Engineering Winter Storage Facilities for Vegetable Crops

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Green Giant
CARROTS
PRODUCE OF U.S.A.
NET WT 5 LB (2.27kg)
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02 01 2006


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Storage is NOT a Hospital:

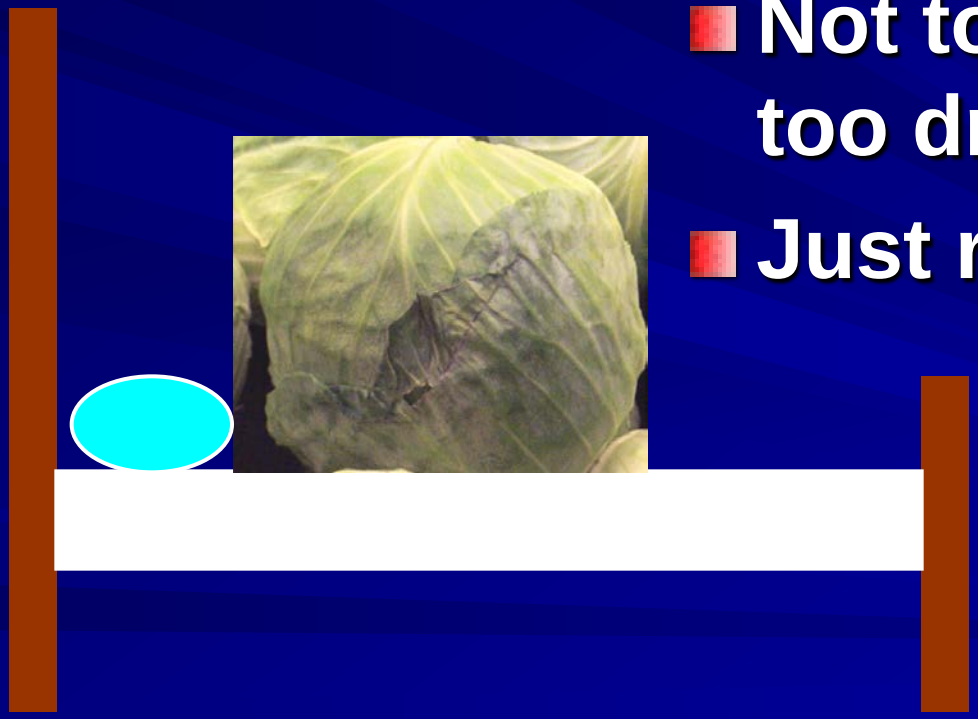
- Do our best to maintain crop quality and minimize weight loss.
- Deliver the best possible product to our customers.
- Maximize returns.

The Three Most Important Factors For Successful Winter Storage of Vegetables:

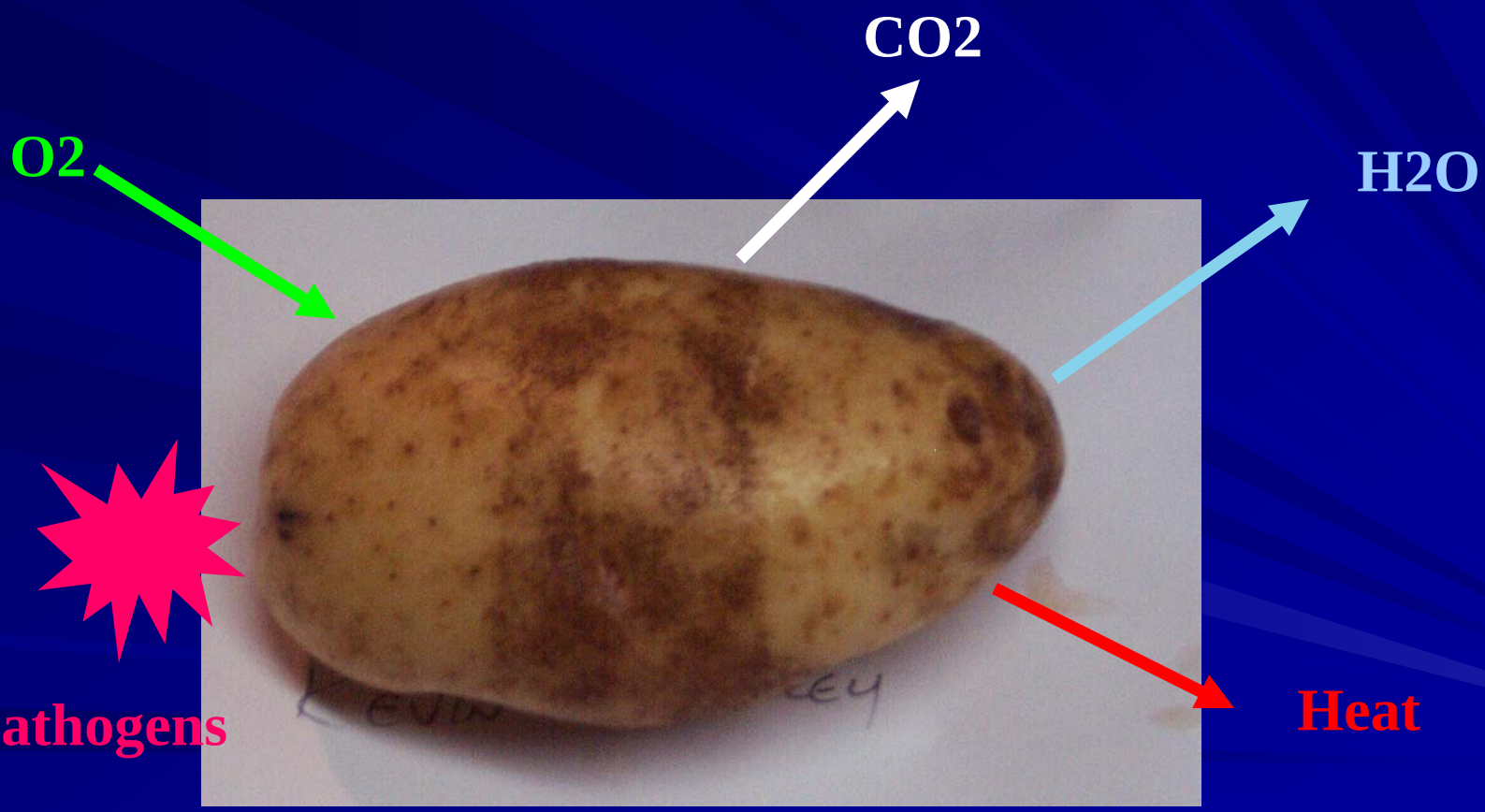
- Clean and dry.
- Free of Disease.
- Free from Harvest Injury.

Storage is a period of rest:

- Not too warm, not too cool.
- Not too humid, not too dry.
- Just right!



Vegetables Respire in Storage



Vegetable Storage Guidelines

Crop	Bulk Density # / cu.ft.	Storage Temp. Deg. F	Relative Humidity %	Airflow Cfm/cwt	Heat of Respiration Btu/ton/day	Time months
Onions	46	32 – 45	70 - 75	2.0 – 2.5	900 - 2500	1 - 8
Garlic	43	32 – 50	60 - 70	2.0 – 2.5	900 – 3100	6 - 7
Carrots	40	32 – 35	90 – 98	0.5 – 1.0	800 – 1400	5 - 6
Squash	40	40 – 55	50 – 70	1.5 – 2.0	5000 – 7500	4 - 6
Beets	48	32 - 40	90 – 98	0.5 – 1.0	1200 – 1900	4 - 6
Potato	40	38 - 45	95 - 100	1.0 – 1.5	800 - 2000	12
Rutabaga	40	32 – 35	98 – 100	1.0 – 1.5	1,500	4 - 6
Cabbage	36	32 – 38	98 - 100	1.0 – 1.5	1,000	5 - 6

Three General Storage Conditions

- **Cool and Dry** – onion and garlic
- **Cool and Humid –** carrot, beet, cabbage, rutabaga, potato
- **Warm and Dry** - squash

What is a Well Designed Facility ?

- Constructed to make interior environmental management possible and effective.
- Insulation to help maintain temperature (warm or cool) with minimal heating or cooling requirement.
  - Wall R-19 or better (6 in. f.g. / 4 in. styro)
  - Ceiling R-30 or better (10 in. f.g. / 6 in. styro)

What is a Well Designed Facility ?

- Insulation protected from physical damage and moisture.
- Structurally sound.
- Tight sealing doors to minimize infiltration.

How do we maintain optimum storage conditions?

- Well Designed facility – allows you to easily and efficiently maintain the desired environment.
- Ventilation and Refrigeration.
- Basic controls and equipment for managing the storage environment.

