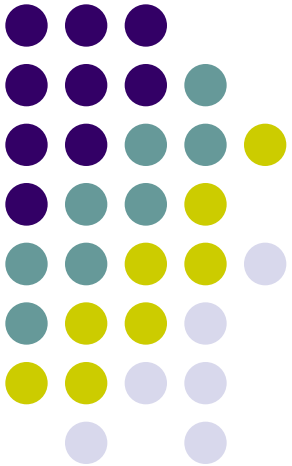
On-Farm Cold Storage
Planning, Design, Management

Scott Sanford
Sr. Outreach Specialist
Rural Energy Program
Biological Systems Engineering
UW-Madison



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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

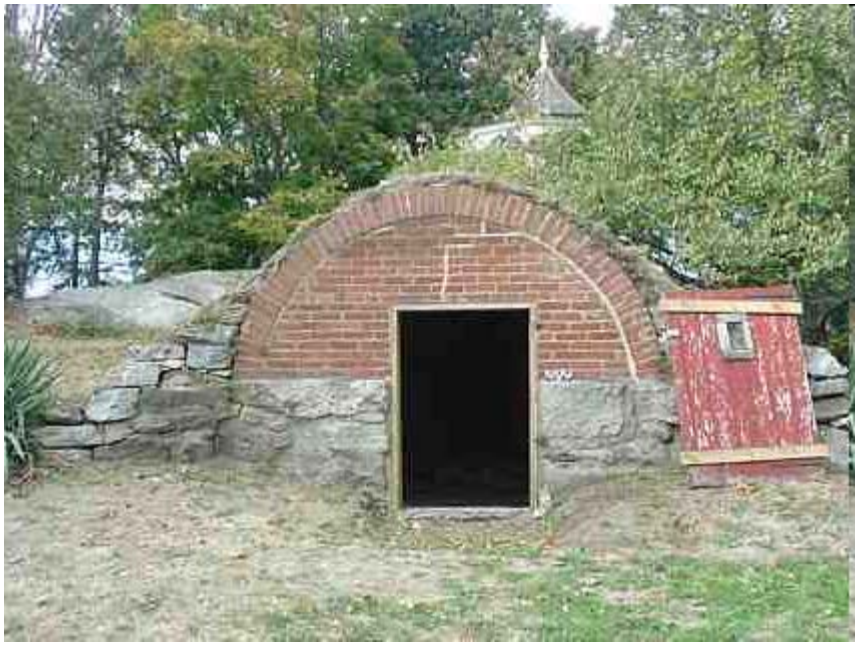
- Root cellars
- Refrigerators
- Walk-in coolers
- Drive-in coolers

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

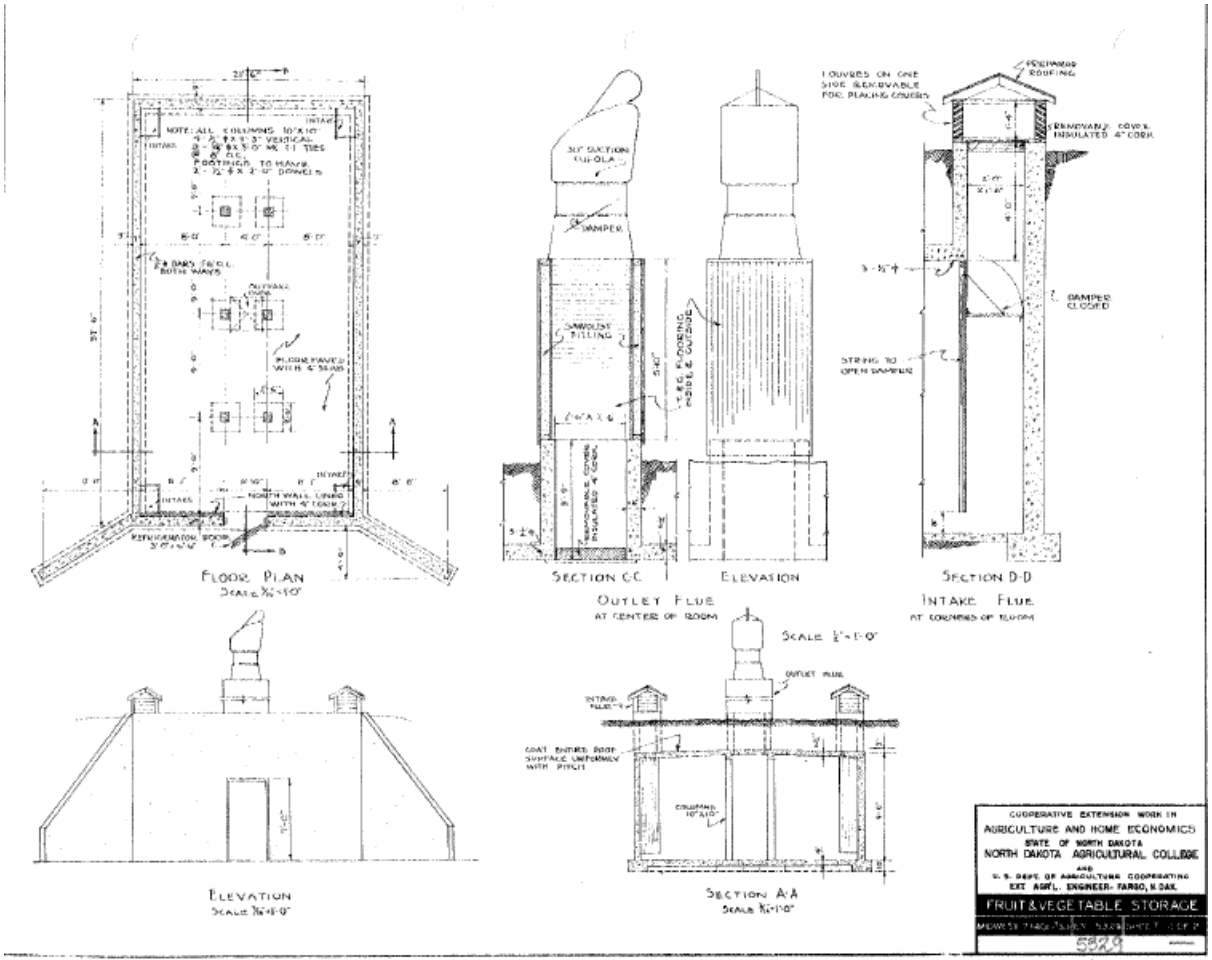
- Use ground temperature
  & outside air for cooling
- Temperature subject to ambient temp
- Vent warm air / respiration gases
- Little/no electrical energy use (fans)
- Not suitable for removing harvest heat
- Access for material handling??
  - Can’t afford to hand carry crops in and out
- Drainage 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
- http://www.ag.ndsu.edu/aben-plans/5329.pdf

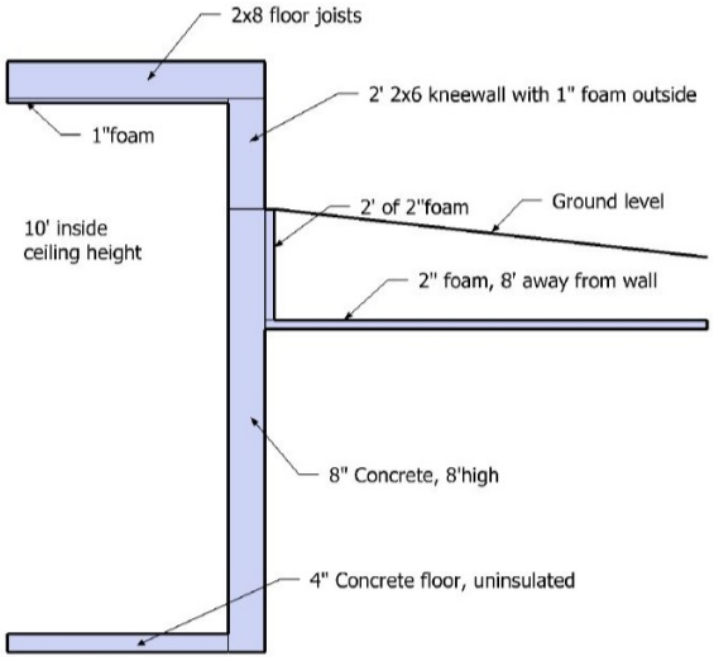


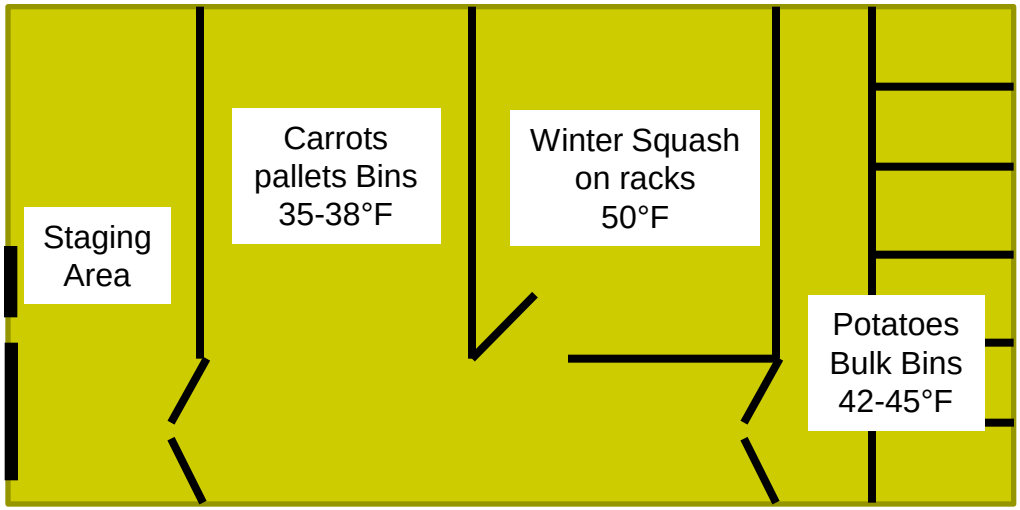
Best for:

- Potatoes
- Short term root crop storage

Modern Root Cellar Concept

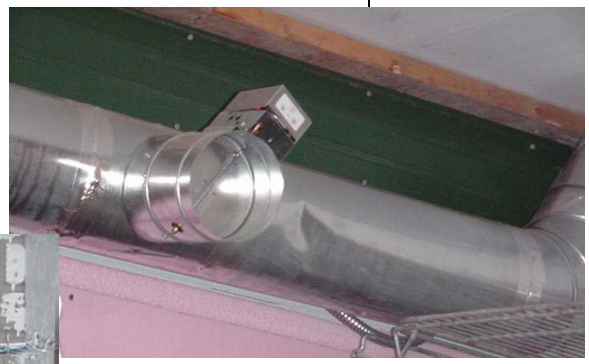
- Earth Contact basement
  - Average ground temperature – 49F
- Office/living 2nd Floor
  - Why not under-ground?
- Fork Truck Accessible
- $36,000 (2001)

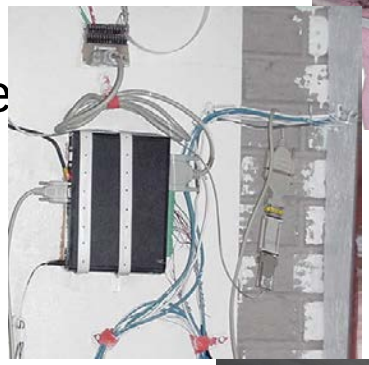




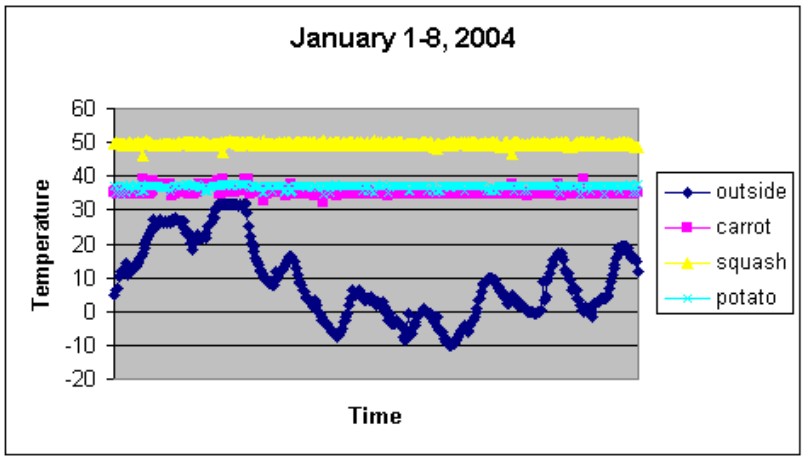
Modern Root Cellar Concept

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





Heater



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

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

Walk-in / Drive-in Coolers Features

Refrigeration system

Thermometer & light switch

Electric Vaporizer evaporates condensed water

Lockable door latch

Polyurethane insulated panels

Environmental Controller

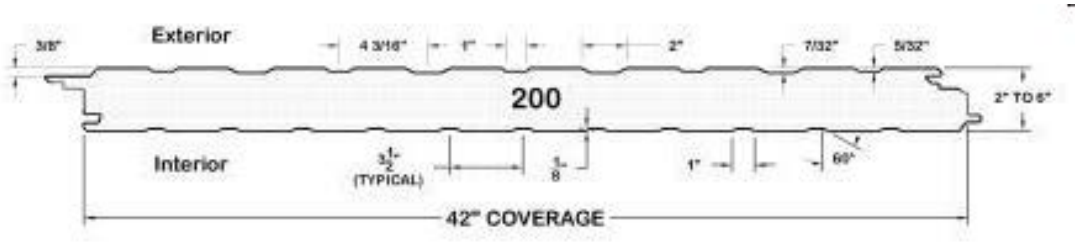
Insulated floor Cleanable material

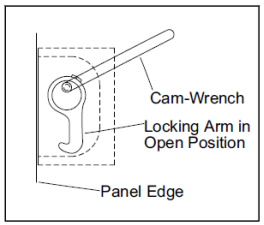
Self closing door with gasket

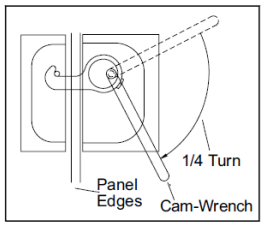
Source: http://www.webstaurantstore.com/nor-lake-walk-in-cooler-6-x-12-x-6-7-indoor/596KLB612.html

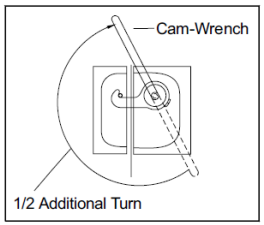
Walk-in / Drive-in Coolers

- 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







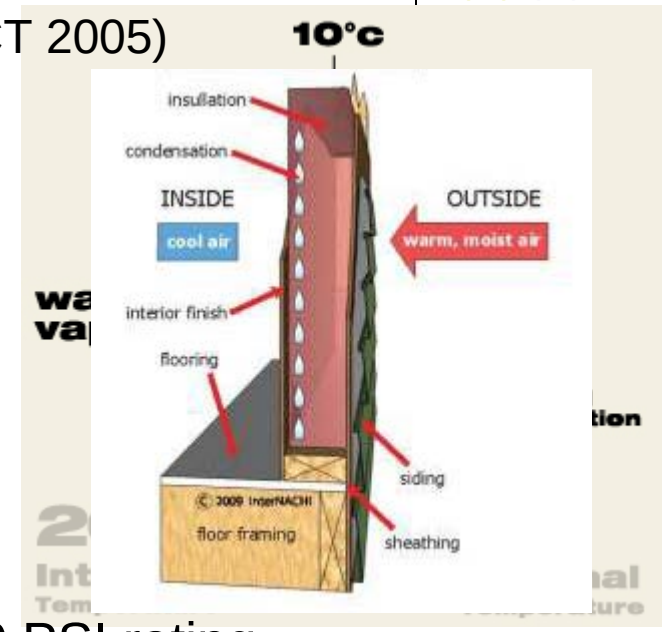


Source: http://www.kingspanpanels.us/ColdStorage/ThermalspanWall/200-Inverted-Rib.aspx

