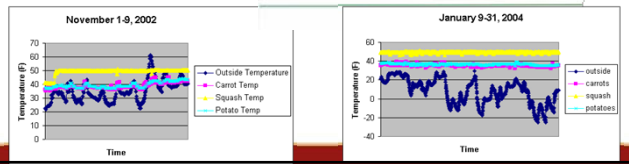
[2] Actual Airstream temperature drop between inlet and outlet. The coil TD will be approximately twice this value.

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

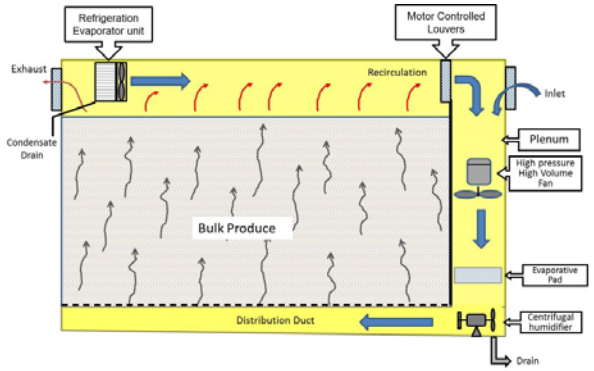
Outdoor air to reduce refrigeration

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

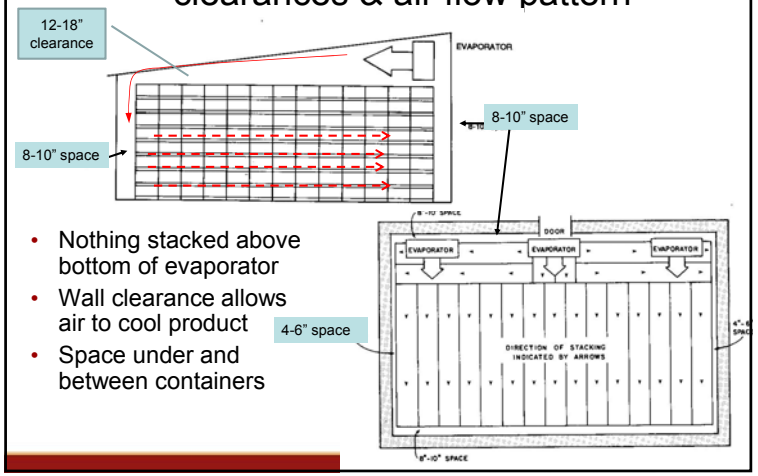




Bulk Storage Air Flow



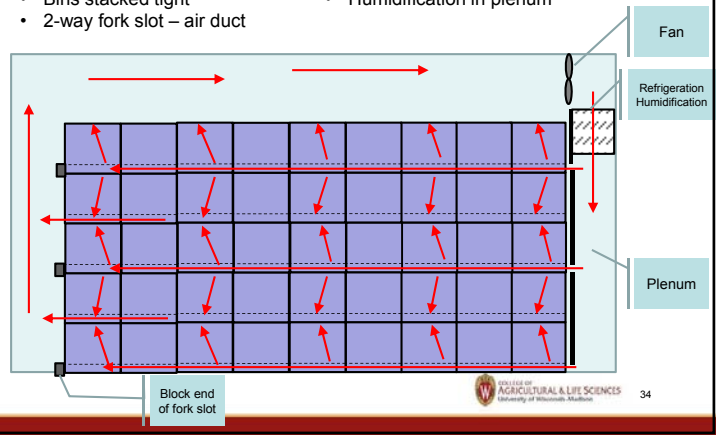
Cold storage – clearances & air flow pattern



- 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

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

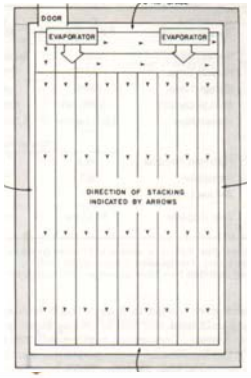
Material Handling Equipment

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

Source: http://www.beechhandlingservices.co.uk/
http://www.prestolifts.com/stuff/contentmgr/files/f243d69b64cf66fa30c5f6092fccb8ec/misc/pallet_stacker.jpg