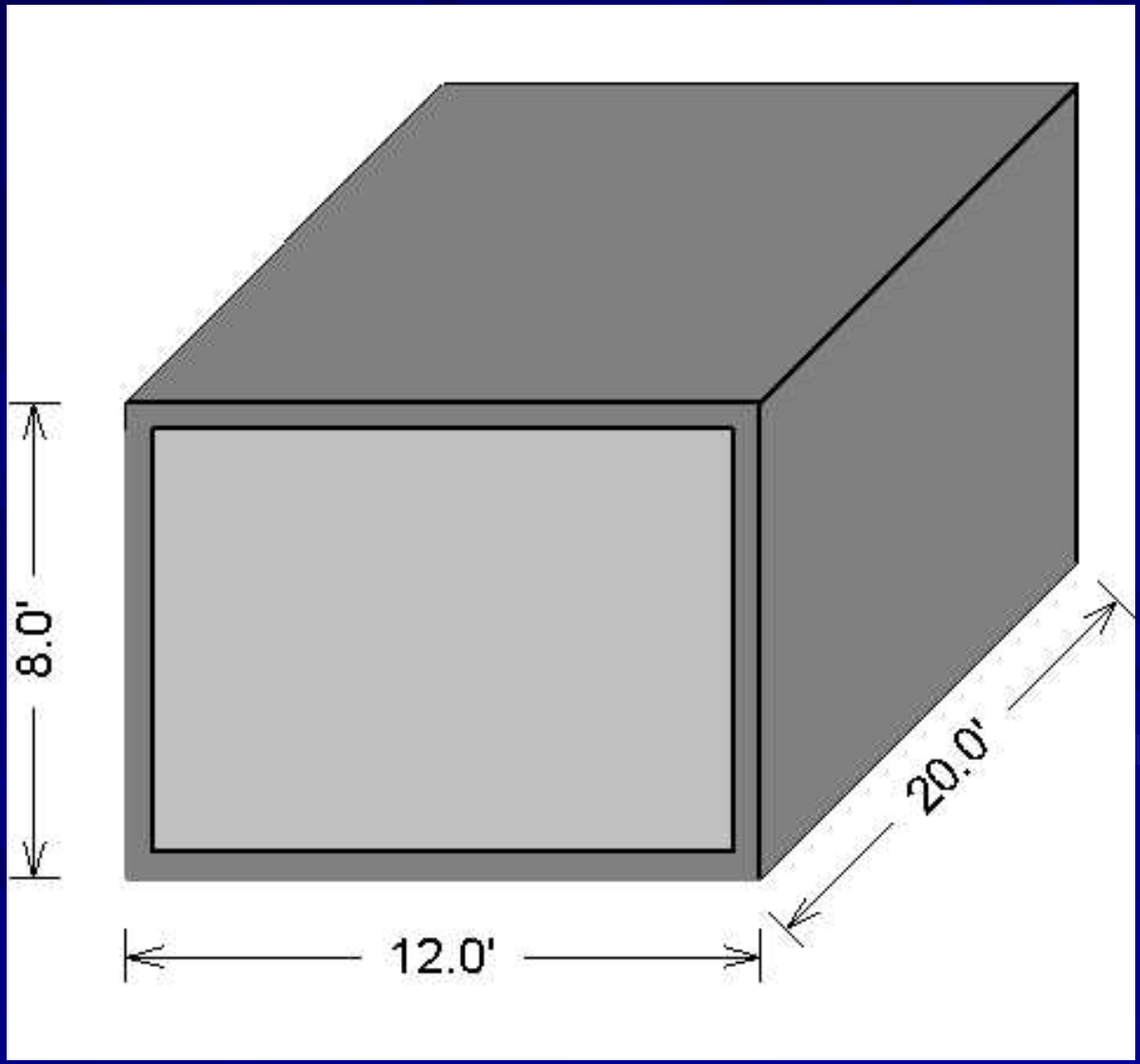
Factors in Effective Storage Environment Control

- Predictable storage space conditions
  - Relatively air tight
  - Insulated
  - Protected from weather extremes
  - Not subject to water infiltration

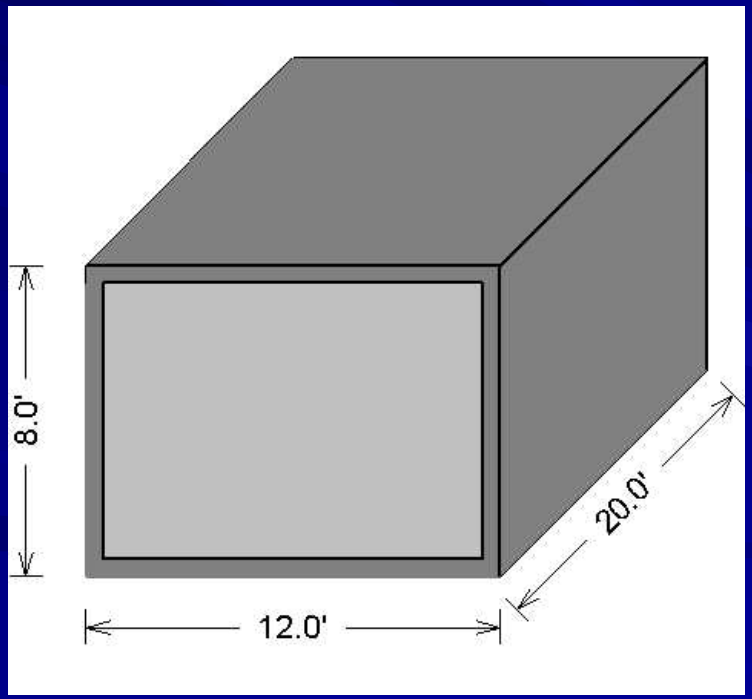
Well Designed Storage – Factors That Determine the Heating or Cooling Load in a Storage

- Heat loss or gain through the structure – CONDUCTION.
- Air infiltration from outside - CONVECTION.
- HEAT OF RESPIRATION from the stored crop.
- Heat produced by equipment and lights.

Conduction – Example Storage Unit

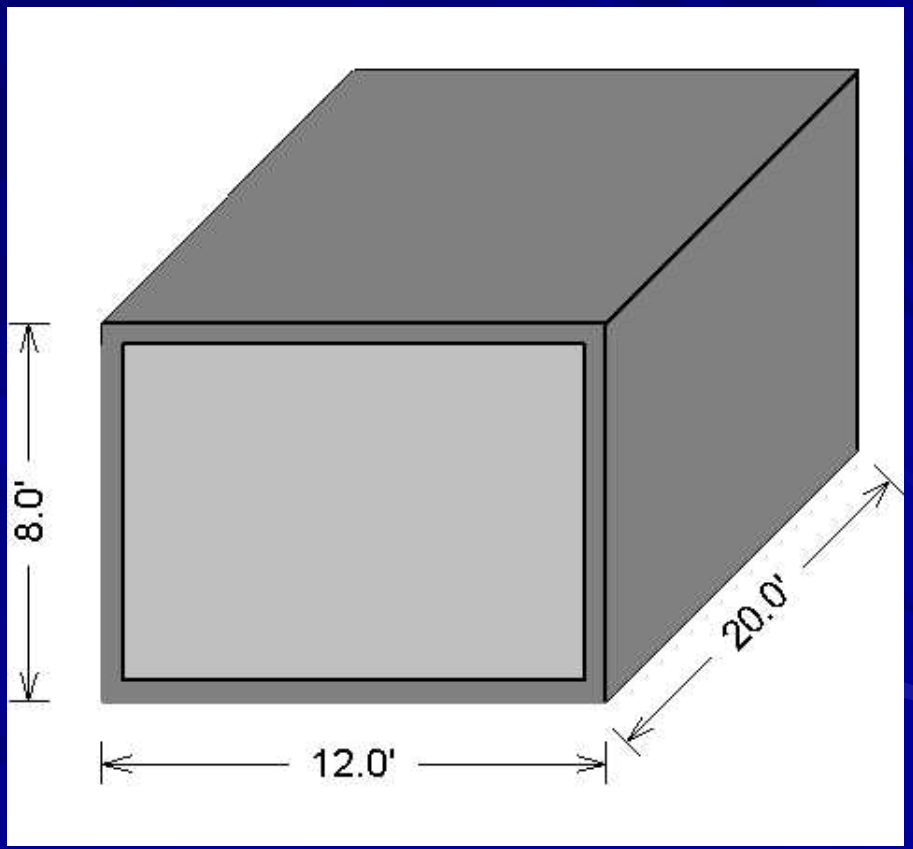


Major Question:
Insulate or Not Insulate?
or
How Much Insulation?

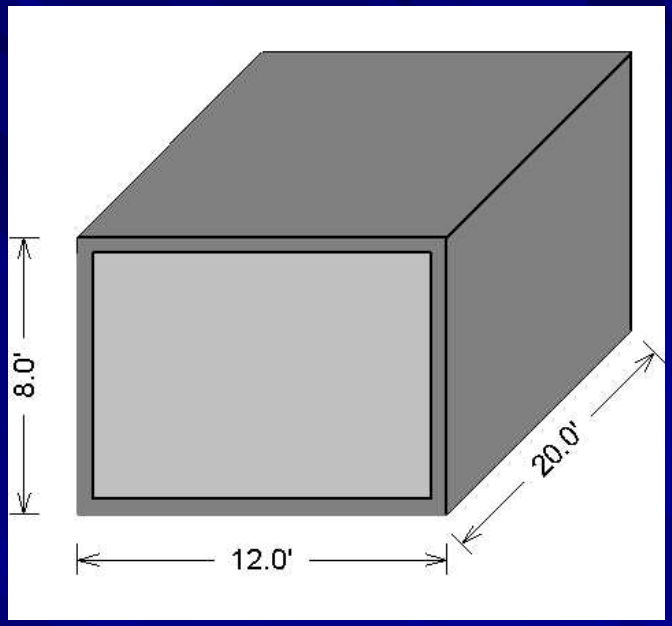


Frame or Panel Construction

- Outside – 5F
- Inside – 40F
- On concrete slab (ground temp.)