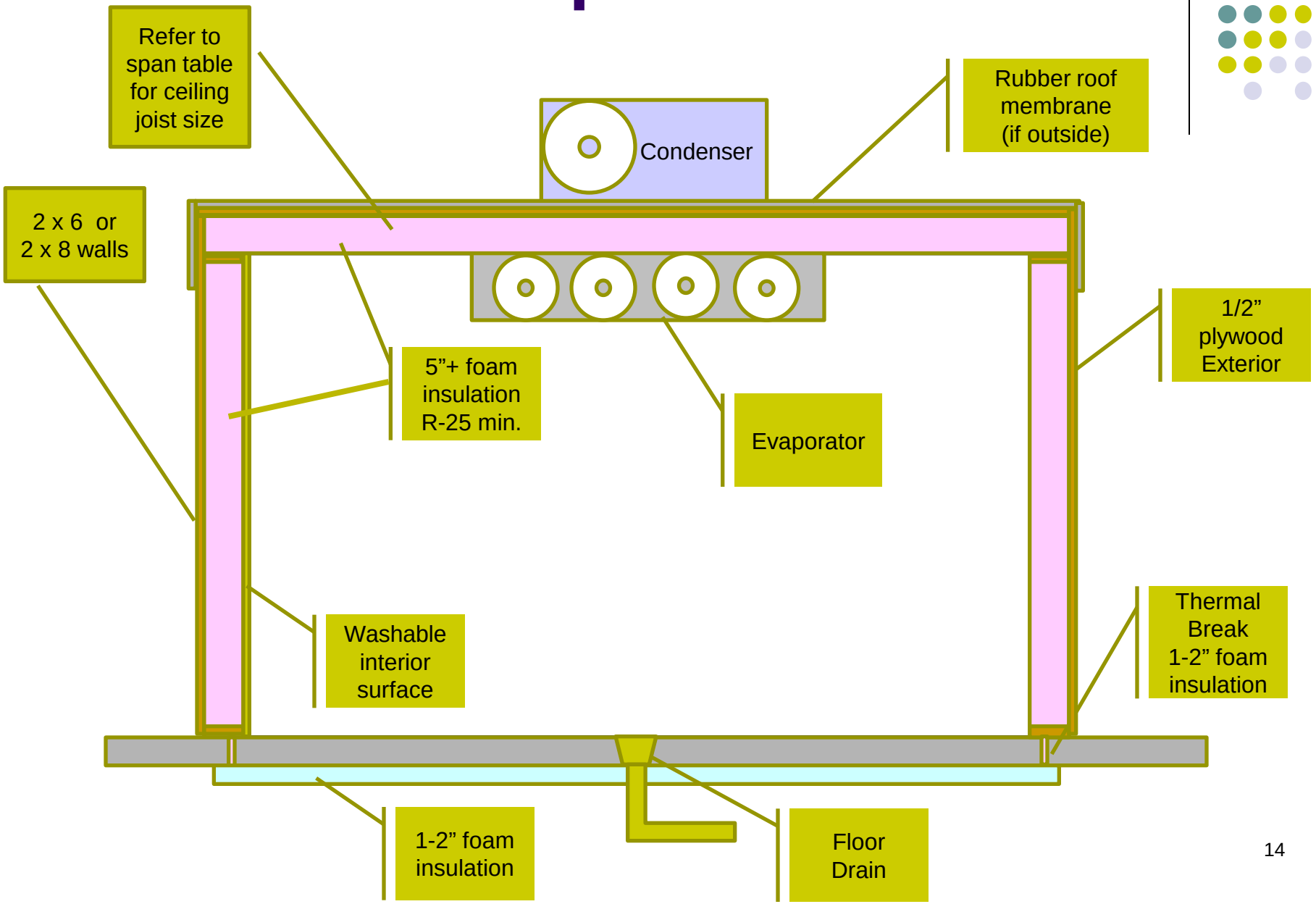
http://www.master-bilt.com/pdfs/io_manuals/walk-in_io.pdf

Built-in-place Cooler

- Insulated walls – R-25 minimum (EPACT 2005)
  - 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

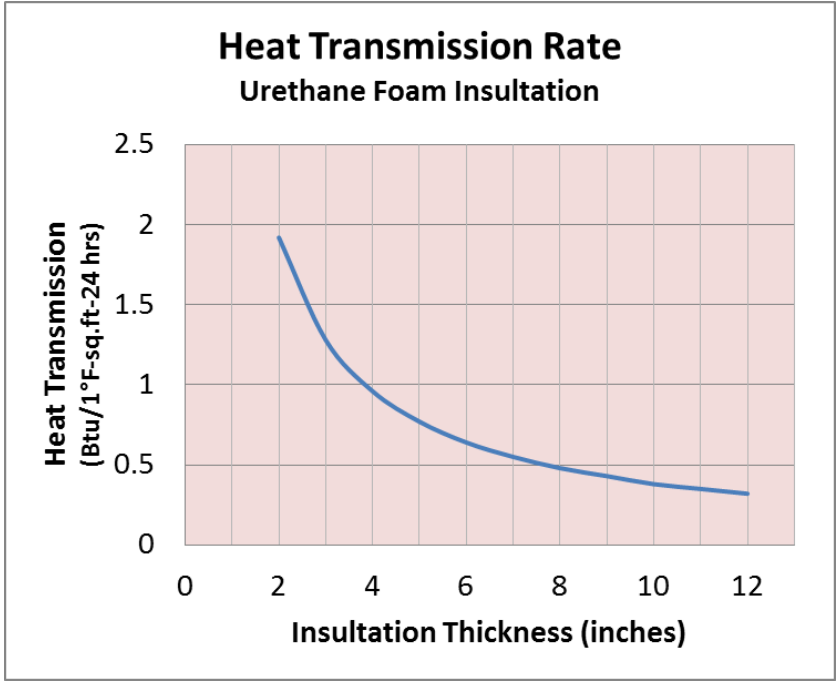


Cooler Envelop



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



Foam Thickness	R-Value
3	19
4	25
5	31
6	38
8	50
10	63
12	75

Ceiling Joist Spacing

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

Span Width (ft)	Joist Size (nominal)
8	2 x 6
10	2 x 8
12	2 x 10
14	2 x 10

Vapor Barriers

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

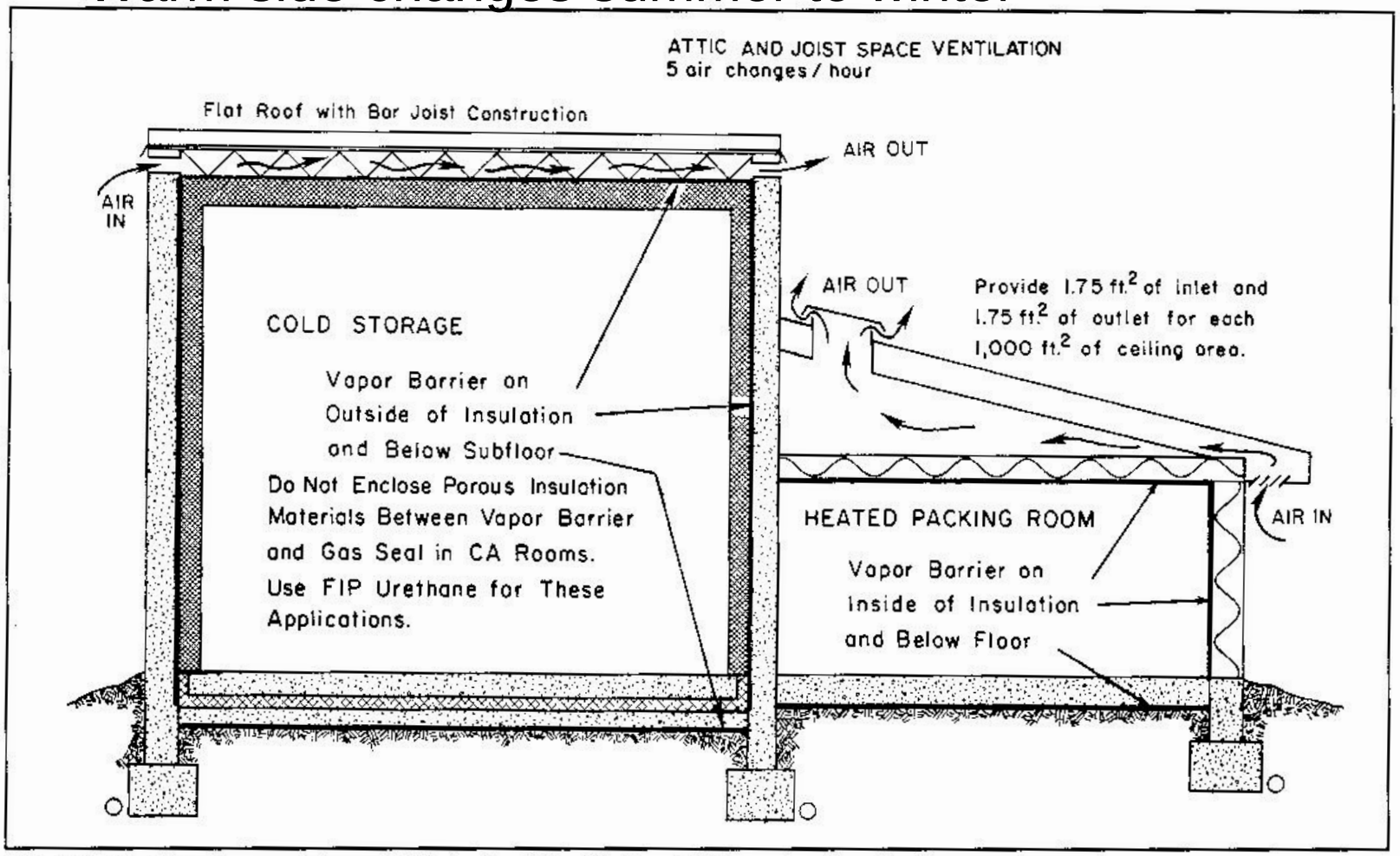


Figure 4. Vapor Barrier Location and Methods of Ventilating Attics

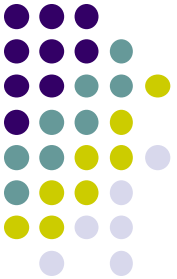
Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22

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%N_2, 21% O_2 & 0.03% CO_2)
  - 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

In-Cooler

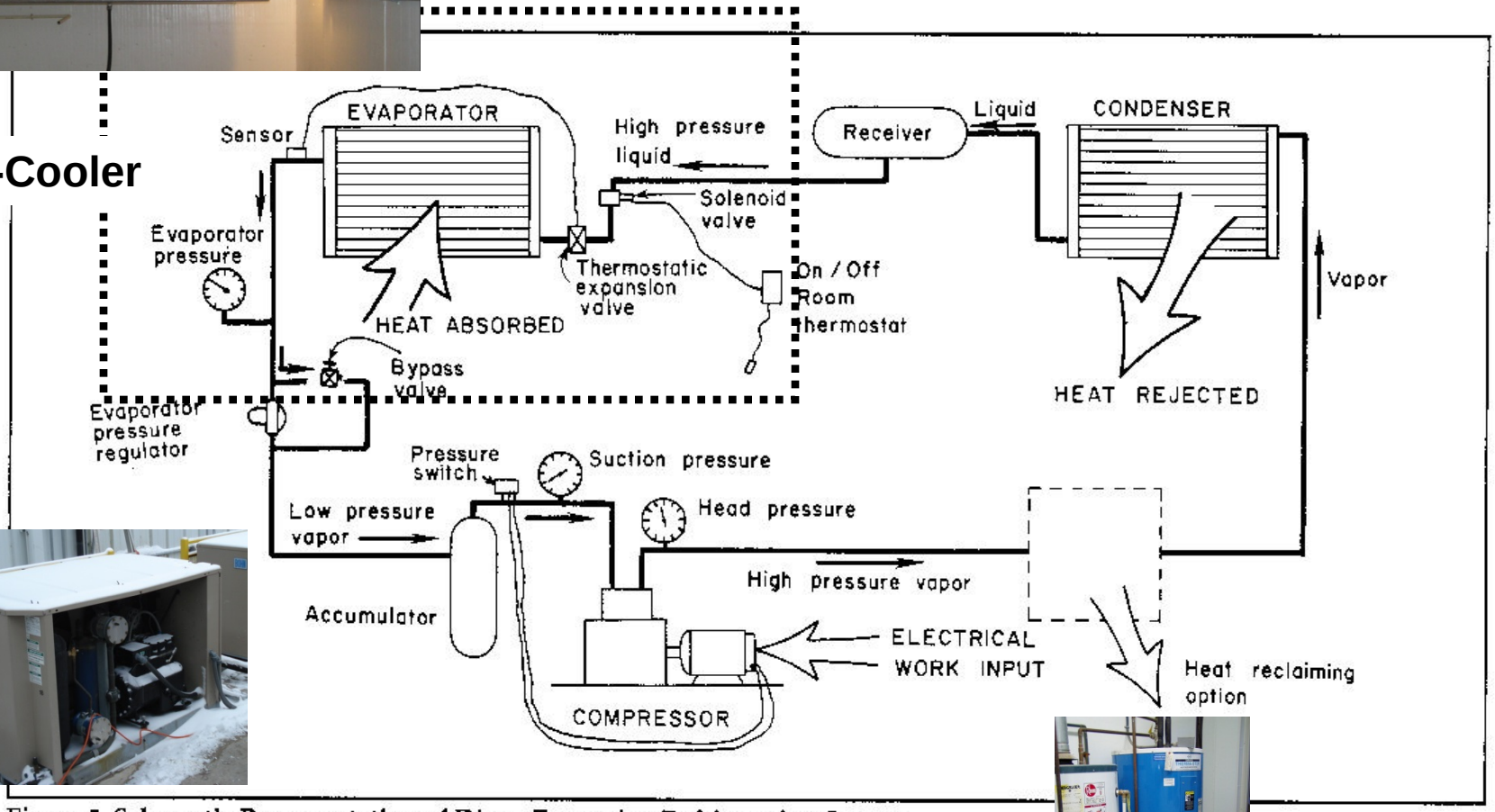


Figure 5. Schematic Representation of Direct Expansion Refrigeration System

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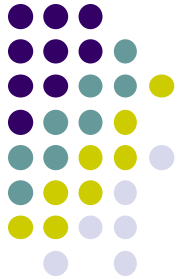
Pre-heat water

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 precooler reduces cooling needs

$$Q_1 = MC\Delta T$$

- Heat load calculation
  - Q_1 = Field heat removal rate, Btu/24 hrs
  - M = mass of product cooled per 24 hrs, lbs
  - C = Specific heat of product, Btu/lb°F
  - ΔT = Temperature drop of product in 24 hrs, °F

Refrigeration Requirement

- Field heat Removal
  - Largest component
  - Short duration
  - Smaller for Fall harvested crops