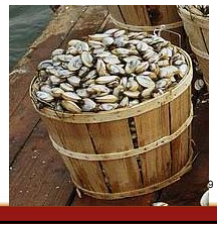
Traffic & Material Flow

- 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



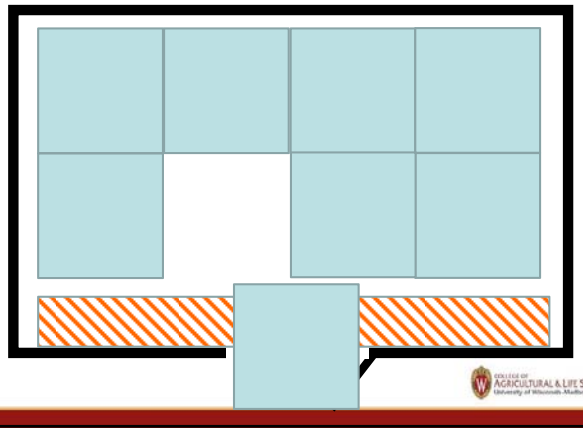
Rules of Thumb

- 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



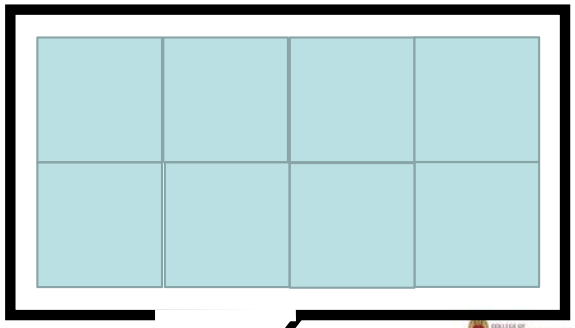
Layout Issues

- Wide or length in-efficient for container size
- Door location doesn’t allow maximum number of containers



Layout Issues

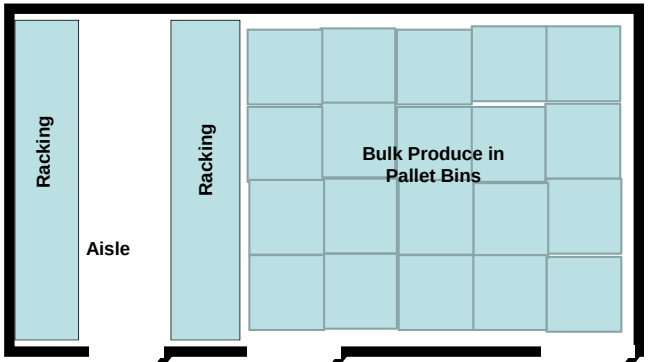
- Door location / sized for bins
- Allows last bin to go straight in.



41

Layout for accessibility

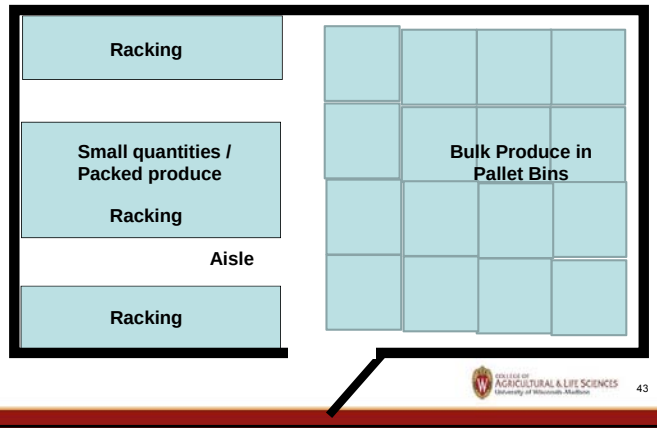
- Add doors to reduce aisle space inside cooler
- Small goods and Bulk area



42

Layout for accessibility

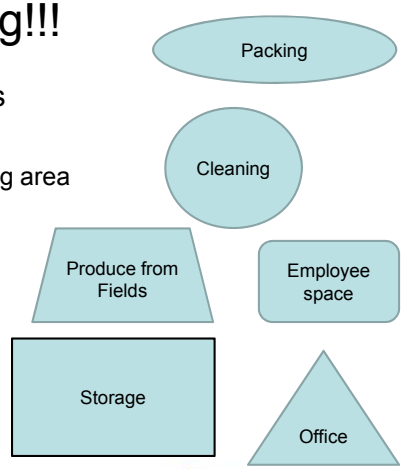
- Small quantities / fragile goods / packed produces