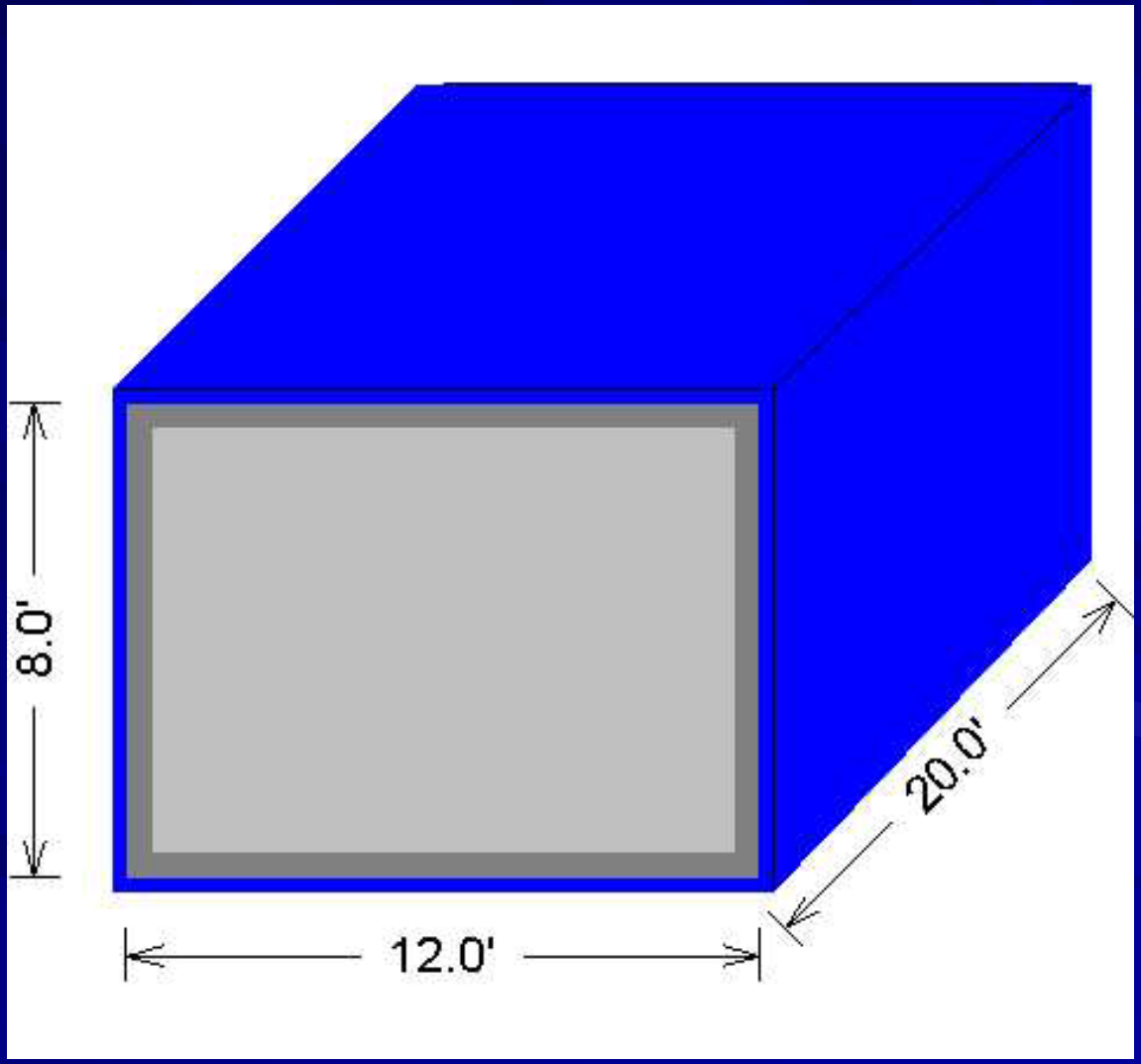
Estimated Heat Loss by Conduction with No Insulation



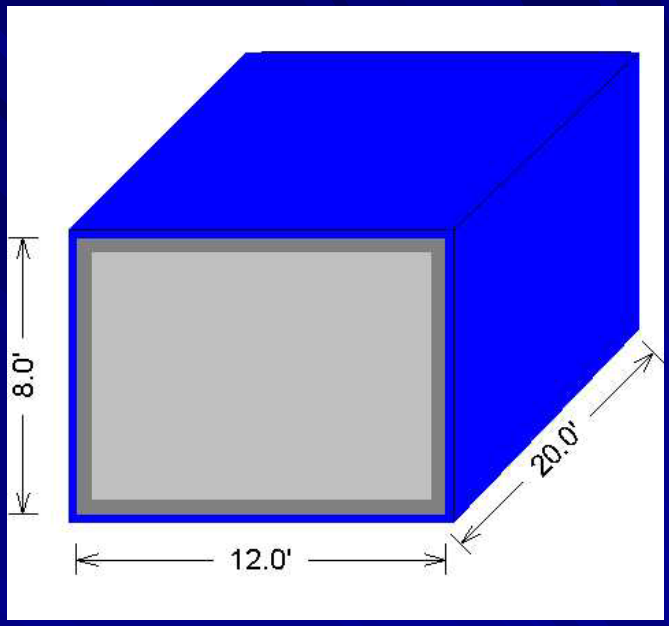
Building components (R-1)
Est. heat loss = 28,700 Btu / Hr.

3,412 Btu / Kw
(8.4 Kw @ $0.16 / Kwh = $32.00 / day)

Insulated Storage Unit

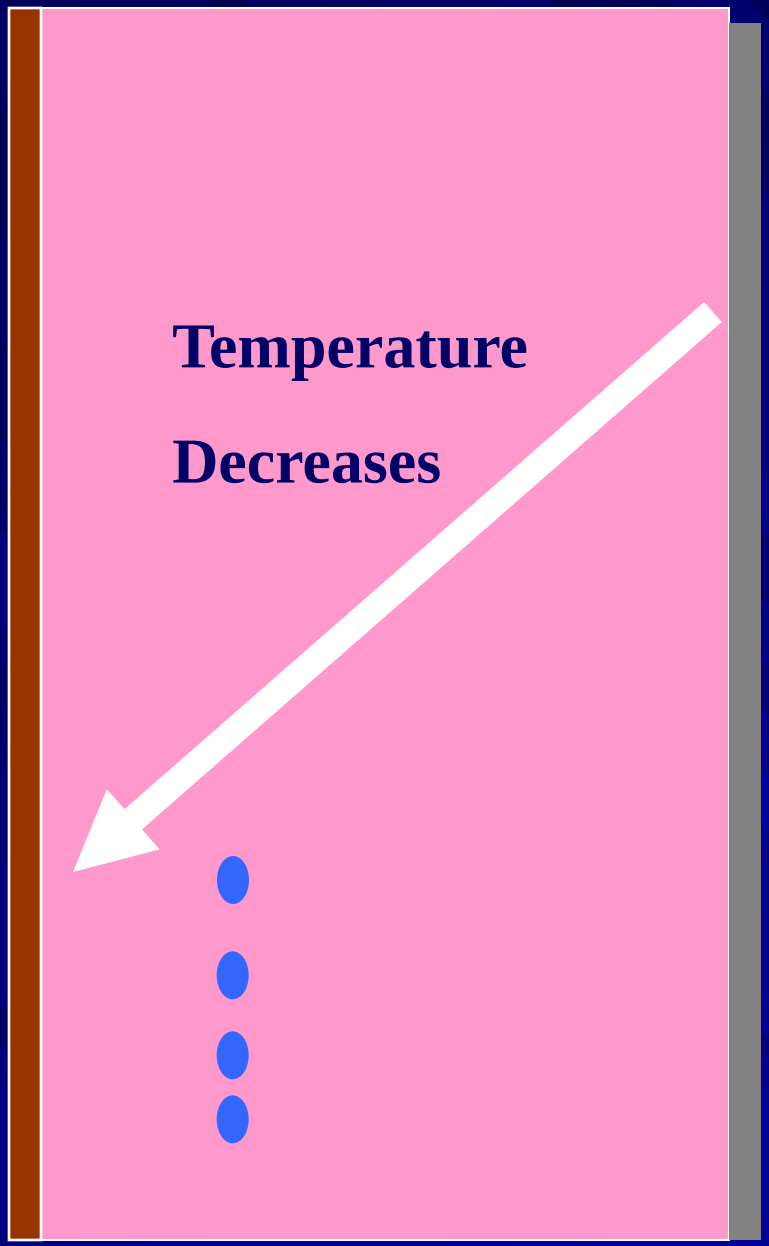


Estimated Heat Loss by Conduction - WITH Insulation



Insulation	Btu / Hr	Kw	$Cost /Day
None	28,700	8.4	32.00
R-10	2,872	0.85	3.36
R-20	1,556	0.46	1.77
R-30	1,117	0.33	1.26