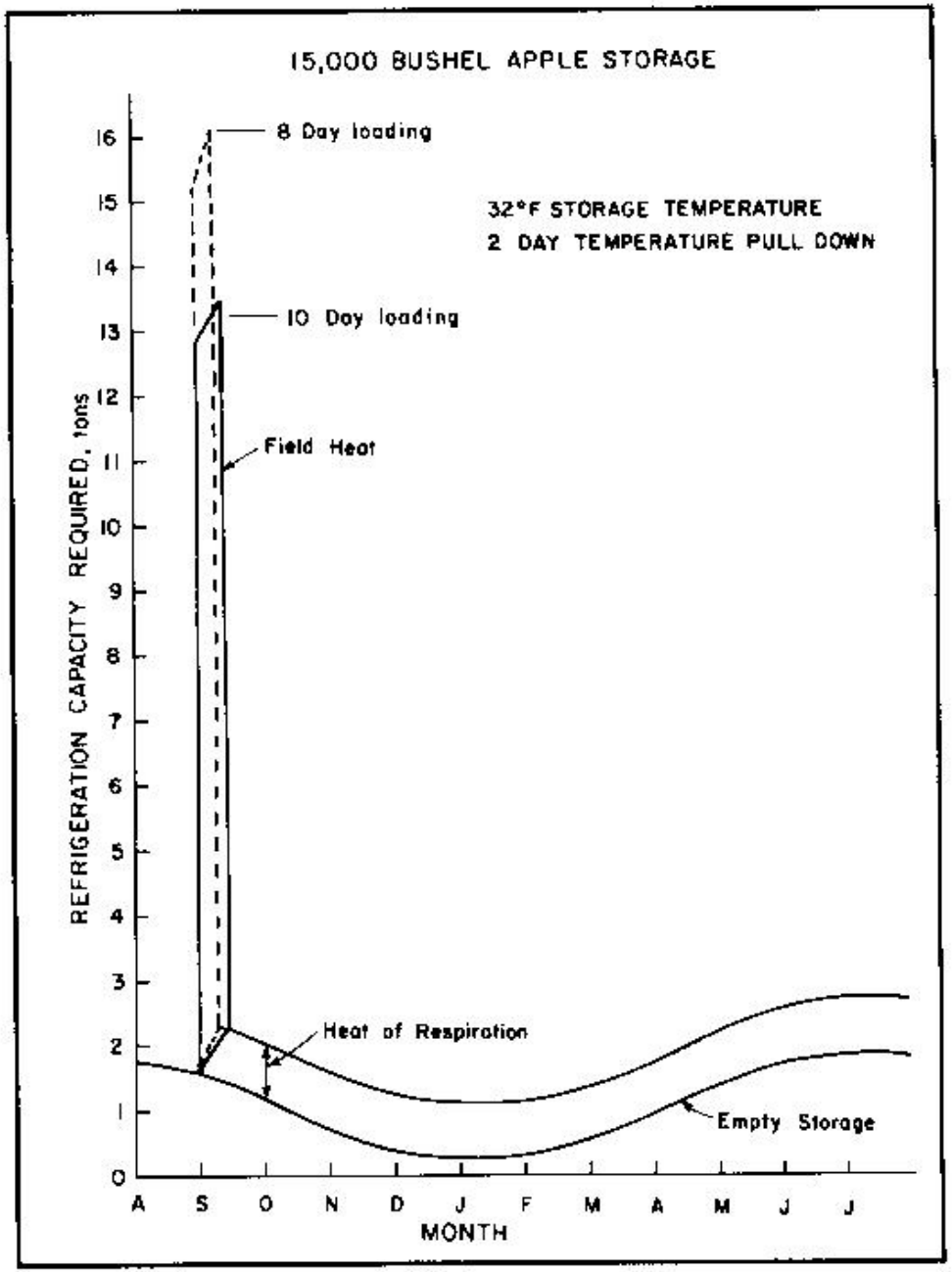


Figure 8. Refrigeration Capacity Needed to Cool and Maintain 15,000 Bushels of Apples

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

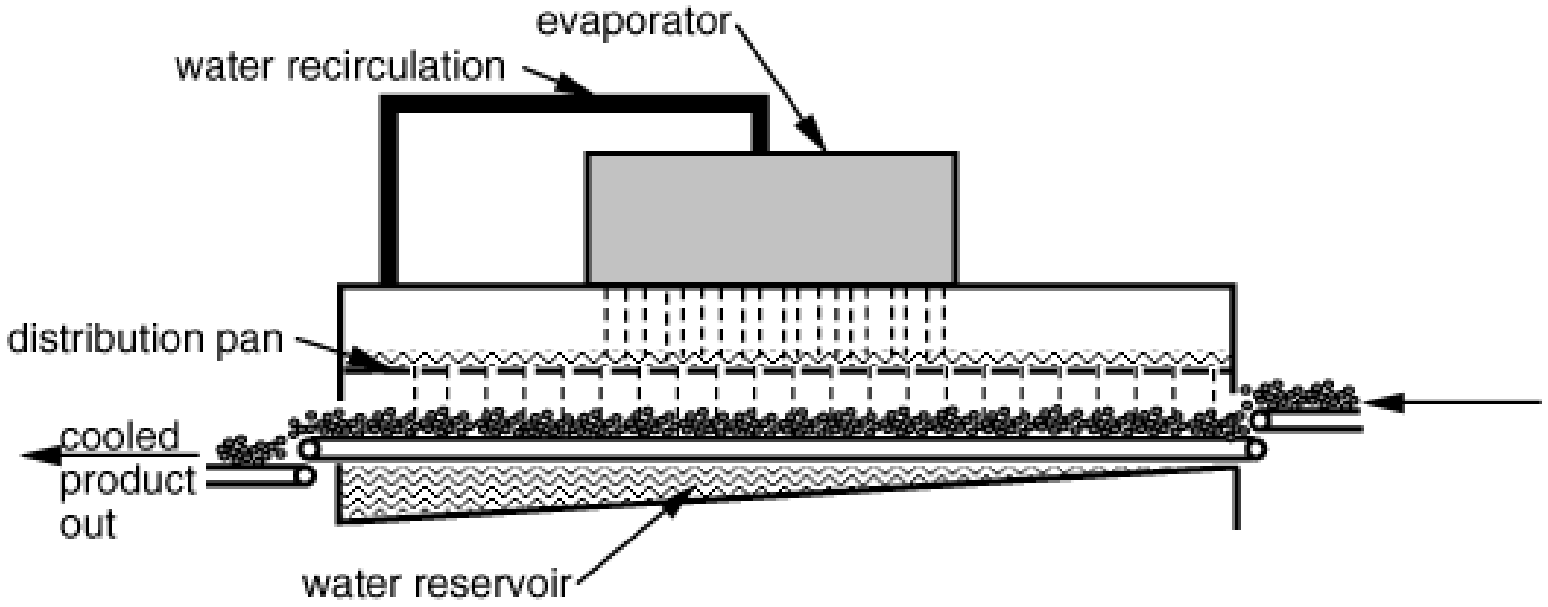
Factors affecting field heat removal

- 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

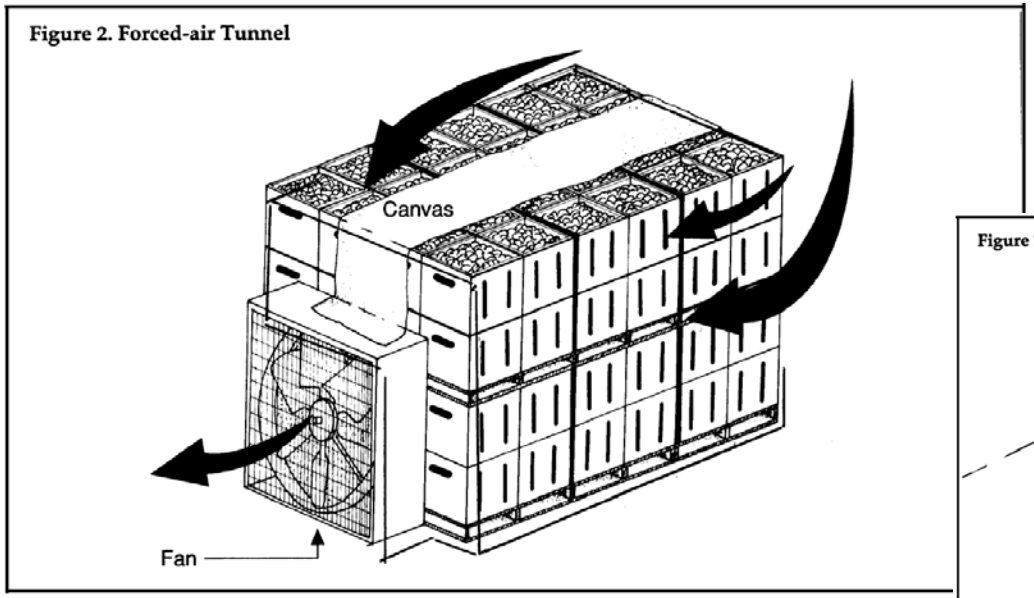
- Hydro –
  - Water bath or shower
  - Disease / pathogen transmission

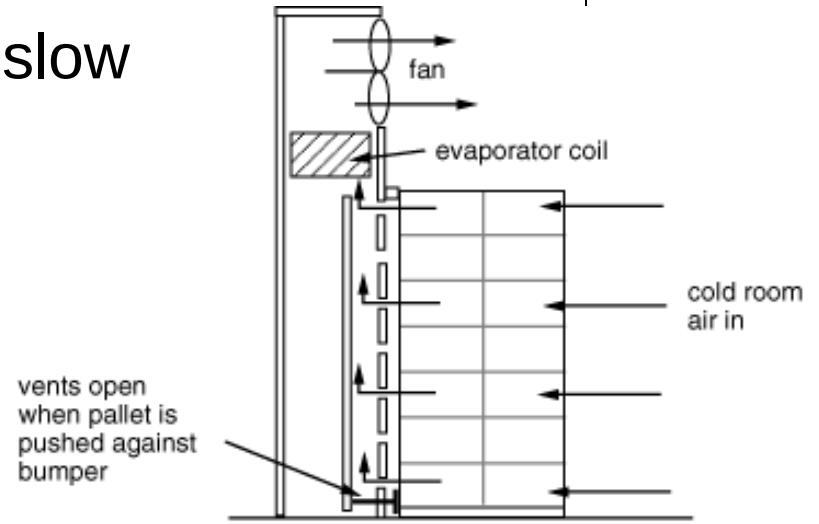


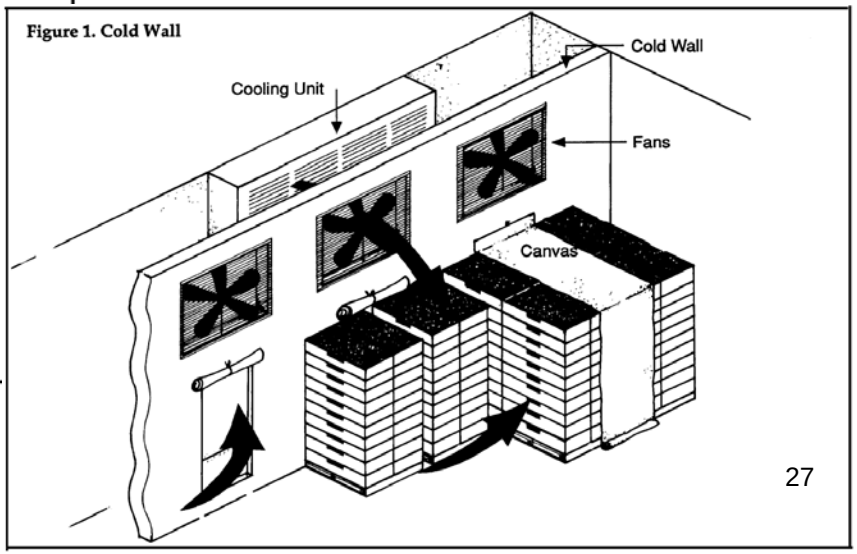
Source: USDA Agricultural Handbook Number 66, 2004

Pre-Coolers for field heat removal

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







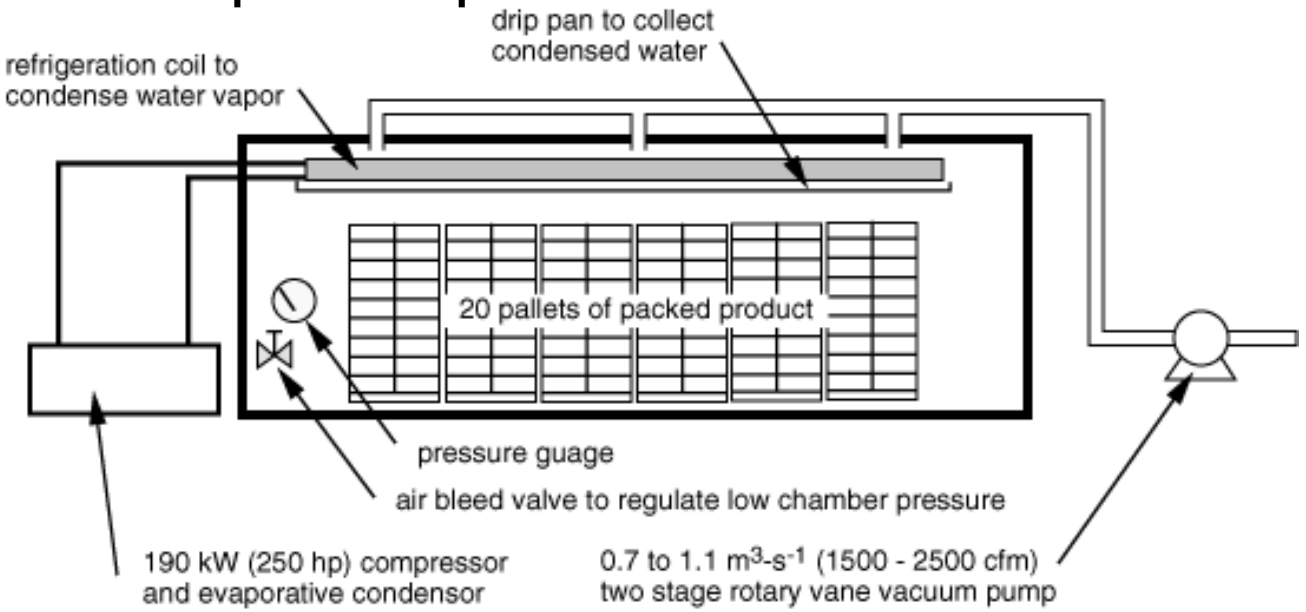
Source: USDA Agricultural Handbook Number 66, 2004

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 increase 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[1]

Commodity	Heat of Respiration, Btu per ton per day at indicated temperature[2] 32°F	40°F	60°F	70°F	80°F	Specific Heat Btu / lb°F
Apples, summer	660–1,320[3]	1,100–2,420	3,960–6,820	4,400–9,020	—	.87
Apples, fall	440–880	1,100–1,540	1,980–4,400	3,300–5,500	—	.87
Apricots	1,100–1,320	1,320–1,980	4,620–7,480	6,380–11,440	—	.88
Artichokes, globe	3,300–9,900	5,720–13,200	16,720–31,900	29,700–51,260	31,900–66,000	.87
Asparagus	5,940–17,600	12,100–29,920	35,200–71,940	60,500–110,000	110,000–132,000	.94
Avocados	—	4,400–6,600	13,640–34,540	16,280–76,340	25,960–94,160	.81
Bananas, green	—	—	4,620–5,060	7,260–7,700	—	.81
Bananas, ripening	—	—	5,500–16,500	7,260–31,240	11,000–53,900	—
Beans, lima	2,200–6,600	4,400–7,920	22,000–27,500	29,260–39,380	—	.73
Beans, snap	4,400	7,700	20,460	28,600	42,460	.91
Bean sprouts	4,620–5,500	9,240	—	—	—	.91
Beets, topped	1,100–1,540	1,980–2,200	3,740–5,060	—	—	.90
Beets, with leaves	2,420	3,080	5,500	8,800	—	—
Berries:						
Blackberries	3,960–4,400	6,820–9,020	16,500	34,100	—	.88
Blueberries	440–2,200	1,980–2,640	7,480–13,640	11,440–19,140	17,160–27,280	.86
Cranberries	—	880–1,100	—	2,420–3,960	—	.90
Gooseberries	1,100–1,540	1,760–3,520	5,940–15,180	9,020–23,100	—	.91
Raspberries	3,960–5,500	6,820–8,580	18,040–22,220	—	—	.86
Strawberries	2,640–3,960	3,520–5,060	15,620–20,240	22,440–43,120	37,180–46,420	.92
Broccoli	4,180–4,620	7,040–8,140	35,420–40,920	61,160–70,400	—	.92
Brussels sprouts	2,200–6,600	4,840–10,560	14,080–29,920	18,920–41,800	—	.88
Cabbage	880–1,320	1,980–2,640	4,400–7,040	6,160–10,780	10,780–13,860	.94
Carrots, topped	2,200–4,400	2,860–5,720	5,720–11,880	10,120–20,900	—	.91
Carrots, bunched	3,960–7,700	5,500–11,220	12,100–23,320	19,140–26,620	—	—
Cauliflower	3,520–4,180	4,180–4,840	9,460–10,780	16,500–18,920	18,480–30,800	.93