43

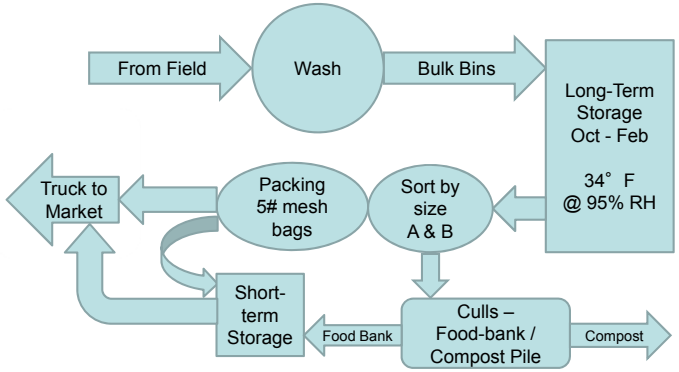
Planning!!!

- Space requirements
- Material Flow
  - Access to processing area
- Material Handling
- Utility needs
  - Water
  - Electricity
  - Drains
  - Temperature
- Labor
- Future Expansion

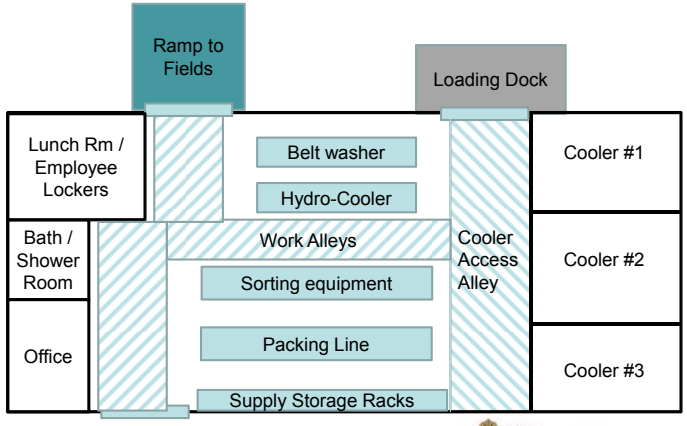


44

Flow Charts – by crop



Building Layout



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.
  - Supplemental heating required
    - Storage units in unheated building/outside

Utility Cost Estimates

Madison, WI (12' x 12' x 9')

	Heating			Refrigeration			Circulating Fans and Lights		Electric cost by Month
	Heating (Btu/mo)	kWh/mo	Heat cost	Cooling (Btu/mo)	kWh/mo	Cooling Cost	kWh	Cost	$USD
January	220606	68	$7	935570	110	$11	269	27	$45
February	107586	33	$3	998719	117	$12	243	24	$39
March	0	0	$0	1396363	164	$16	269	27	$43
April	0	0	$0	1888260	222	$22	260	26	$48
May	0	0	$0	2487550	293	$29	269	27	$56
June	0	0	$0	2768388	326	$33	260	26	$59
July	0	0	$0	2930126	345	$34	269	27	$61
August	0	0	$0	2821733	332	$33	269	27	$60
September	0	0	$0	2491730	293	$29	260	26	$55
October	0	0	$0	2310927	272	$27	269	27	$54
November	0	0	$0	1538737	181	$18	260	26	$44
December	115122	36	$4	1090925	128	$13	269	27	$43
Yearly heat loss	443313	137	$14	23659027	2783	$278	3,169	$317	
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

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

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
  - **http://www.fsa.usda.gov/programs-and-services/price-support/facility-loans/farm-storage/index**

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

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

Other Resources

- Bartsch, J.A.,G.D.Blanpied,"Refrigeration and Controlled Atmosphere Storage for Horticultural Crops", NRAES-22, Natural Resource, Agriculture and Engineering Service, Cornell U., Ithaca, NY, 1990. (Out of Print)
- Roper, T., K. Delahaut, B.Ingham., Storing fruits and vegetables from the home garden, A3823, University of Wisconsin-Extension, 2006. http://learningstore.uwex.edu/Assets/pdfs/A3823.pdf
- _____, The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks, USDA-ARS, Agricultural Handbook Number 66, 2004. Available at http://www.ba.ars.usda.gov/hb66/contents.html
- De Long, Eric, Storage Guidelines for Fruits & Vegetables, Cornell Cooperative Extension, 2004. 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 can be emailed or call to discuss.
Scott Sanford
Distinguished Outreach Specialist
Biological System Engineering
University of Wisconsin
sasanford@wisc.edu
608-262-5062
NORTH CENTRAL SARE
Sustainable Agriculture Research & Education
UW Extension
Learning for life
College of Agricultural & Life Sciences
University of Wisconsin-Madison