F. G. Insulated Wall - Heating



Inside - 40 F

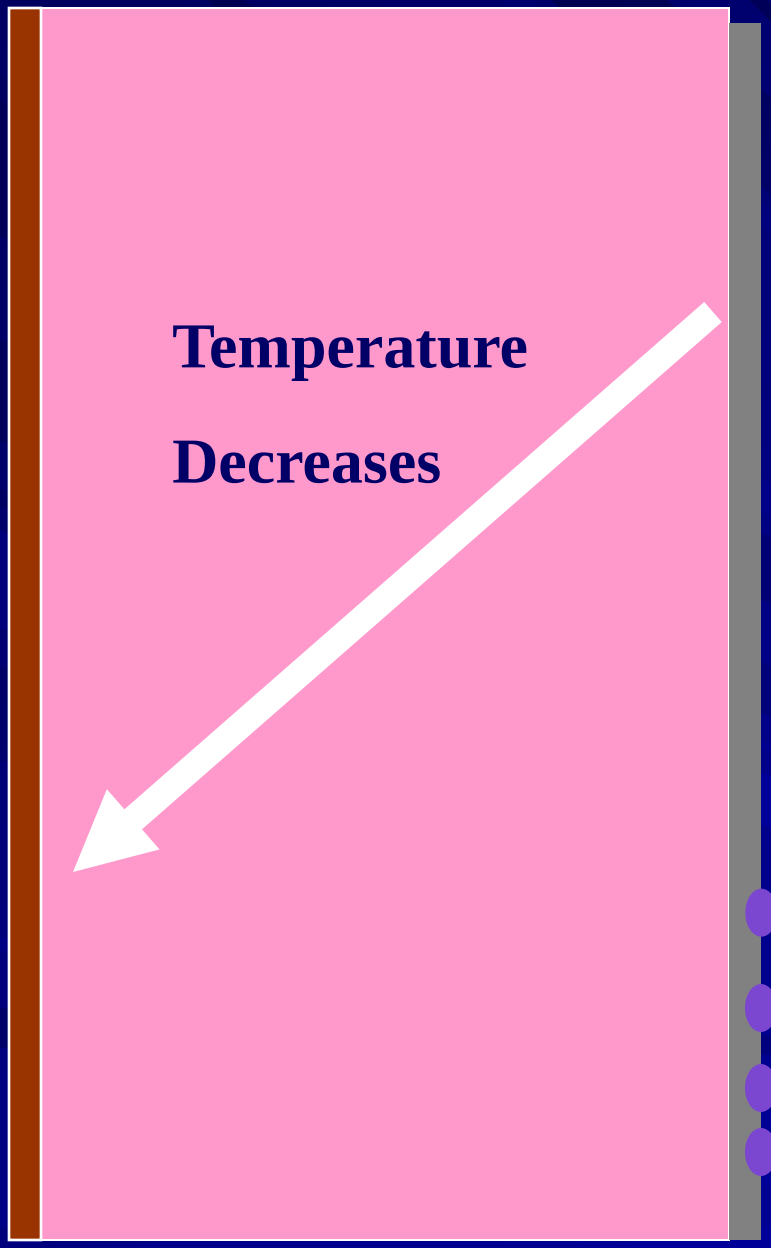
95% RH

15 F

Out

Water Vapor

F. G. Insulated Wall - Heating



Inside - 40 F

95% RH

Temperature

Decreases

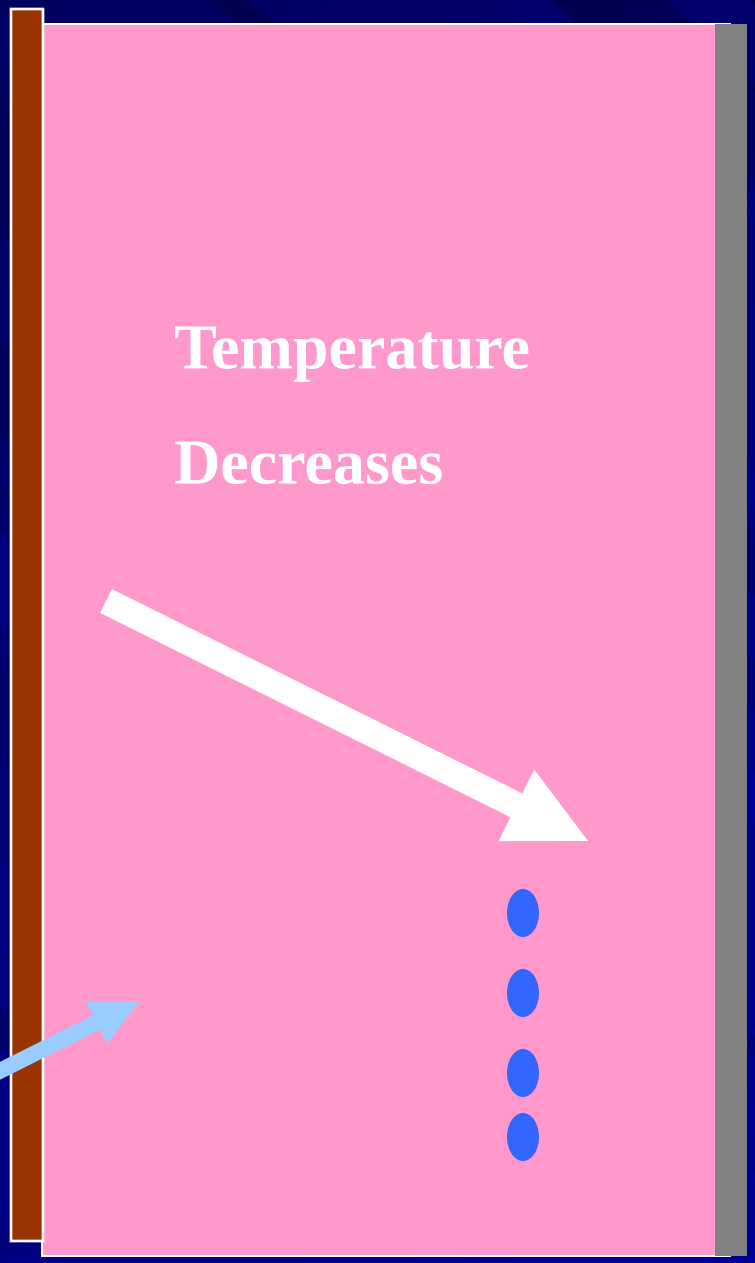
15 F

Out

Vapor Barrier

Water Vapor

F.G. Insulated Wall - Cooling



Outside 75 F

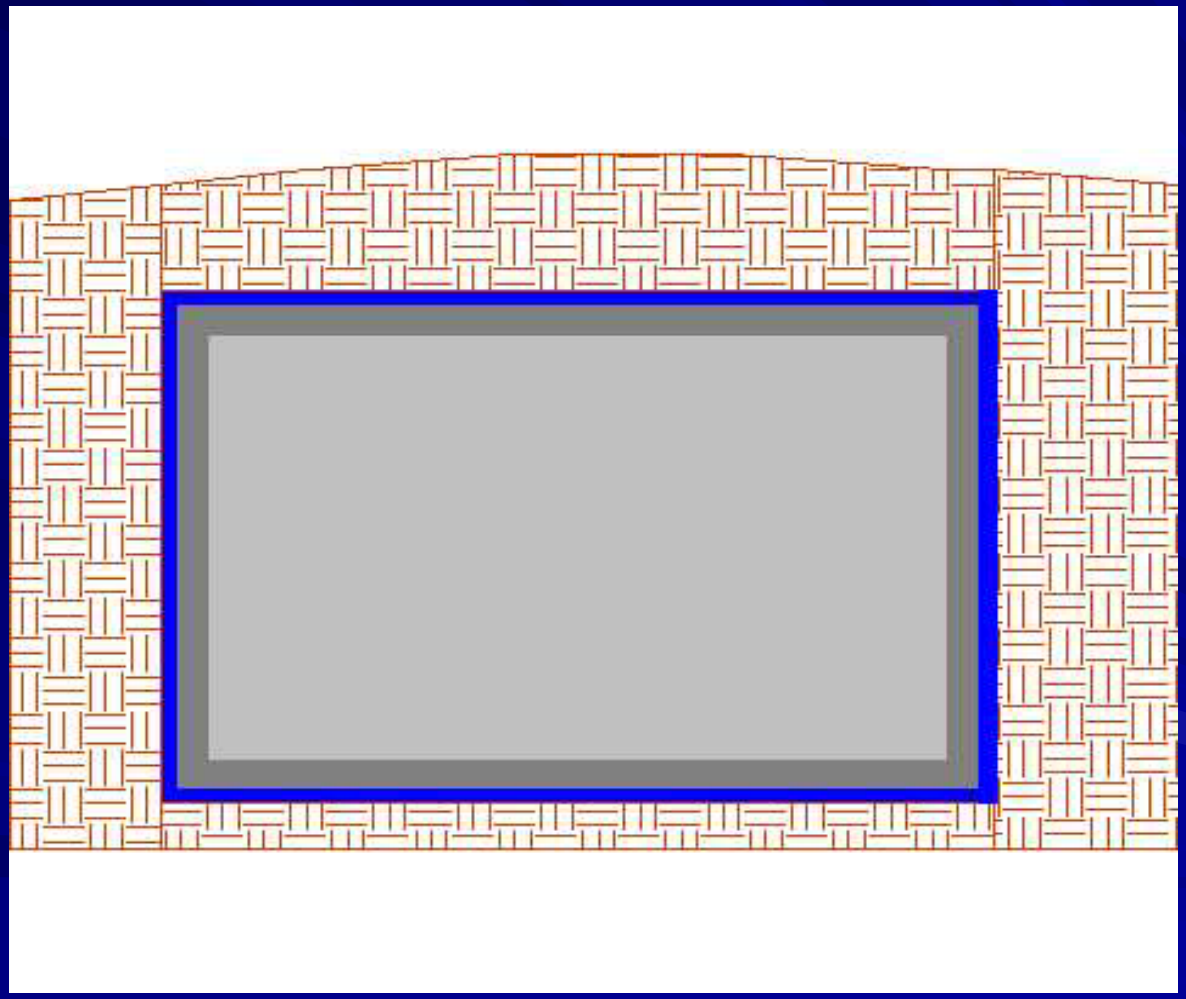
70% RH

40 F Inside

Water Vapor

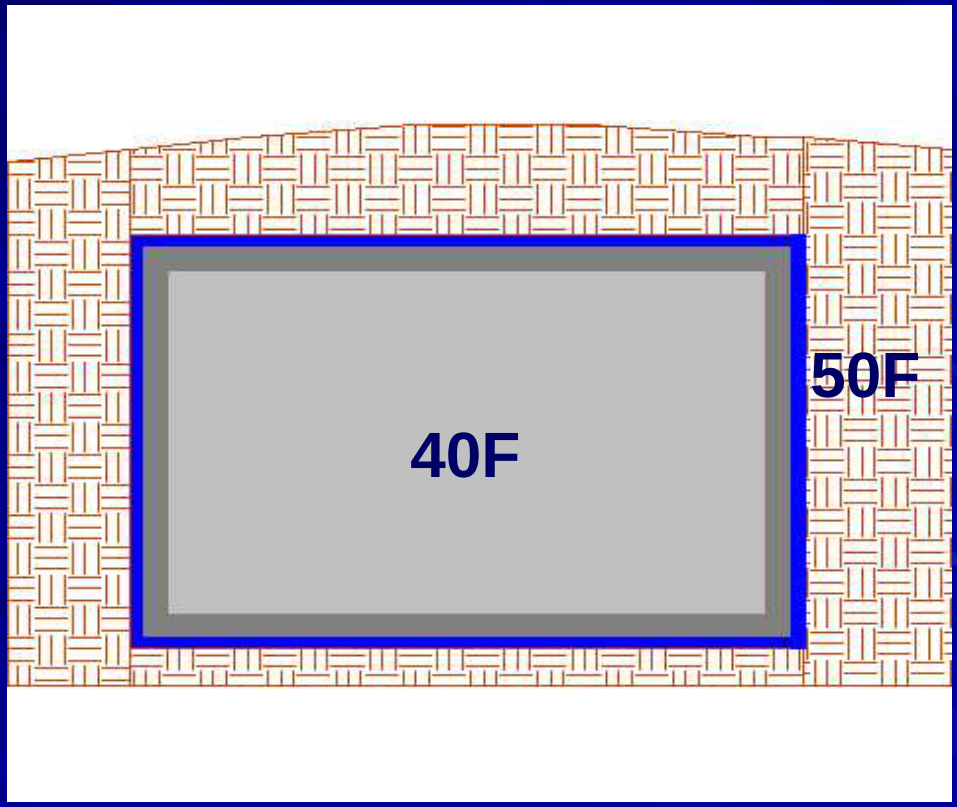
Where Should the Vapor Barrier Be??