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

$$Q_3 = 24\ A(T_o - T_i) / R$$

- 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

$$Q_4 = (h_o - h_i)V\ N\ /13.5$$

- 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

Volume cu. ft.	Air Changes per 24 hr.		Volume cu. ft.	Air Changes per 24 hr.	
	Above 32 F	Below 32 F		Above 32 F	Below 32 F
200	44.0	33.5	6,000	6.5	5.0
300	34.5	26.2	8,000	5.5	4.3
400	29.5	22.5	10,000	4.9	3.8
500	26.0	20.0	15,000	3.9	3.0
600	23.0	18.0	20,000	3.5	2.6
800	20.0	15.3	25,000	3.0	2.3
1,000	17.5	13.5	30,000	2.7	2.1
1,500	14.0	11.0	40,000	2.3	1.8
2,000	12.0	9.3	50,000	2.0	1.6
3,000	9.5	7.4	75,000	1.6	1.3
4,000	8.2	6.3	100,000	1.4	1.1
5,000	7.2	5.6			

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

$$Q_5 = (kW \times 3430)\,tl + (Hp \times 2545)\,tm$$

- Equation heat gain
  - Q_5 = heat produced by equipment, Btu/24 hrs
  - kW = 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

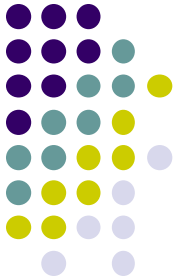
Compressor Capacity Recommendation for Small Coolers

Dimensions feet	Volume cubic feet	Cooling Load Btu/hr	Compressor Size Hp[2]
6x6x9	324	2,800	0.50
6x12x9	648	4,500	0.75
8x8x9	576	4,100	0.75
8x12x9	864	5,500	0.75
8x16x9	1152	7,100	1.00
10x10x9	900	5,600	0.75
10x15x9	1350	7,900	1.50
12x12x9	1296	7,700	1.00
12x20x9	2160	9,800	1.50
20x20x9	3600	15,800	3.00

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

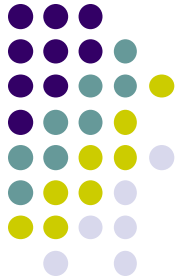
Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22

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

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

Table 2. Vegetables that require cool, moist conditions

Vegetable	Temperature (°F)	Relative Humidity (%)	Length of Storage
Beans, snap	40-50	95	7-10 days
Cucumbers	45-50	95	10-14 days
Eggplant	45-50	90	1 week
Cantaloupe	40	90	15 days
Watermelon	40-50	80-85	2-3 weeks
Peppers, sweet	45-50	95	2-3 weeks
Potatoes, early	50	90	1-3 weeks
Potatoes, late	40	90	4-9 months
Tomatoes, green	50-70	90	1-3 weeks
Tomatoes, ripe	45-50	90	4-7 days

Table 3. Vegetables that require cool dry conditions.

Vegetable	Temperature (°F)	Relative Humidity (%)	Length of Storage
Garlic	32	65-70	6-7 months
Onions	32	65-70	6-7 months

Table 4. Vegetables that require warm dry conditions.

Vegetable	Temperature (°F)	Relative Humidity (%)	Length of Storage
Peppers, hot	50	60-65	6 months
Pumpkins	50-55	70-75	2-3 months
Squash, winter	50-55	50-60	2-6 months
Sweet Potato	55-60	80-85	4-6 months

Storage Guidelines for Fruits & Vegetables, E. de Long, S. Reiners, Cornell Cooperative Extension-Chemung Co., 2004

http://www.gardening.cornell.edu/factsheets/vegetables/storage.pdf

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

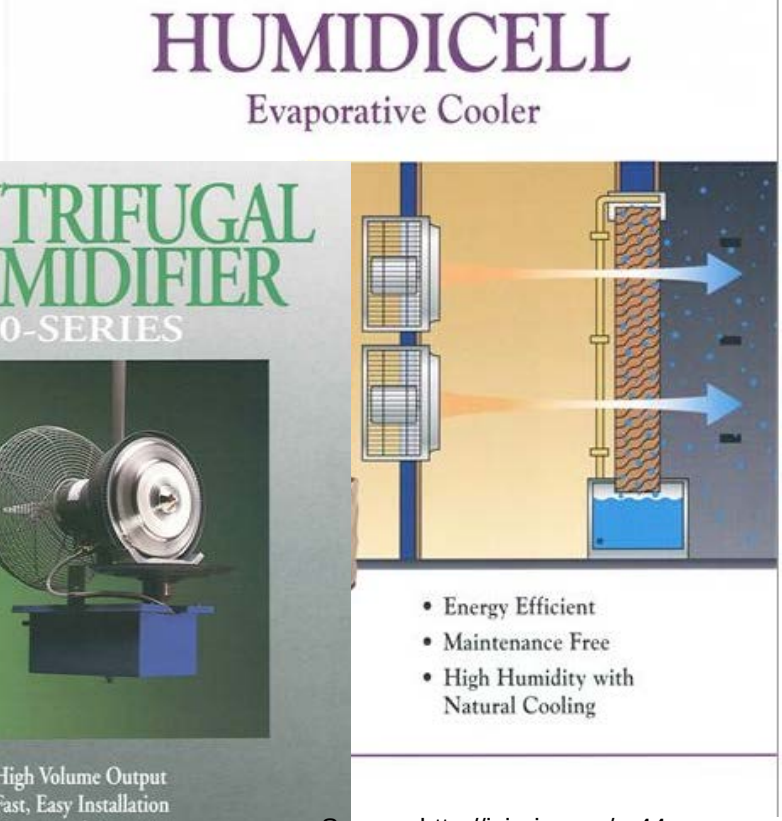
Products			Effects
Apples or Pears	with	Celery Cabbage Carrots Potatoes Onions	Ethylene from apples and pears damages or causes off flavors in vegetables. Potatoes cause "earthy" flavor in fruit. Potatoes are injured by cold temperatures. High humidity causes root growth in onions. Ethylene causes bitterness 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
- Atomizer
- Misting
  - No water on crops
- Pack in Plastic bag
- Pack crops in damp sand or 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 $130 - $500

Centrifugal Humidifier

- Utilities: Electric & Water

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

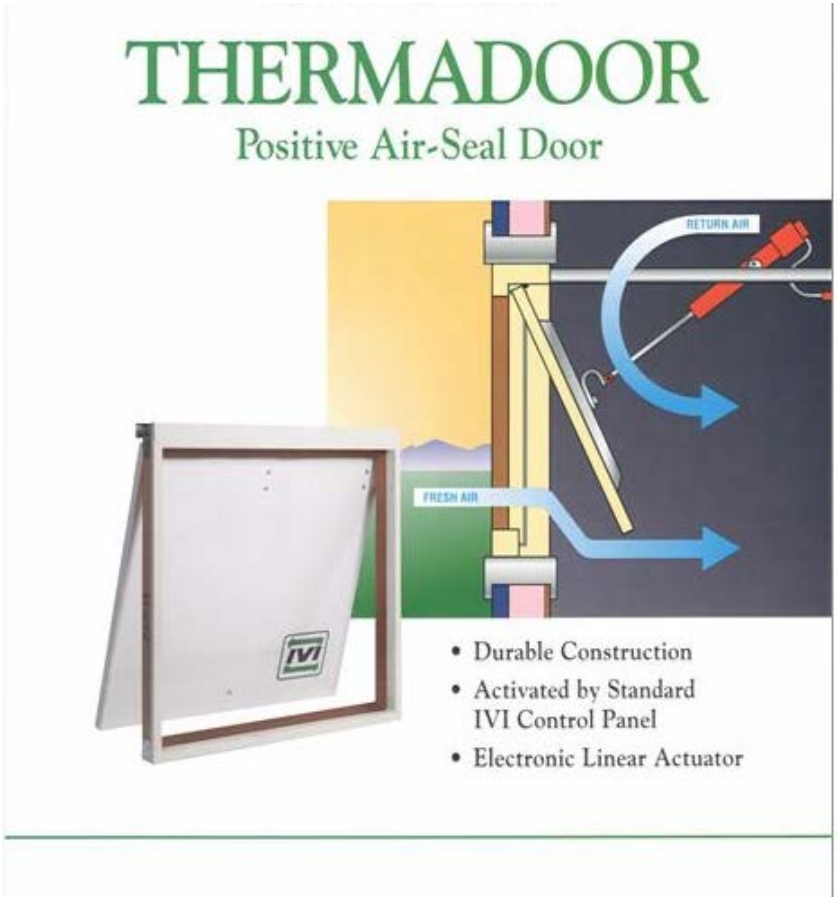
[1] Calculated from Psychrometric Tables

[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

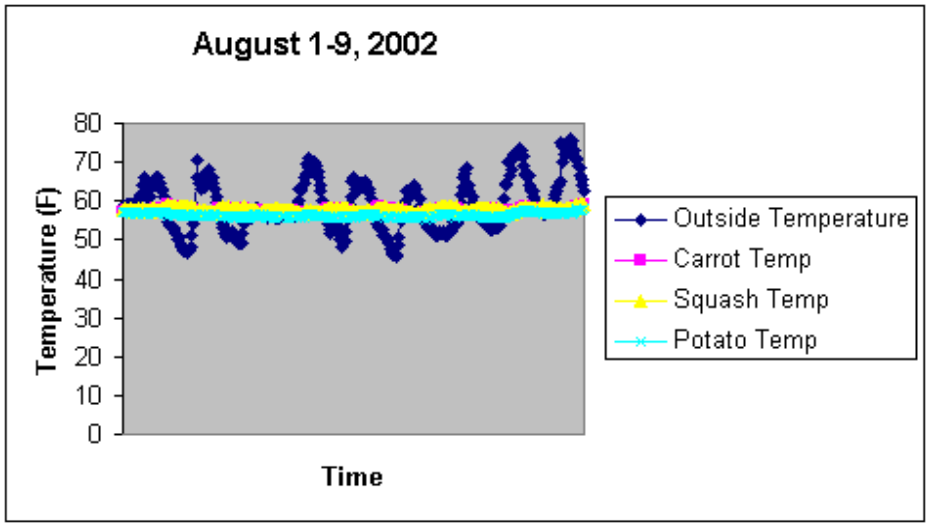
Outdoor Air Cooling

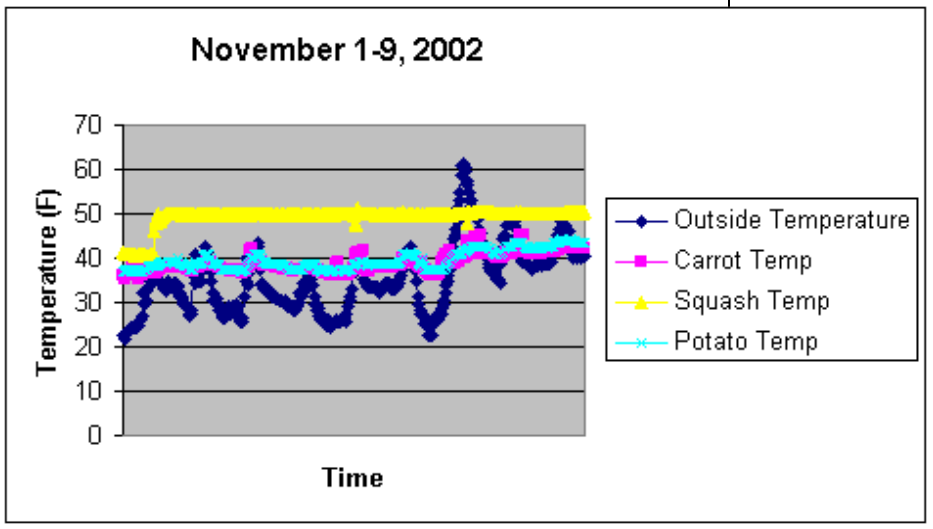
- Fall - use cool night air to reduce refrigeration
- Exchange air
- Controls
  - Manual
  - Automatic
    - Temperature
    - Time of day
- Disadvantage
  - Loss of humidity
  - Colder air is dryer

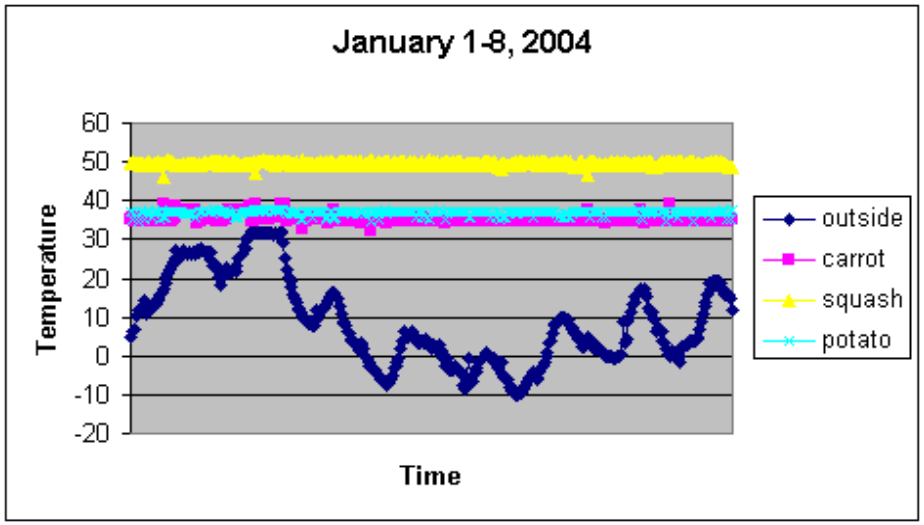


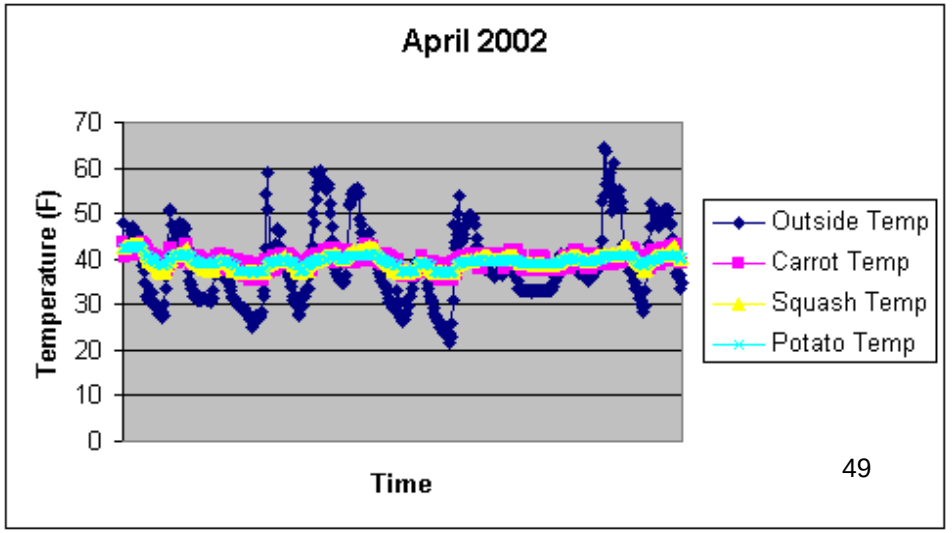
Outside Air Cooling

Food Farm , Wrenshall, MN









Air Flow/Ventilation Patterns

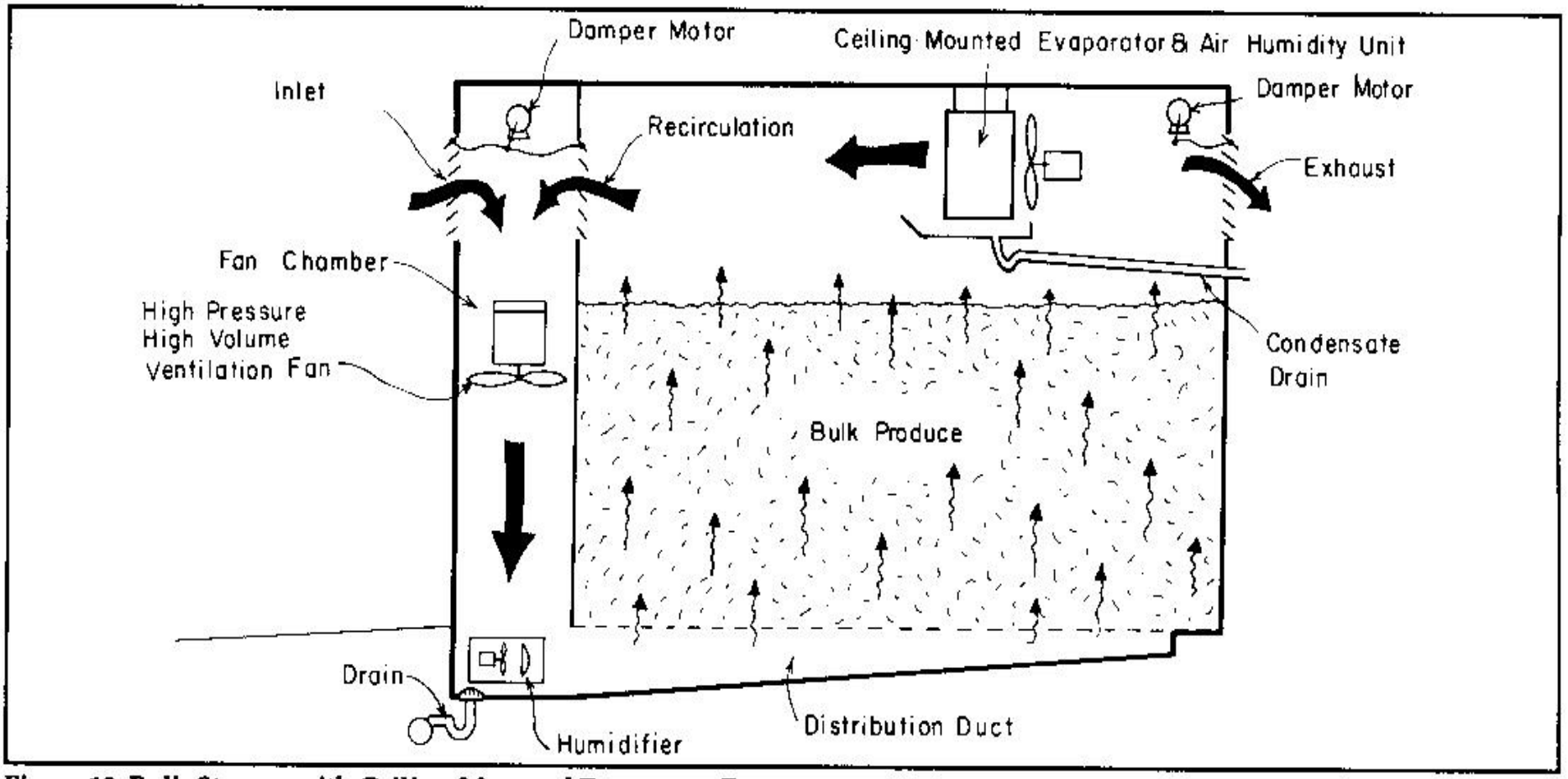
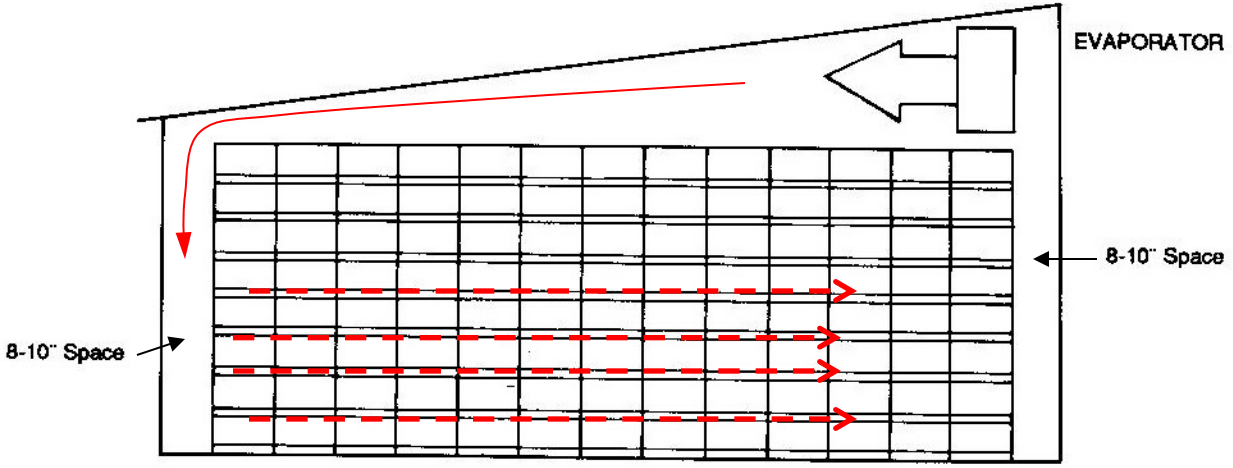
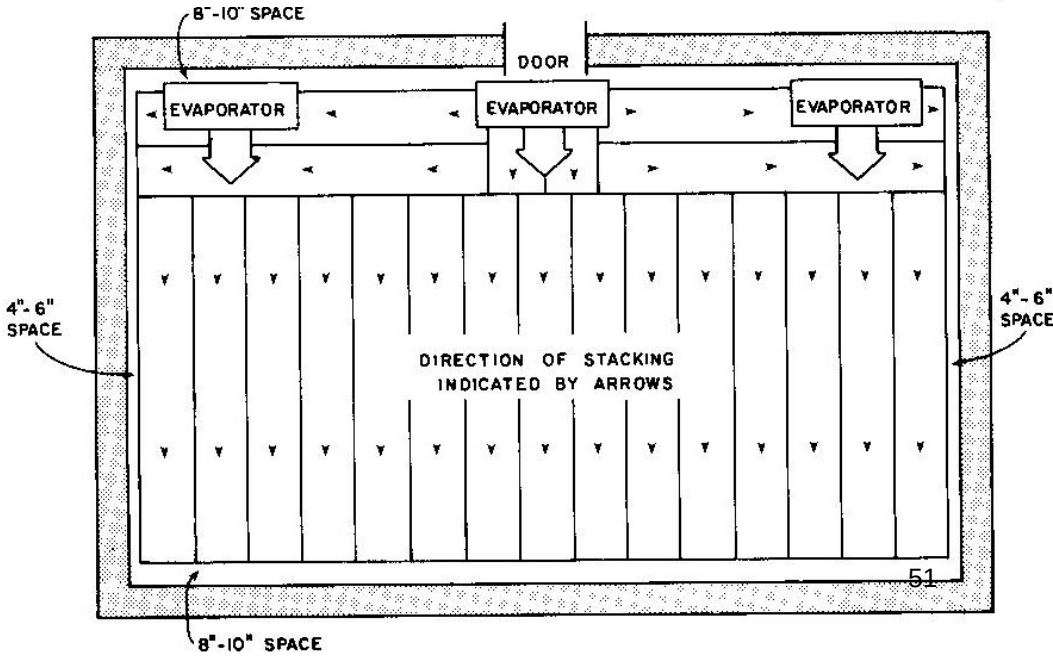


Figure 12. Bulk Storage with Ceiling-Mounted Evaporator Fan

Cold storage – wall & ceiling clearance

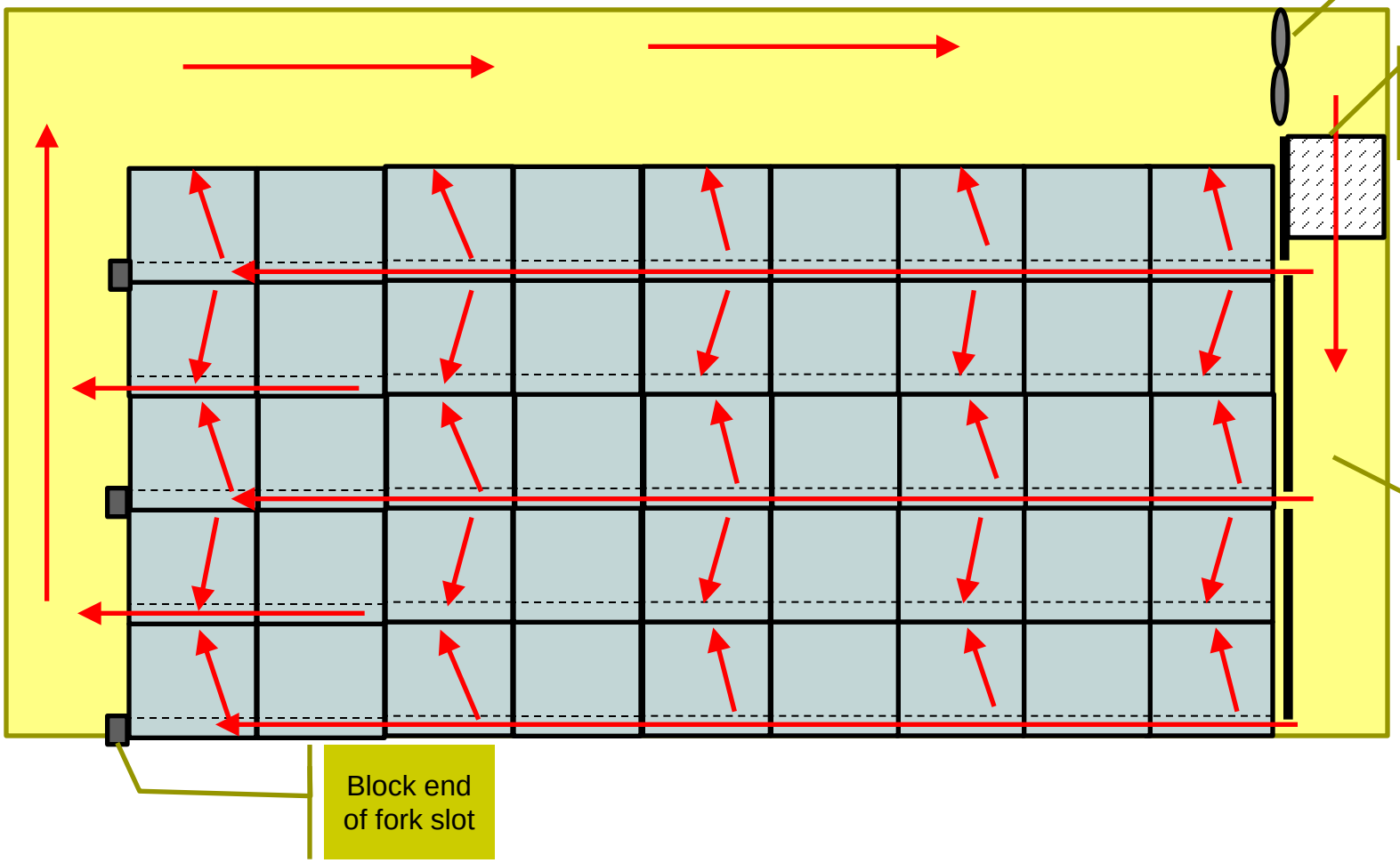


- Nothing stacked above bottom of evaporator
- Wall clearance allows air to cool product
- Space under and between containers



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

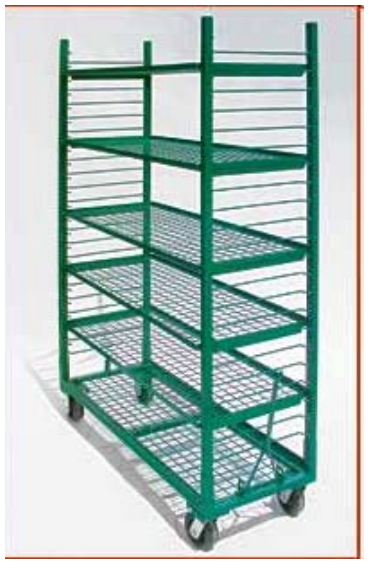
- Materials:
  - Wood – repairable, heavier, absorb moisture
  - Plastic – FDA approved plastic, easily sanitized
- Rated for loading
- Stackable
- Covers available
- Vented sides / bottom
  - Minimum 8-11% of bottom open
- Handle with Fork Truck or Pallet Jack
- Fit standard racking

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

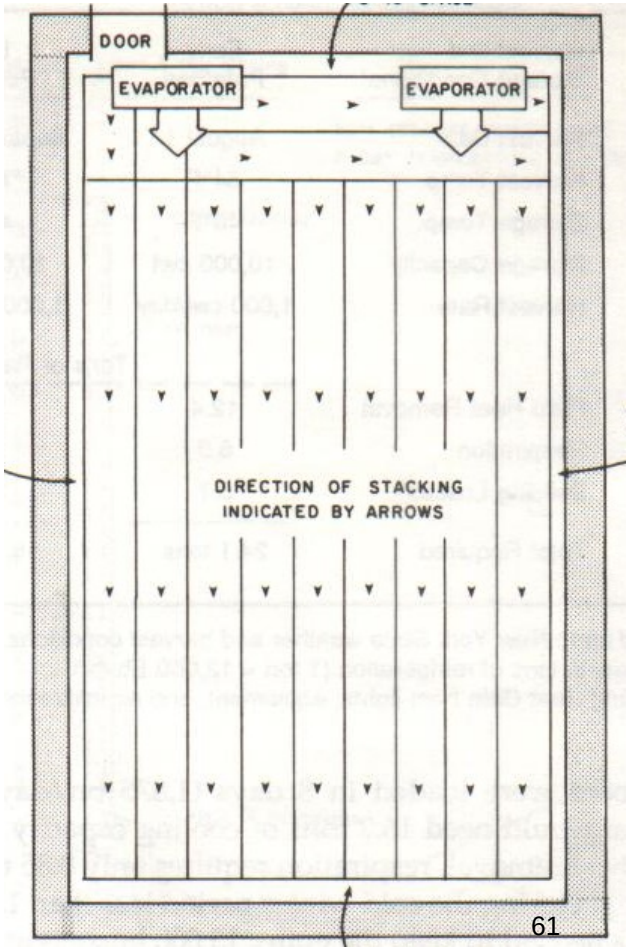
- Pallet Jacks
- Pallet Lift
  - Need smooth level hard surface
  - Narrower aisle than needed for fork truck
- Fork Truck
- Skid Steer w/ Pallet Forks