In-ground Storage
- Protection From Extremes -

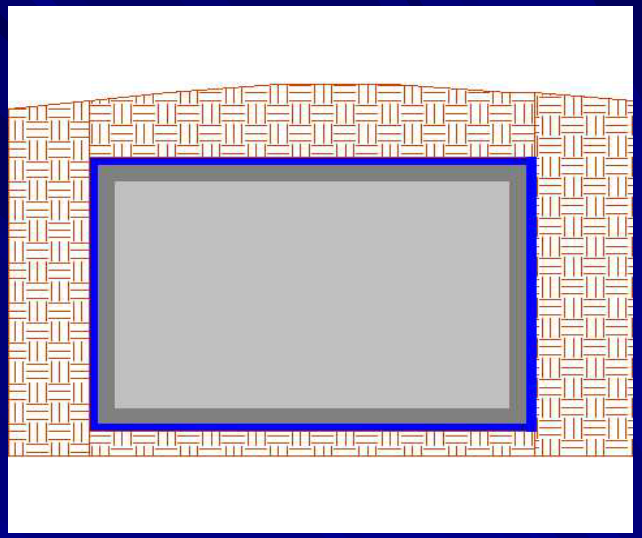


In-Ground Storage

- Inside - 40F
- Outside – 5F
- Ground temp – 50F



In-ground Storage Est. Cooling Load



Insulation	Btu / Hr	Tons Refrig.	Cost per Day $
None	4,960	0.41	1.43
R-10	992	0.08	0.29
R-20	616	0.05	0.17
R-30	491	0.04	0.14

Factors in Effective Storage Environment Control

- Predictable storage space conditions:
- Mechanicals:
  - Fan
  - Cooler
  - Humidifier
  - Heater
  - Controls

Moving Air Into and Within the Storage for Cooling

Cooling / Ventilating with Outside Air

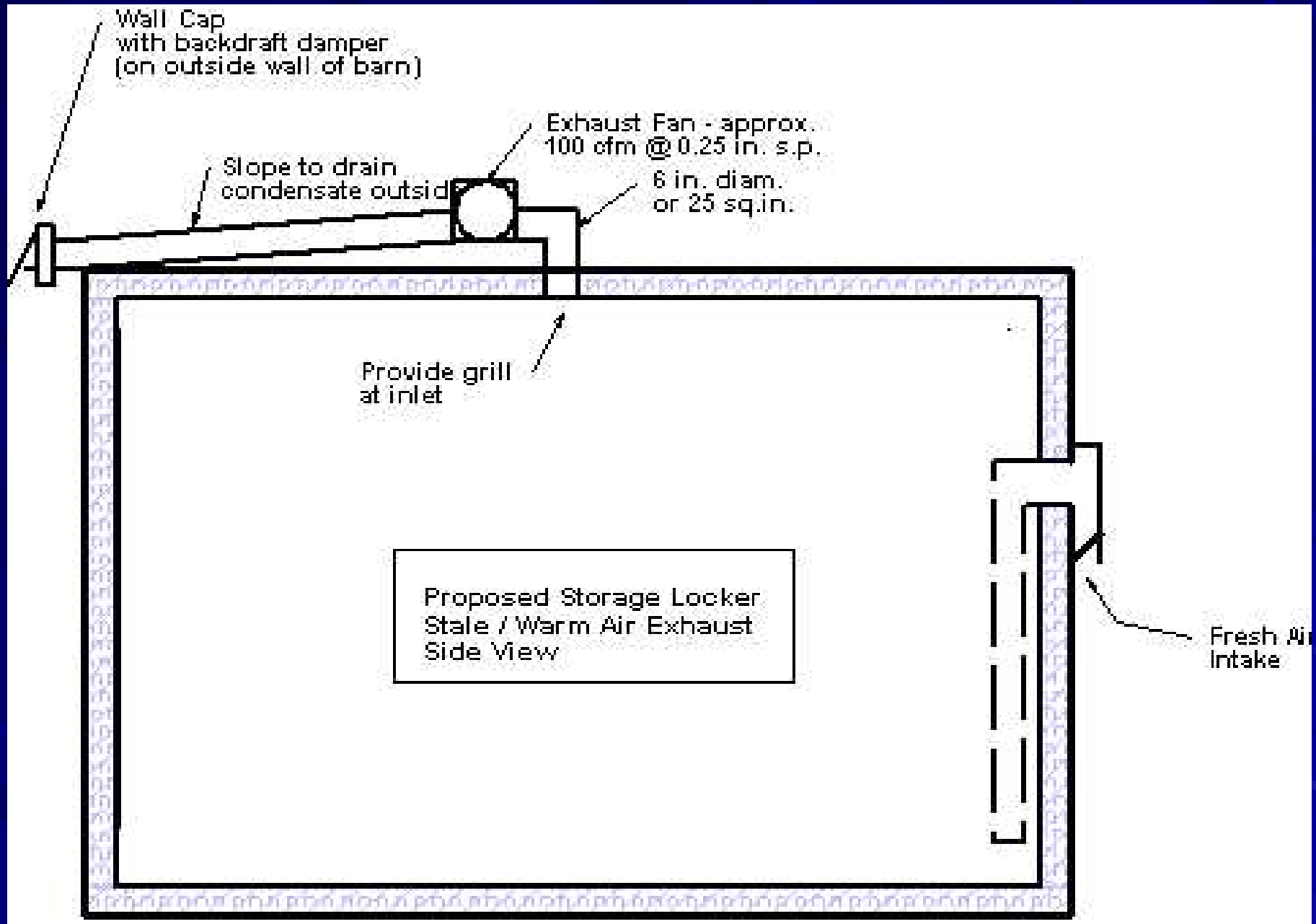
- Most economical cooling method.
- Amount of cooling air required will vary significantly from day to day and week to week as outside air temperatures vary and as cooling load in the storage locker changes.
- Requires at least minimal controls.

Ventilation

- Summer and early Fall – remove Field Heat and Heat of Respiration.
  - Usually requires refrigeration
  - Usually short term storage.
- Late Fall and Winter – remove heat of respiration.
- Also have to consider heat gain through structure.

Shell Ventilation

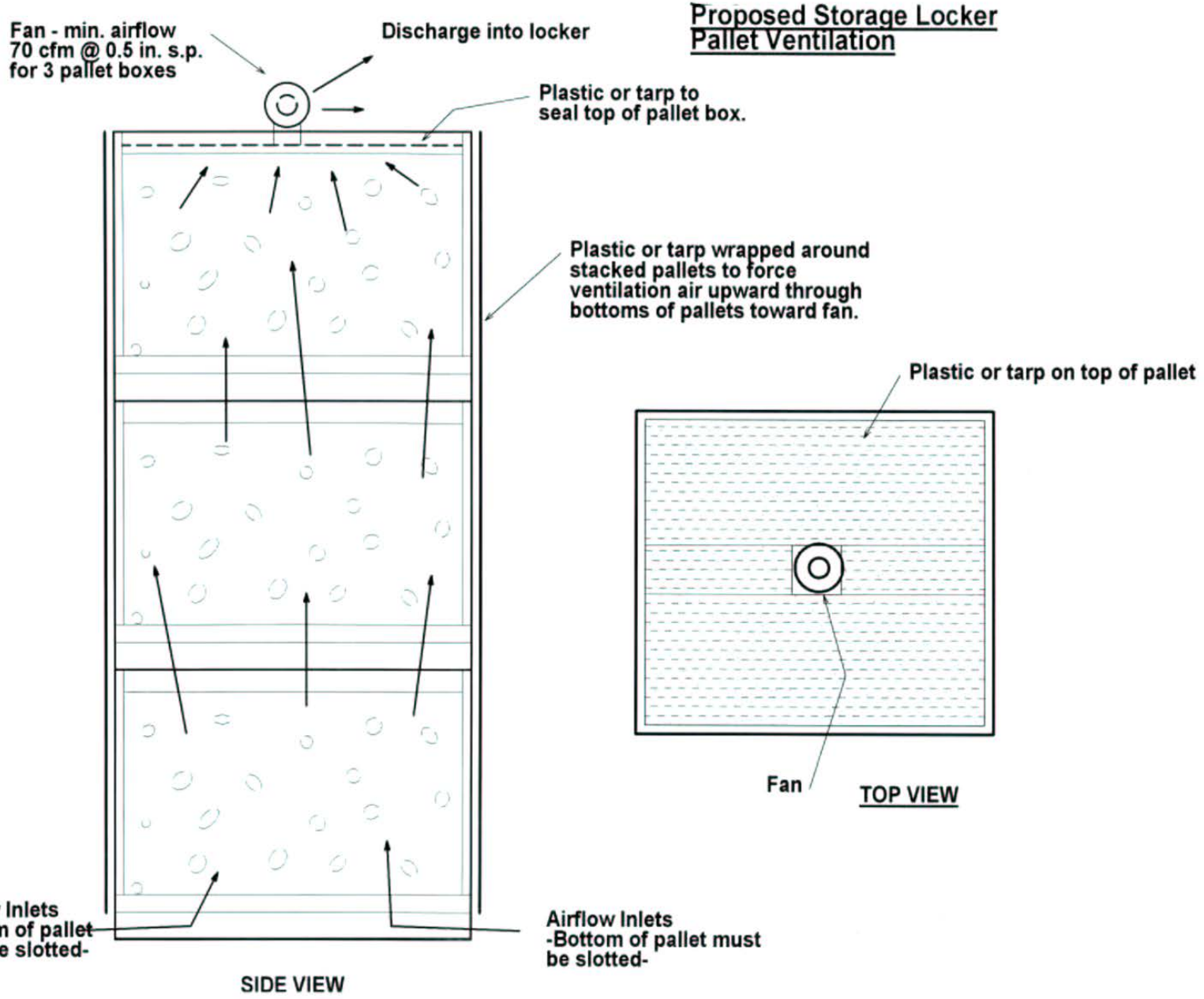
- Cools inside of locker or storage room.
- Produce relies on air circulation through room and around bins / bags.
- Generally need 0.25 – 0.50 cfm / cwt of stored product … or 4 to 8 air changes per hour (fan output @ 0.25 in. s.p.).
- Multiple fans or variable speed fans are most effective for varying conditions.