Source: http://www.getprice.com.au/images/uploadimg/910/350__1_pallet_jack.jpg

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

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



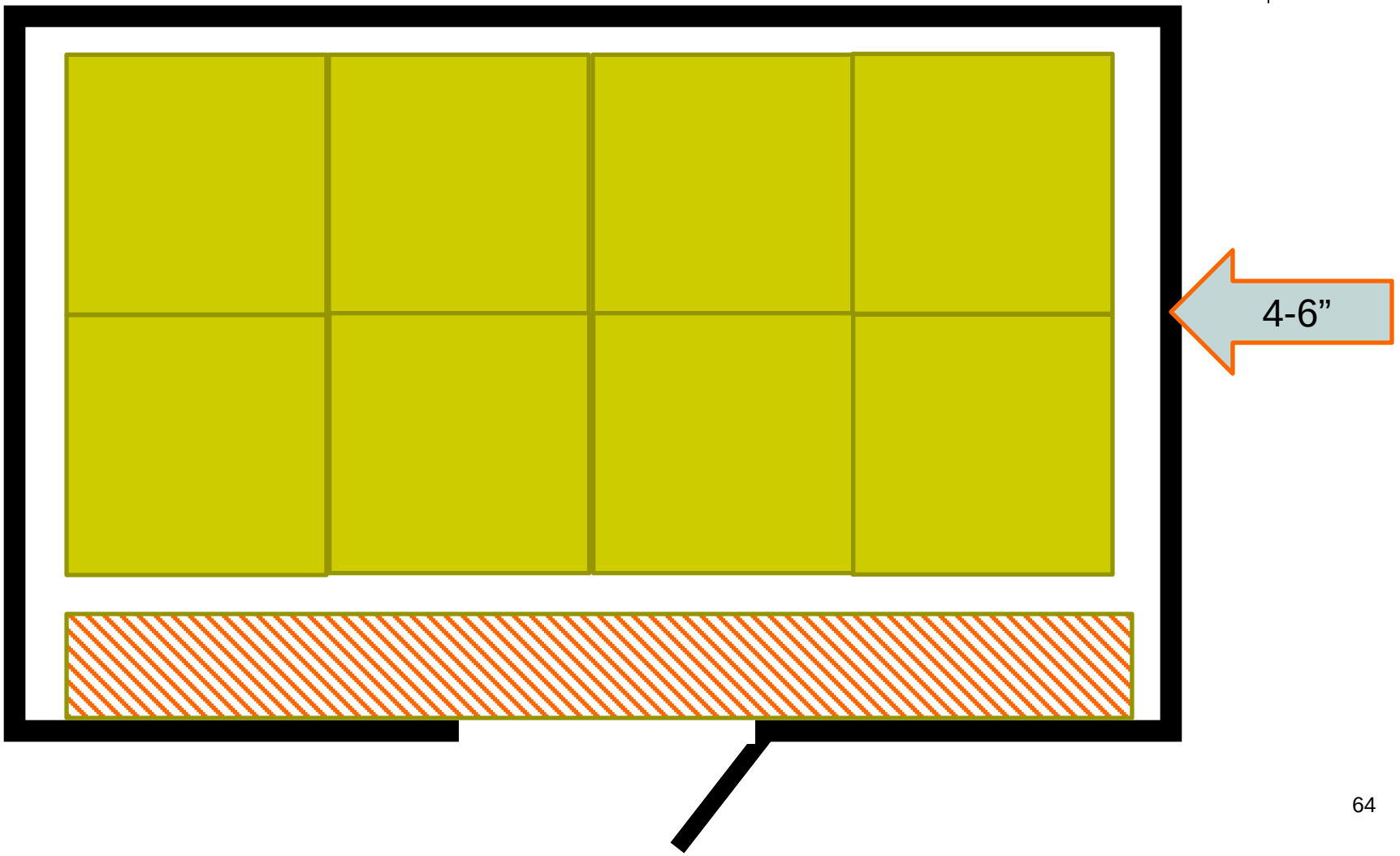

HYSTER 30

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

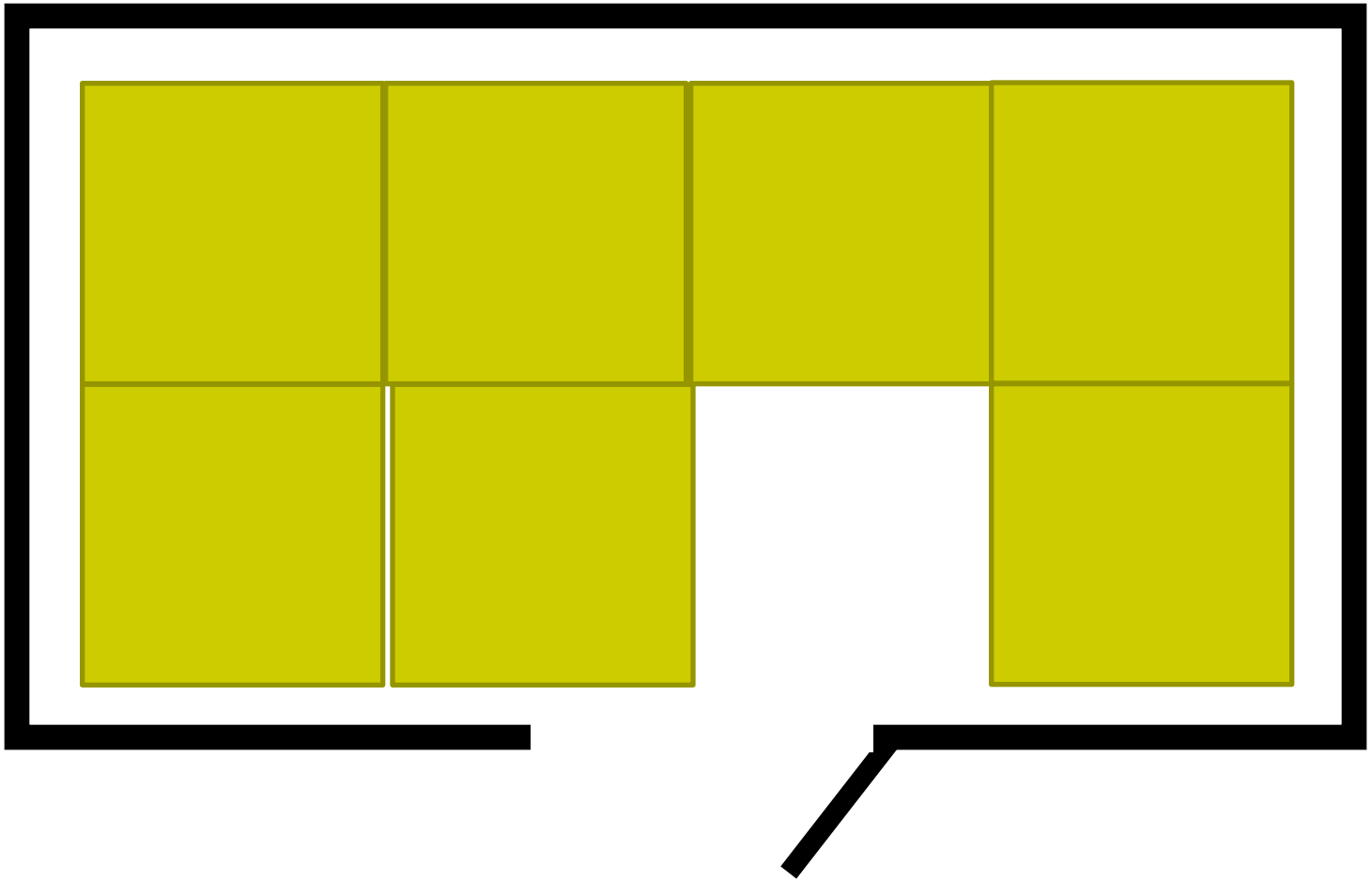
Layout Issues

- Wide or length in-efficient for container size



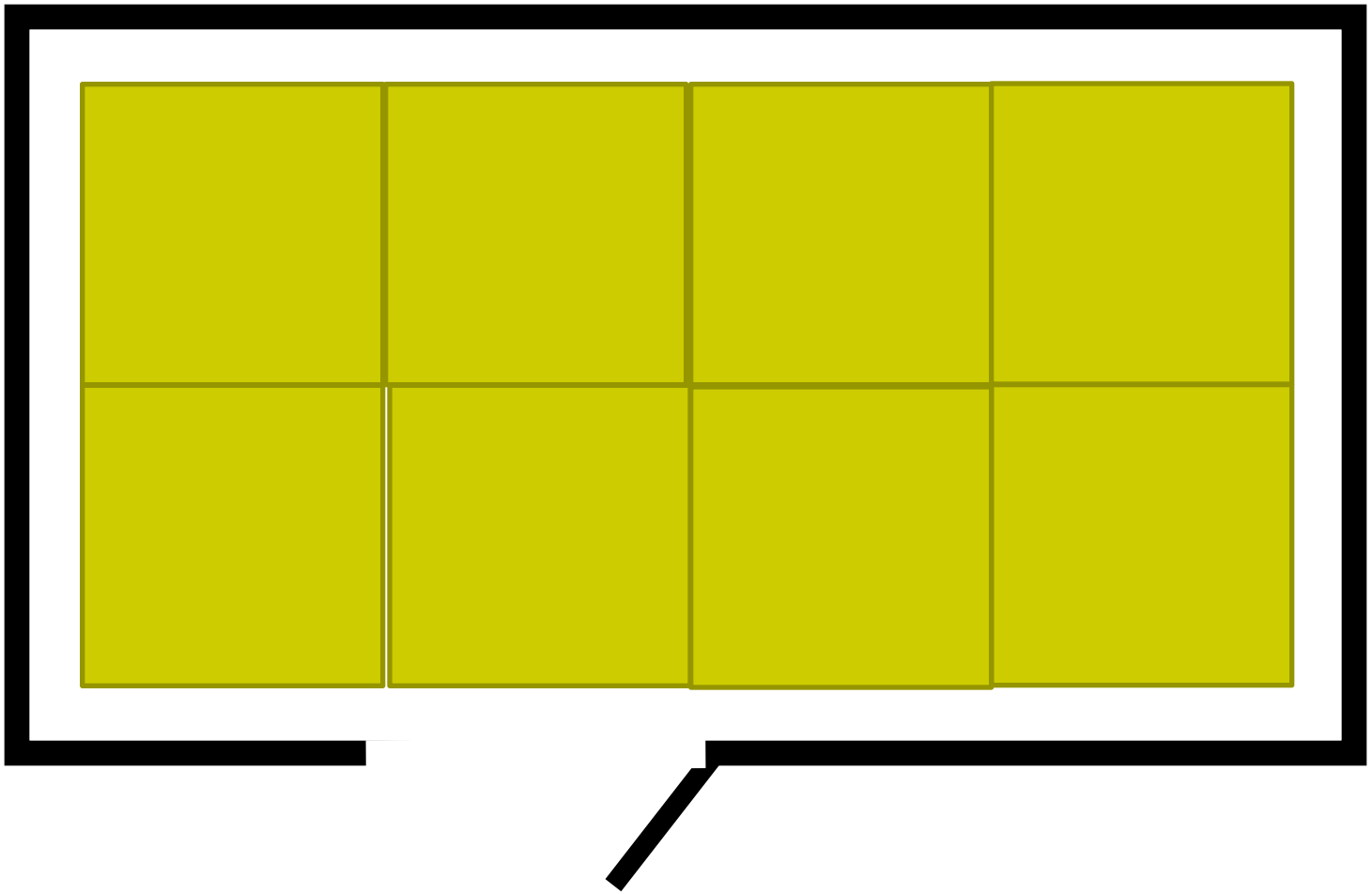
Layout Issues

- Door location doesn't allow maximum number of containers



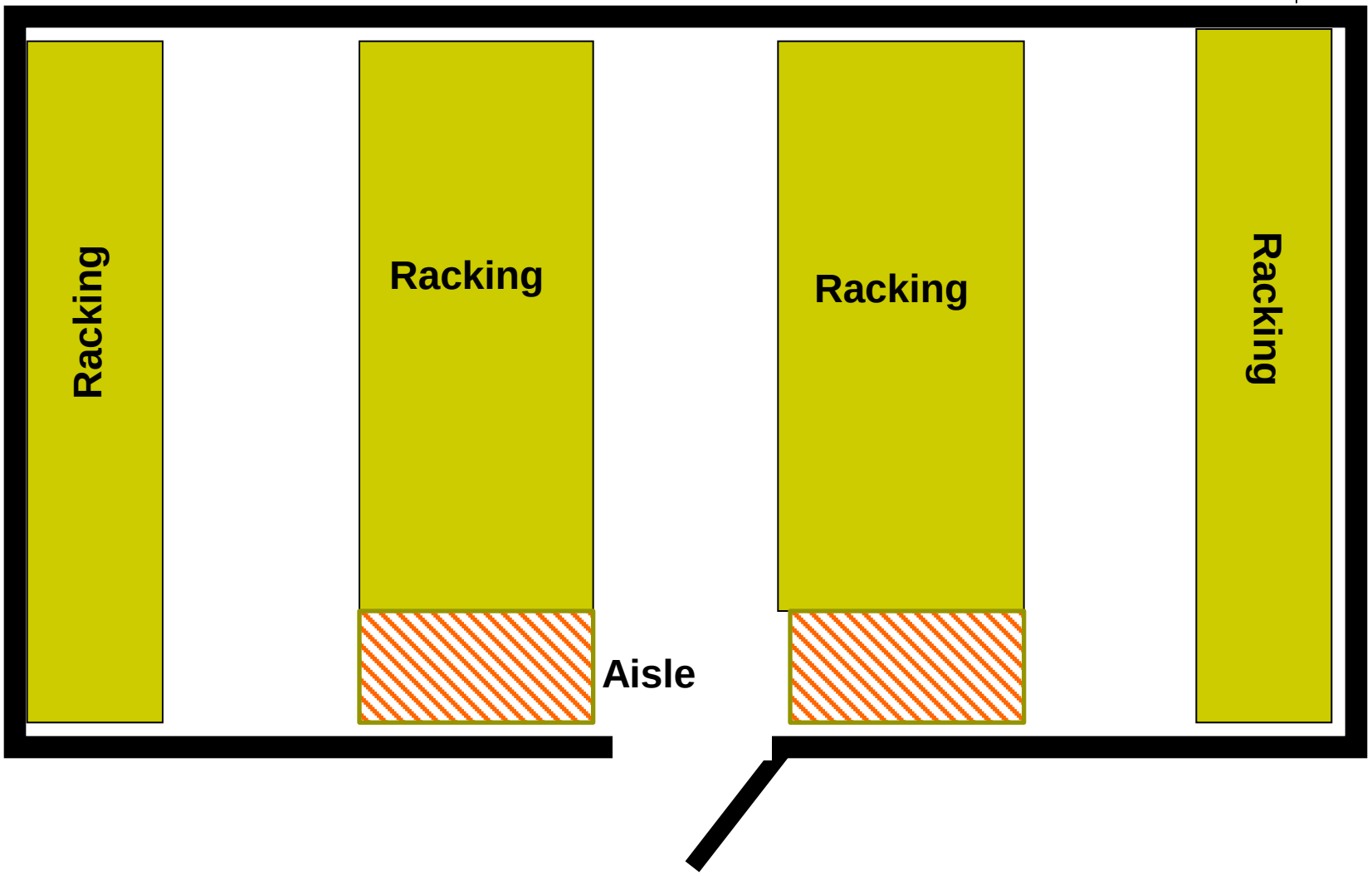
Layout Issues

- Door location
- Allows last container to go straight in.