Wall Cap
with backdraft damper
(on outside wall of barn)
Exhaust Fan - approx.
100 cfm @ 0.25 in. s.p.
Slope to drain
condensate outsid
6 in. diam.
or 25 sq.in.
Provide grill
at inlet
Proposed Storage Locker
Stale / Warm Air Exhaust
Side View
Fresh Air
Intake

Fresh Air Intake and Exhaust

Pallet Boxes Stacked in Storage Unit

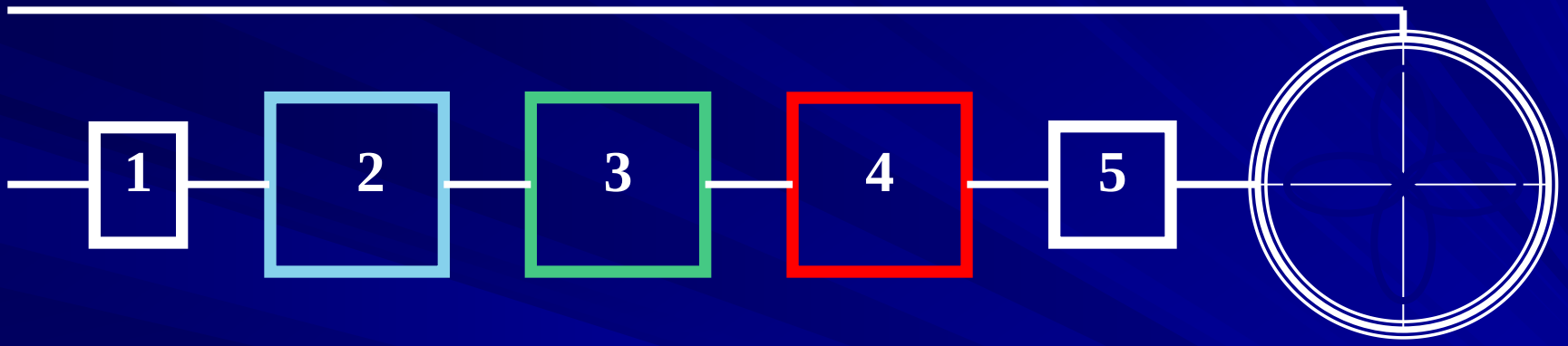
Proposed Storage Locker Pallet Ventilation



What Are Basic Controls and Equipment?

- Temperature sensor with readout
- Thermostats
- Heaters
- Humidification equipment
- Relative humidity sensing
- Air handling

Basic Ventilation Control Panel Components



1 – 24 hr. timer

2 – Low Limit Thermostat

3 – Inside Temperature Thermostat

4 – Outside Temperature Thermostat

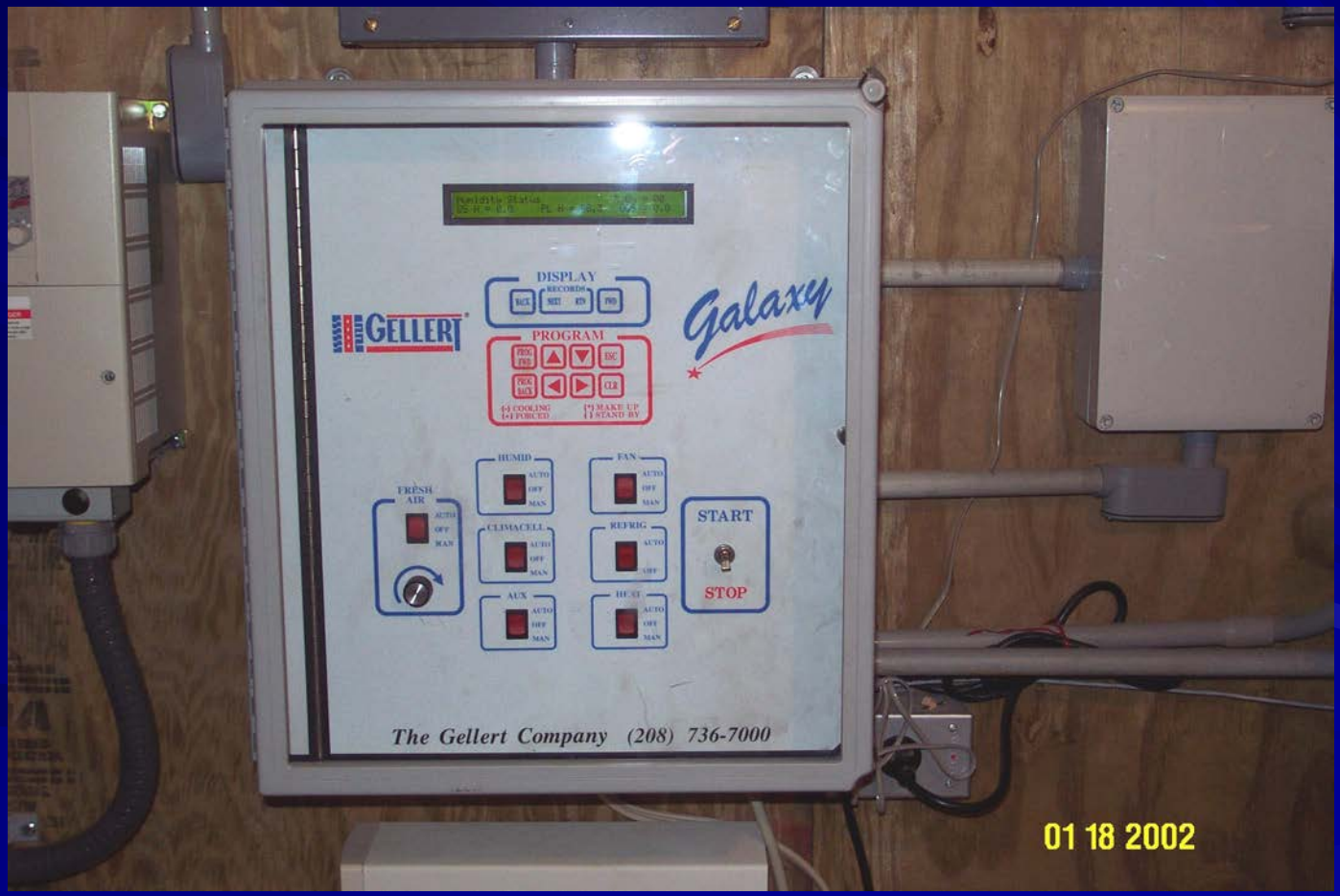
5 – On / Off Switch

Ventilation Fan

Prototype Basic Ventilation Control Panel


TORK
E101PB
DIGITAL TIME SWITCH
SPECIFICATIONS
WIRING INSTRUCTIONS & DIAGRAM
POWER IN
LOW TEMP
SHUT OFF
INSIDE AI
THERMOSTA
OUTSIDE AI
THERMOSTA
FAN
12/05/2011

Modern Computer Based Ventilation Control



Ventilation Fan

0.25 – 0.5 cfm / cwt

or

4 to 8 AC / Hr.

(Fan Capacity @ 0.25 in. s.p.)