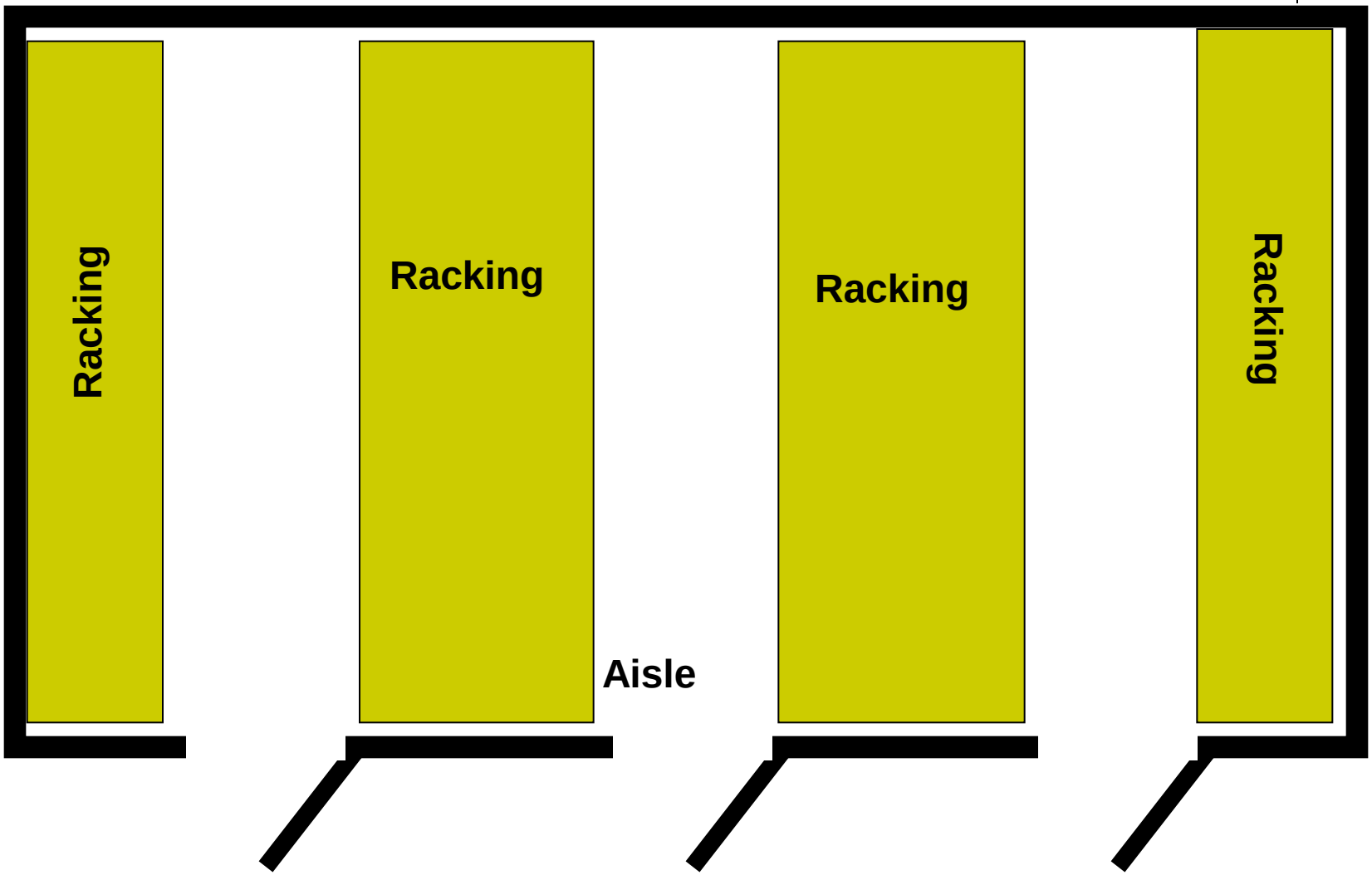
Layout for accessibility

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



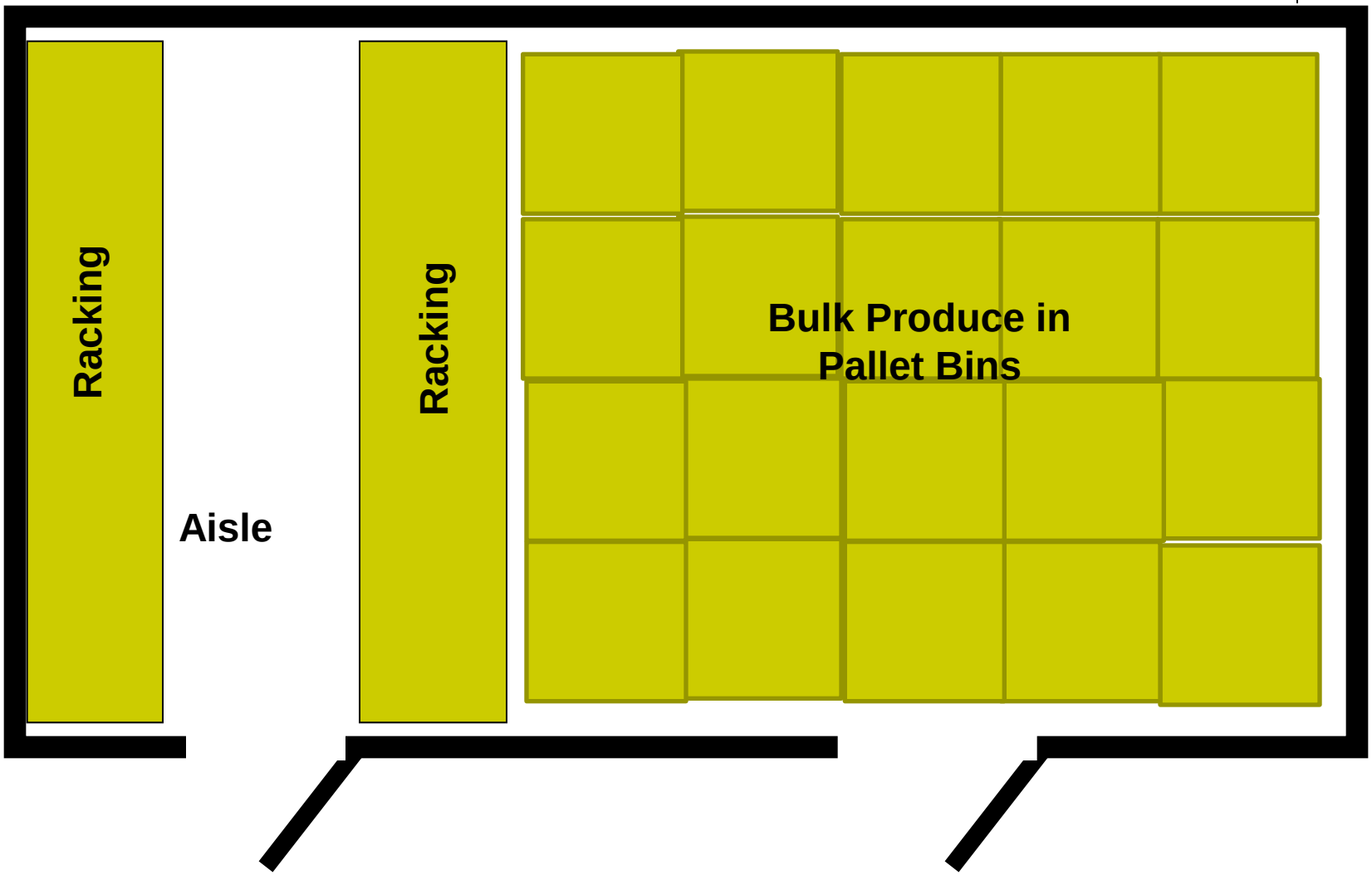
Layout for accessibility

- 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

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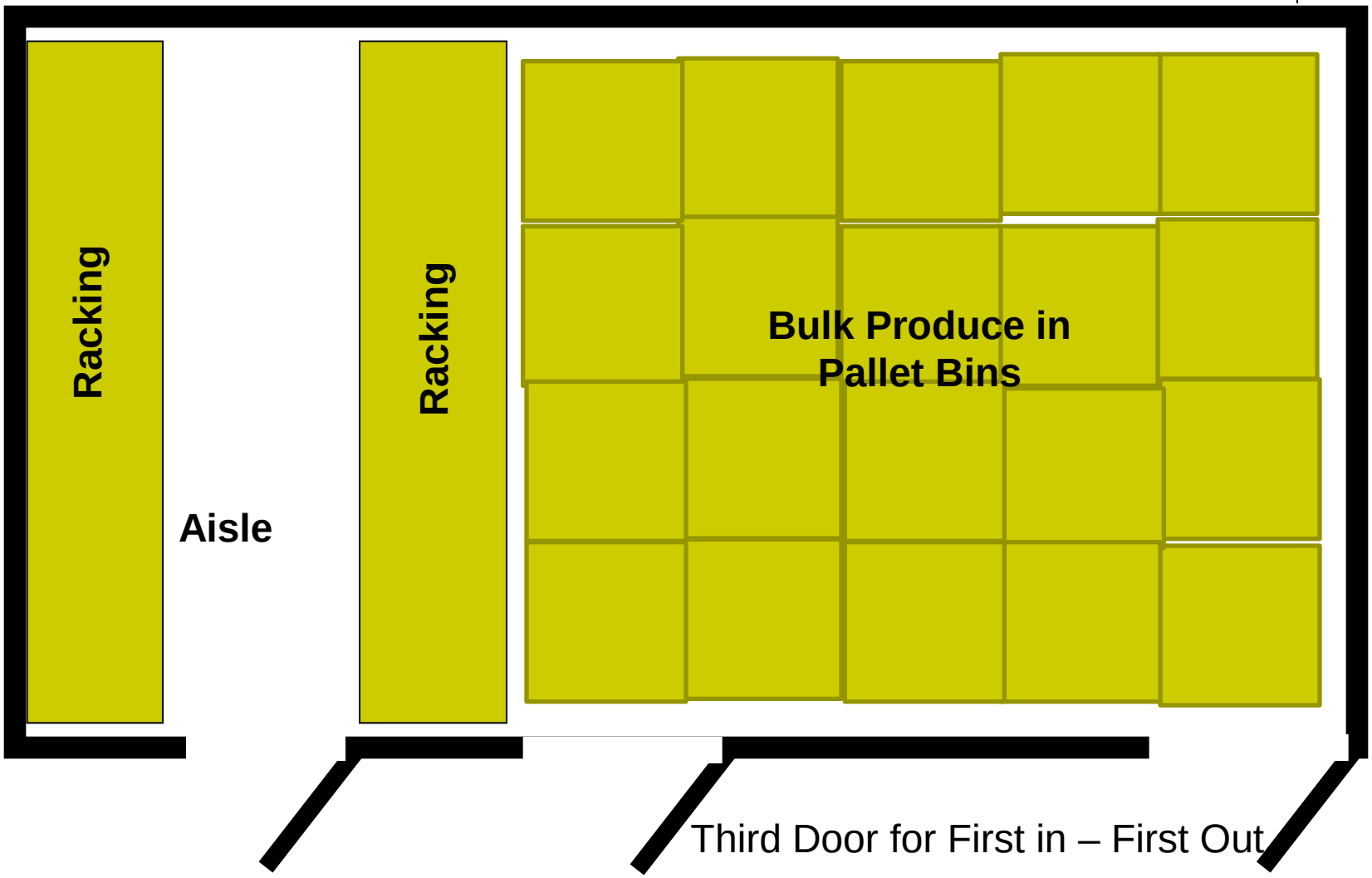
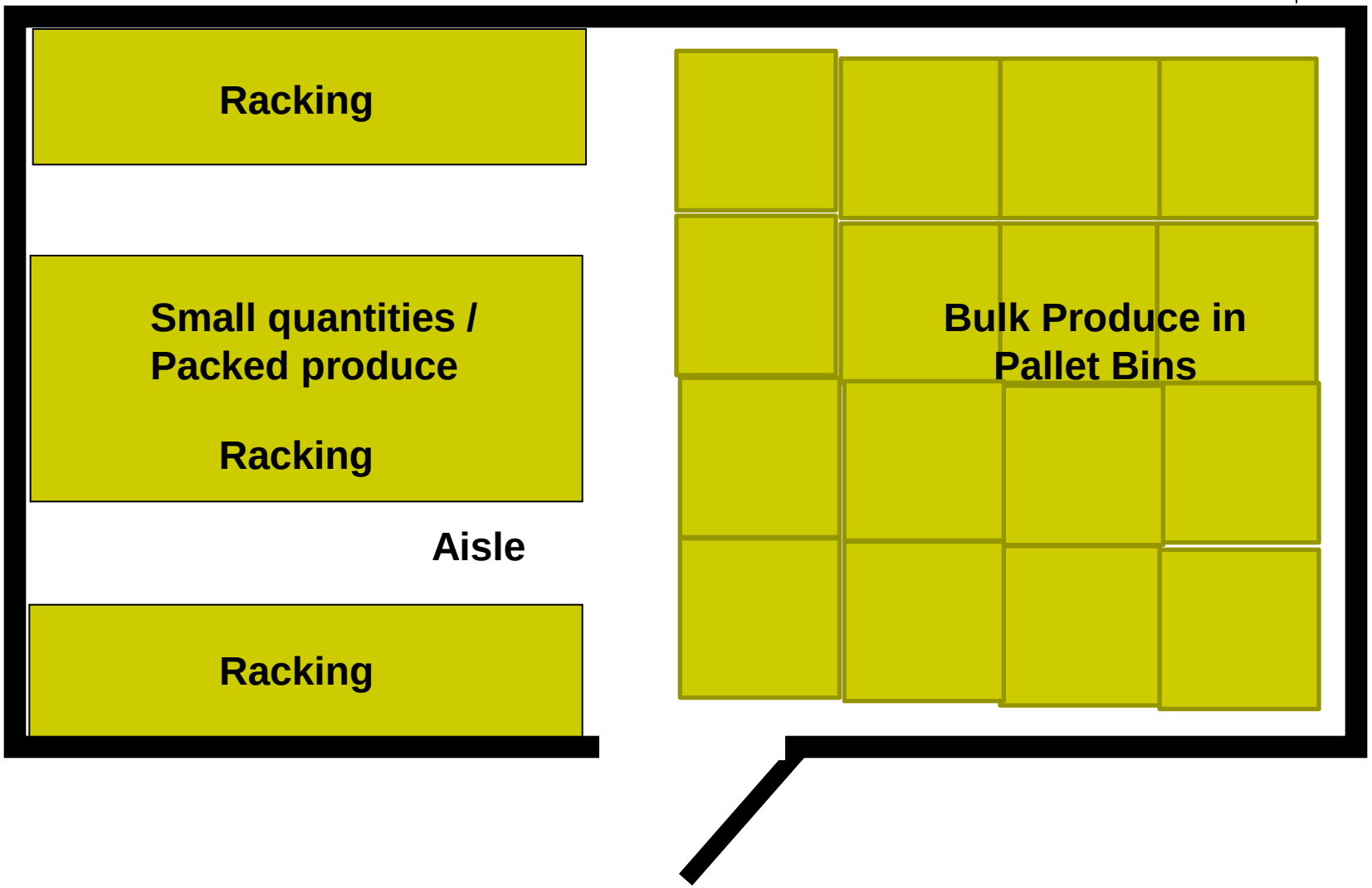