Motorized Fresh Intake Damper

Air Handling Unit

Adding Humidity

- almost always required for long term storage

Portable Humidifier

Centrifugal Humidifier

Evaporative Media Humidifier

Evaporative Media Humidifier

Evaporative Cooler
= Humidifier + Cooler

Humidity Sensing

- Sometimes a Difficult Task -

Hygrometer


ABBEON
CERTIFIED HYGROMETER
usable in temperatures up to 250 °F
0/0 relative humidity
MADE IN WEST GERMANY

Digital Psychrometer

Electronic

Humidity

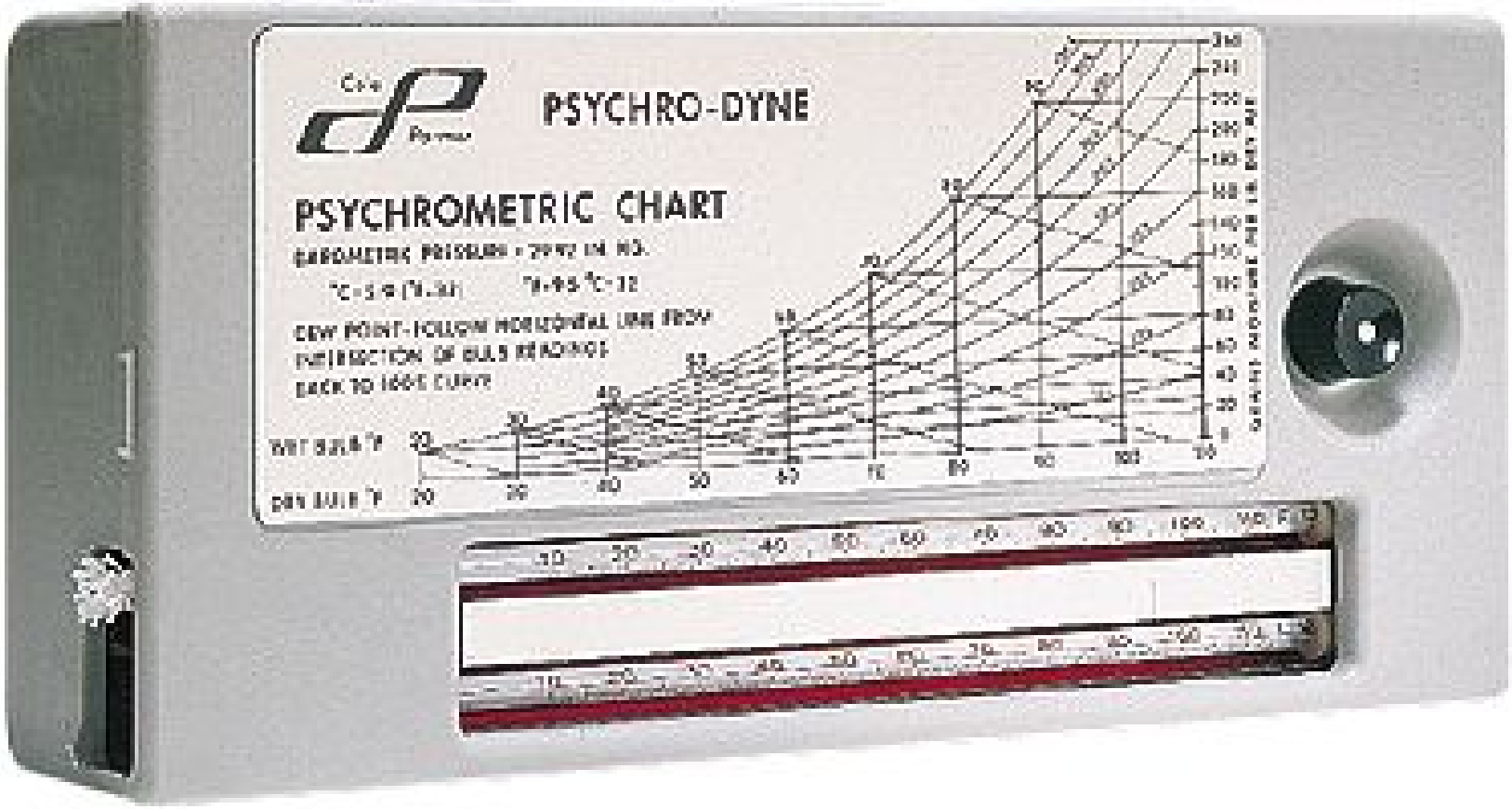
Control

- Only as good

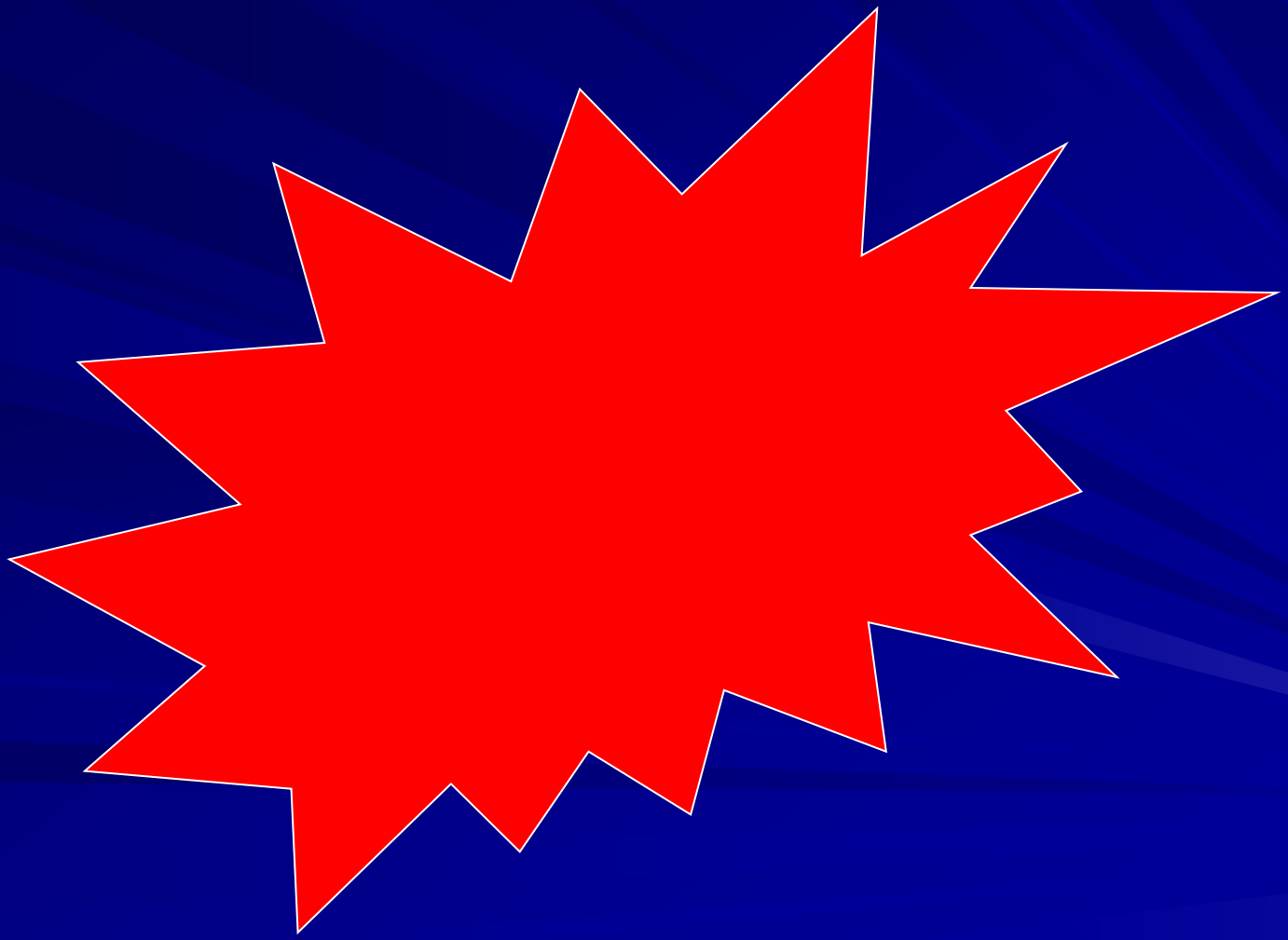
as the sensor.

Electronic Humidity Sensor - Used with Commercial Ventilation Control Panel

Power Psychrometer



Adding Heat



Electric Space Heater

Refrigeration

- Eliminates / minimizes vagaries of outside conditions or harvest temperatures.
- Requires more involved calculation of heat removal.

Calculating Cooling Load

- Contributors to cooling load:
  - Field heat
  - Heat of respiration
  - Heat gain through structure
  - Use Excel calculator or formulas in Refrigeration Manual

Cooling Load Calculations

- 12 x 20 storage room with 8 ft. ceiling
- 4 in styrofoam in ceiling and walls
- 2 in. styrofoam under concrete slab
- 1 pass door 3’ x 7’
- Minimal traffic through door
- Minimal lighting
- 40F inside
- 75F outside / ground temperature 50F

Cooling Load - Structure

- Q = A dT / R
- Walls
  - A = (20+20+12+12) x 8 = 512 s.f.
  - dT = 75F outside – 40F inside = 35F
  - R = 20
- Qw = 512 x 35 / 20 = 896 btu/hr.
- Ceiling
  - A = (12 x 20) = 240 s.f.
- Qc = 240 x 35 / 20 = 420 btu/hr.

Cooling Load - Structure

- Floor
  - A = (12 x 20) = 240 s.f.
- Qf = 240 x 10 / 5 = 480 btu / hr.
- Door
  - A = (3 x 7) = 21 s.f.
- Qd = (3 x 7) x 35 / 7.5 = 98
- Summary
  - Walls + ceiling + floor + door

  = 896 + 420 + 480 + 98 = <u>1894 btu / hr</u>

Cooling Load – Field Heat

- 500 # corn @ 70F
- Specific heat = 0.79
- Qfh = MCdT (btu/day)
  - M = mass = 500 #
  - C = specific heat = 0.79 btu/lb.-F
  - dT = 24 temperature drop = 30F
- Qfh = 500 x 0.79 x 30 = 11,850 btu / day
- Qfh = <u>494 btu / hr.</u>

Cooling Load – Heat of Respiration

- Qr = MK
  - M = mass (tons)
  - K = respiratory heat production (btu/ton-day)
- Qr = (500 # / 2,000 #/ton) x 20,000

  = 0.25 x 20,000 = 5,000 btu / day

  = <u>208 btu / hr</u>

Cooling Load - Infiltration

- Qi = (ho – hi) x VN / 13.5
  - ho and hi are enthalpy values for outside and inside air (get values from Table 9).
  - V = volume of room = 1,920 c.f.
  - N = number of air changes per hour = 0.25
  - 13.5 = ave. specific volume of air, c.f. / lb.
- Qi = (38.62-15.23) x 1,920 x 0.25 / 13.5
  = 832 btu / hr.