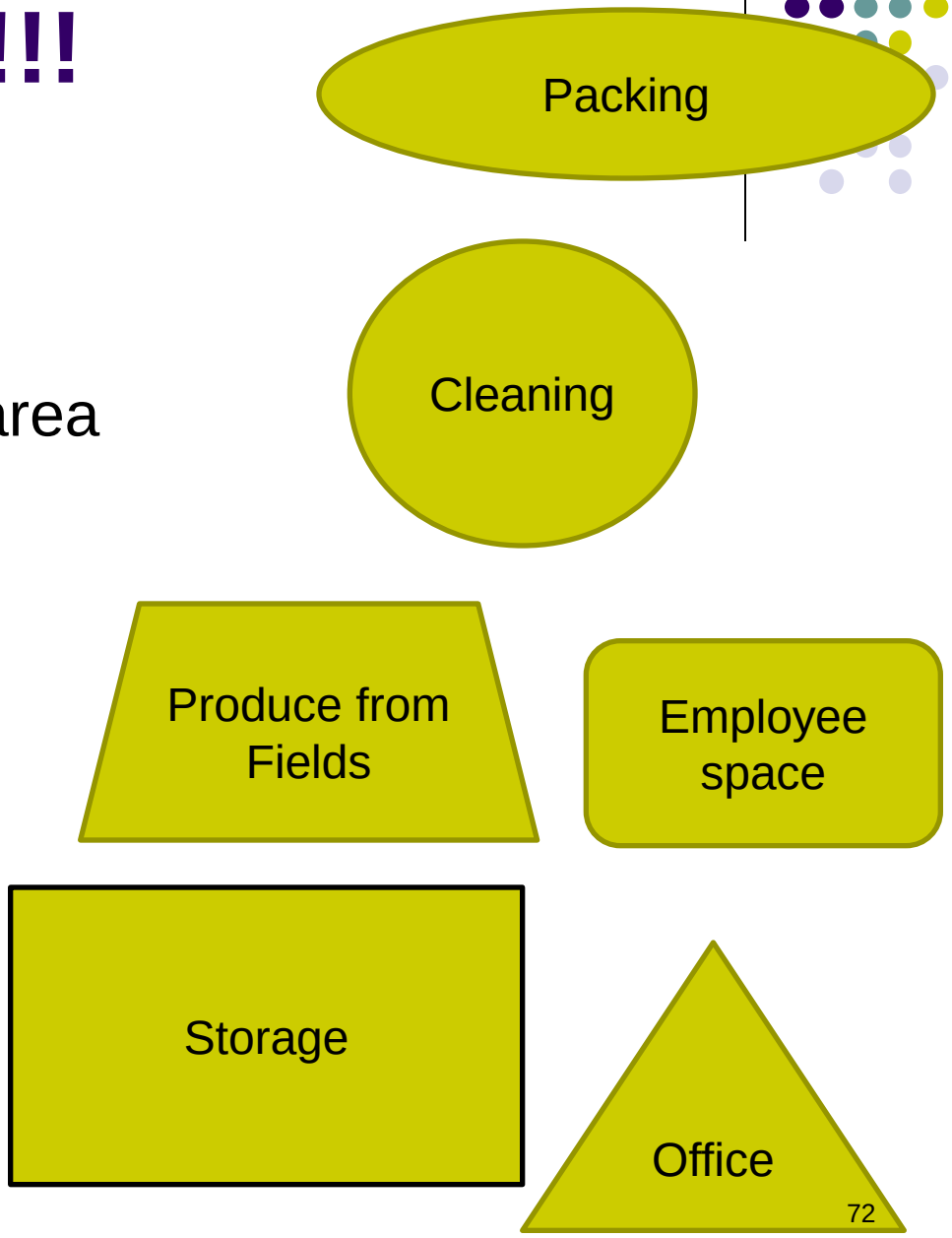
Layout for accessibility

- Small quantities / fragile goods / packed produces

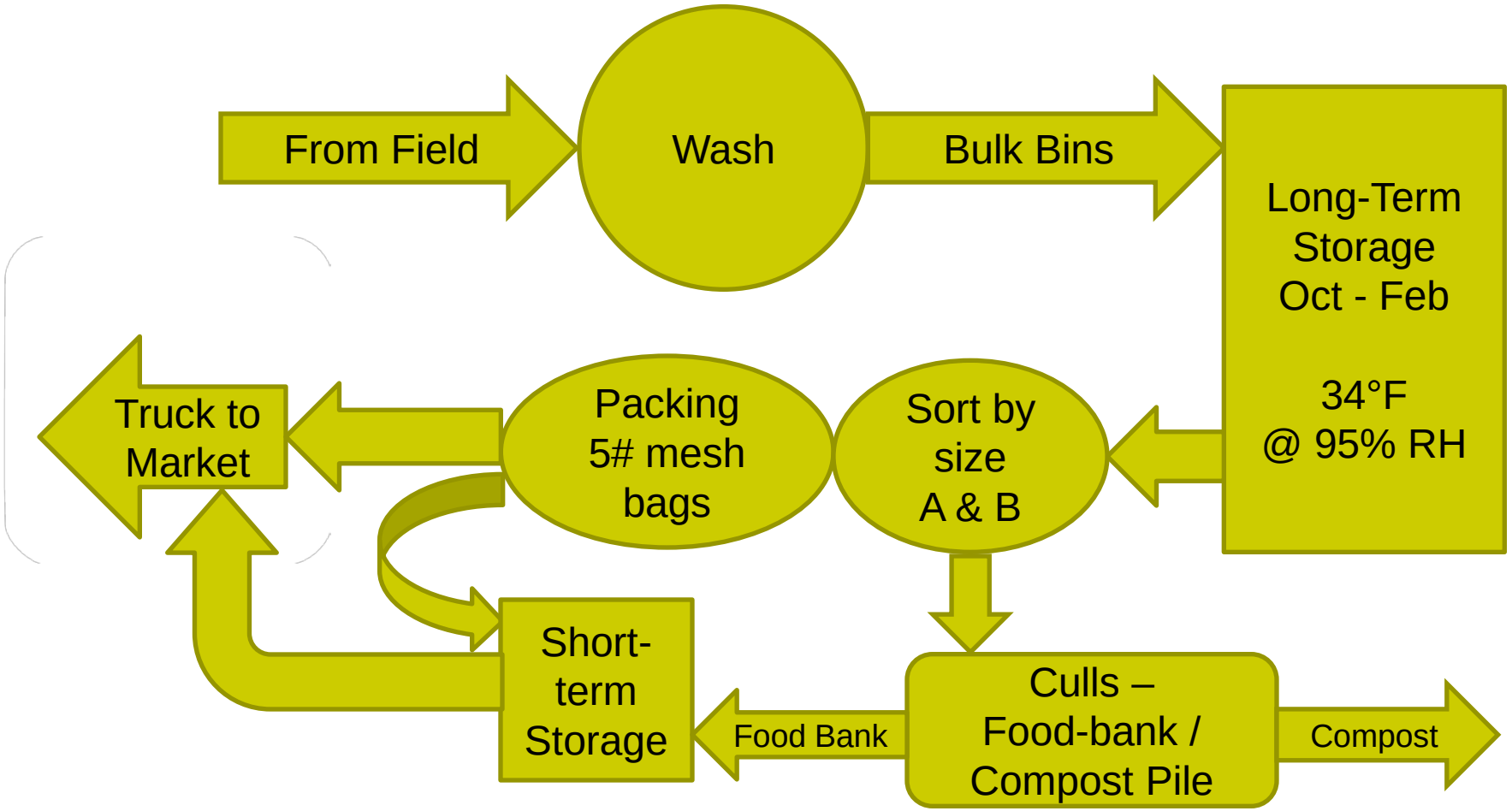


Planning!!!

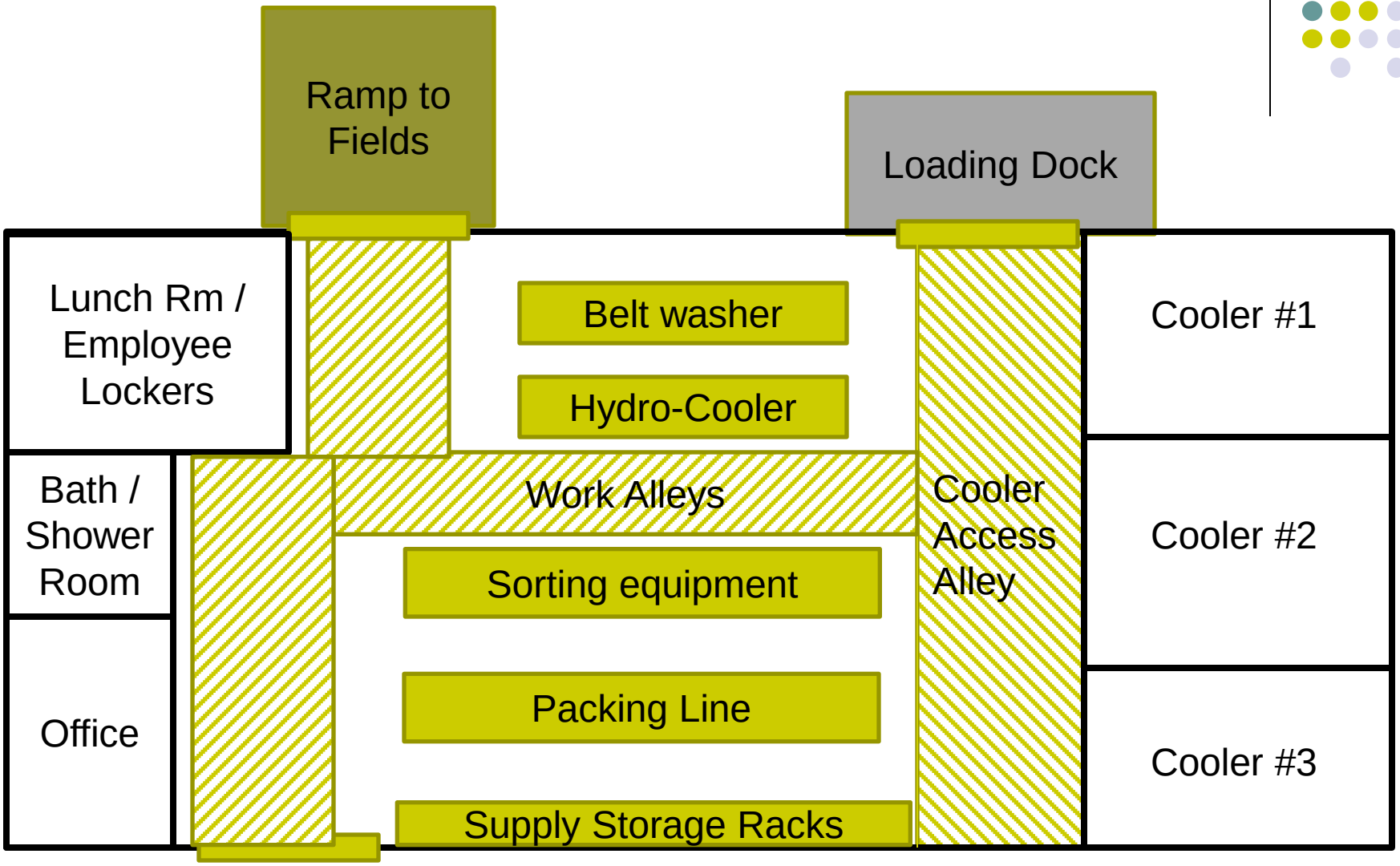
- Space requirements
- Material Flow
  - Access to processing area
- Material Handling
- Utility needs
  - Water
  - Electricity
  - Drains/waste
  - Temperature
- Labor
- Future Expansion



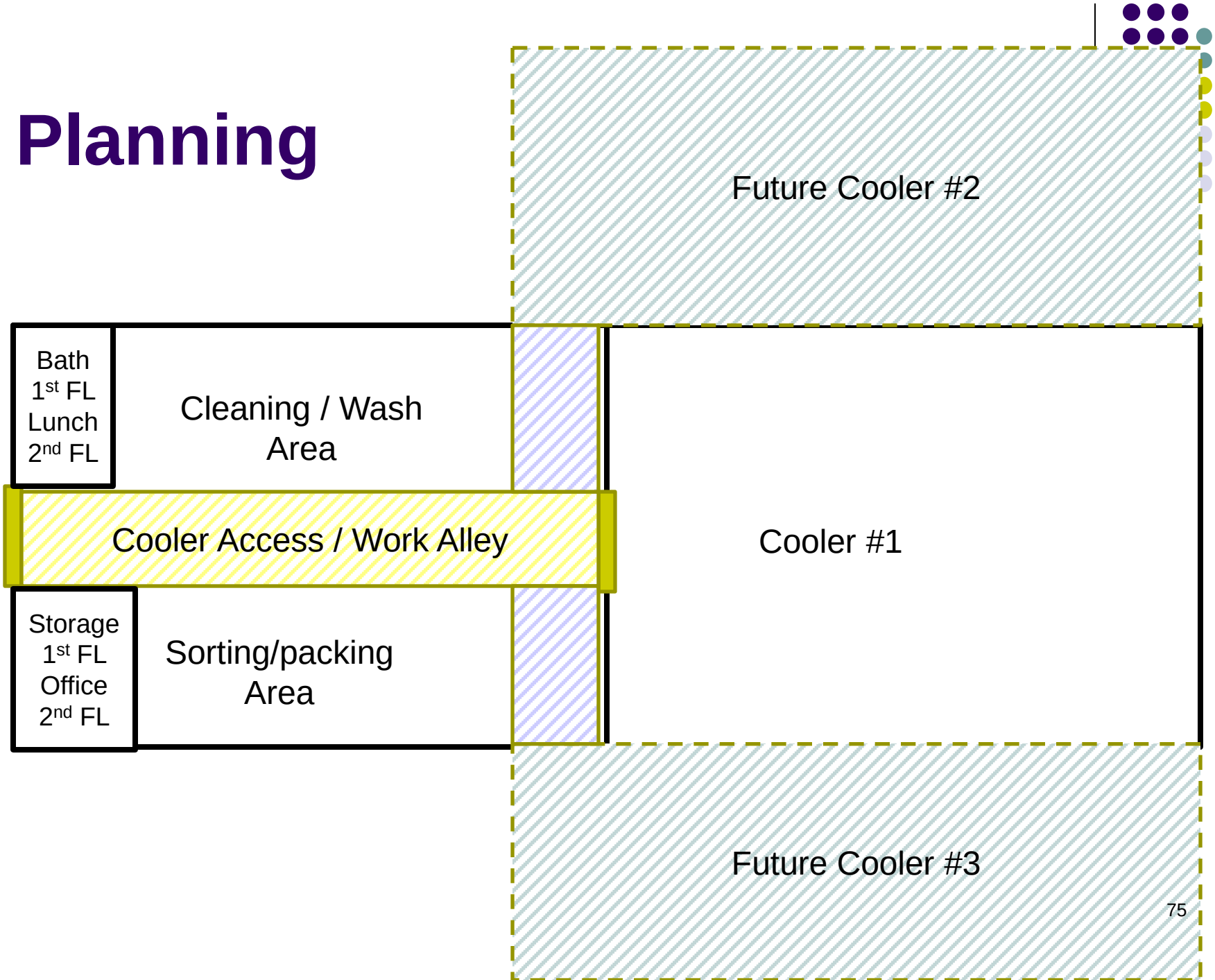
Flow Charts – by crop



Building Layout



Planning


Future Cooler #2
Bath
1st FL
Lunch
2nd FL
Cleaning / Wash Area
Cooler Access / Work Alley
Cooler #1
Storage
1st FL
Office
2nd FL
Sorting/packing Area
Future 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)

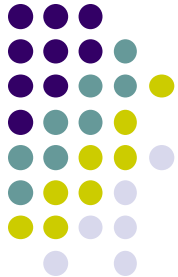
Costs and Pricing

- 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’)



	---------- 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								

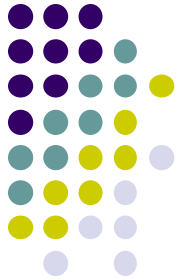
Shrinkage and Labor Costs

- 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/FSA/webapp?area=home&subject=prsu&topic=flp-fp**

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

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  http://www2.ca.uky.edu/agc/pubs/aen/aen96/aen96.pdf
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Questions??

Scott Sanford
Senior Outreach Specialist
Biological System Engineering
University of Wisconsin
sasanford@wisc.edu
608-262-5062

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