Cooling Load – Summary

- Total cooling load = structure + field heat + heat of respiration + infiltration

  = 1894 + 563 + 208 + 832

  = 3,497 btu / hr.

Refrigeration Sizing

- Refrigeration sizing = calculated cooling load x Service Factor x Defrost Factor

  = 3,497 btu / hr. x 1.1 x 1.1

  = 4,615 btu / hr.

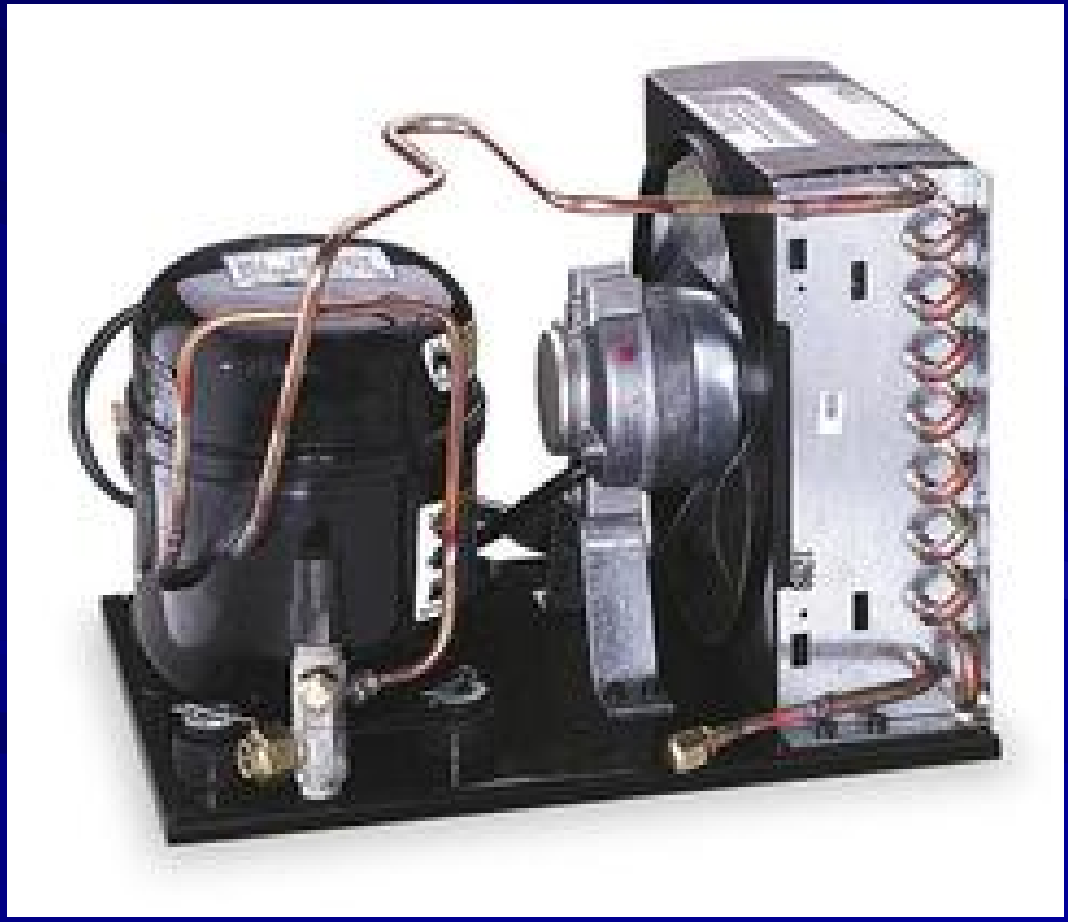
  1 ton of refrigeration = 12,000 btu / hr.

  Approx. 1 – 1.25 hp / ton of refrigeration

Common Household Air Conditioner

Common Household Air Conditioner + Cool Bot

Small Scale Refrigeration Condensing Unit



Commercial Refrigeration Evaporator

Wall Mounted Refrigeration

Other Considerations

Easy Access:

-Wide door

-Low threshhold

Easy Access / Easy Clean Up

Well Lighted

Cabbage in Controlled Storage
- Racks Increase Storage Capacity -

Pallet Jack for Handling and Loading Dock

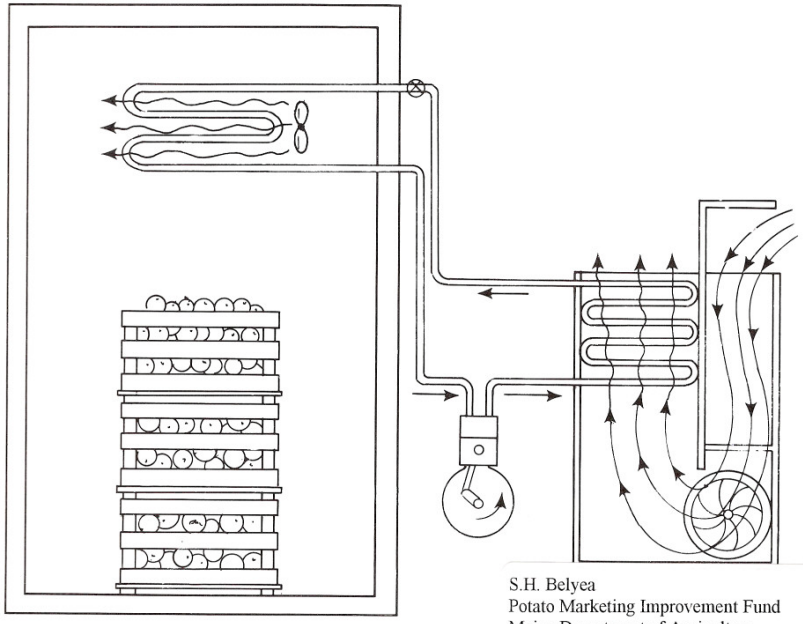
Reference Resources

NRAES 22

WAS Available from MidWest Plan Service

www.mwps.org

Refrigeration and Controlled Atmosphere Storage for Horticultural Crops



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Maine Department of Agriculture
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Presque Isle, ME 04769

Northeast Regional Agricultural Engineering Service
COOPERATIVE EXTENSION

USDA – Agriculture Handbook 66

The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks

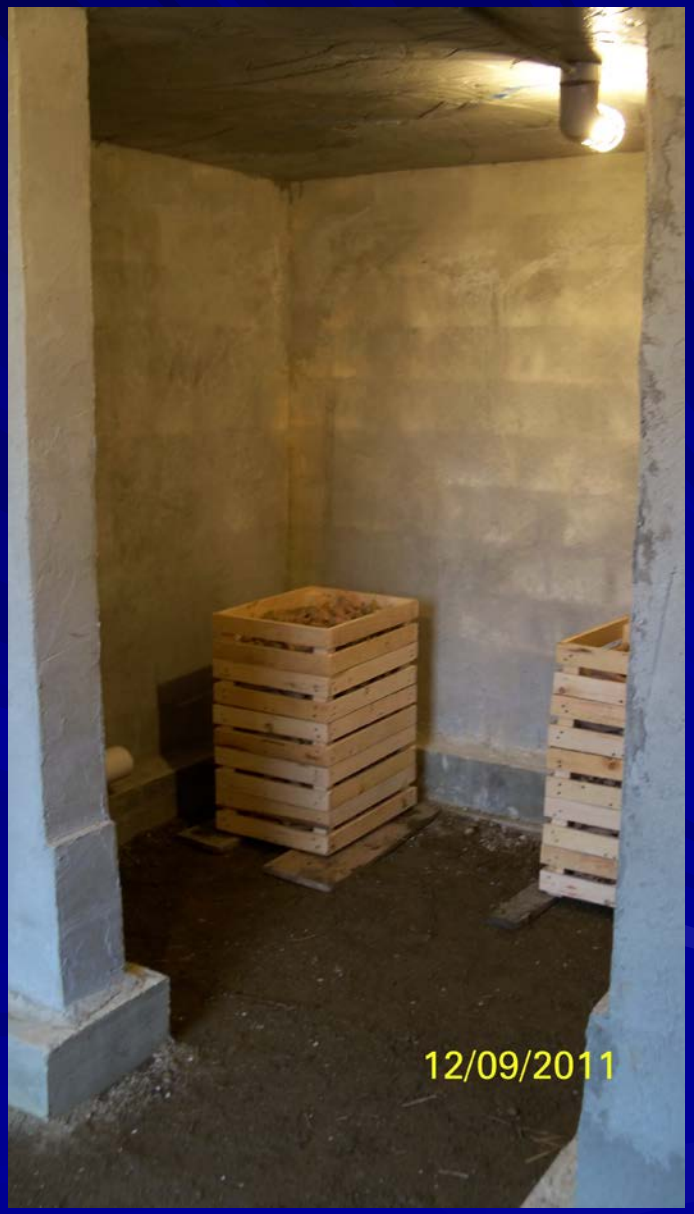
www.ba.ars.usda.gov/hb66

Squash in Controlled Storage
-Any Questions?-

Unity College
College / Community Root Cellar
Completed December 2011

Custom Storage Boxes
Gravel Floor to be Concrete
Floor Drain in Center

Unity College Root Cellar
2 Compartments



Unity College Root Cellar
Student / Staff Project
Dedication Day

How to Estimate Storage Space Requirements

or

How to Estimate the Capacity of Your Storage Area

Sizing a Storage Unit

- Assume that the bulk density is approximately 40 lbs. / cu.ft.
- Only 75% of floor space is usable.
- Good air circulation.
- Leave space for easy access to different products.
- Shelves or pallets increase the total capacity by more efficient space utilization.

Pallet Box Example

- Measurements – 4 ft. x 4 ft. x 3 ft.
  = 48 cu. ft.
  - Potatoes – 40 lbs. / cu. ft.
  - 48 cu. ft. x 40 lbs. / cu. ft. = 1,920 lbs.

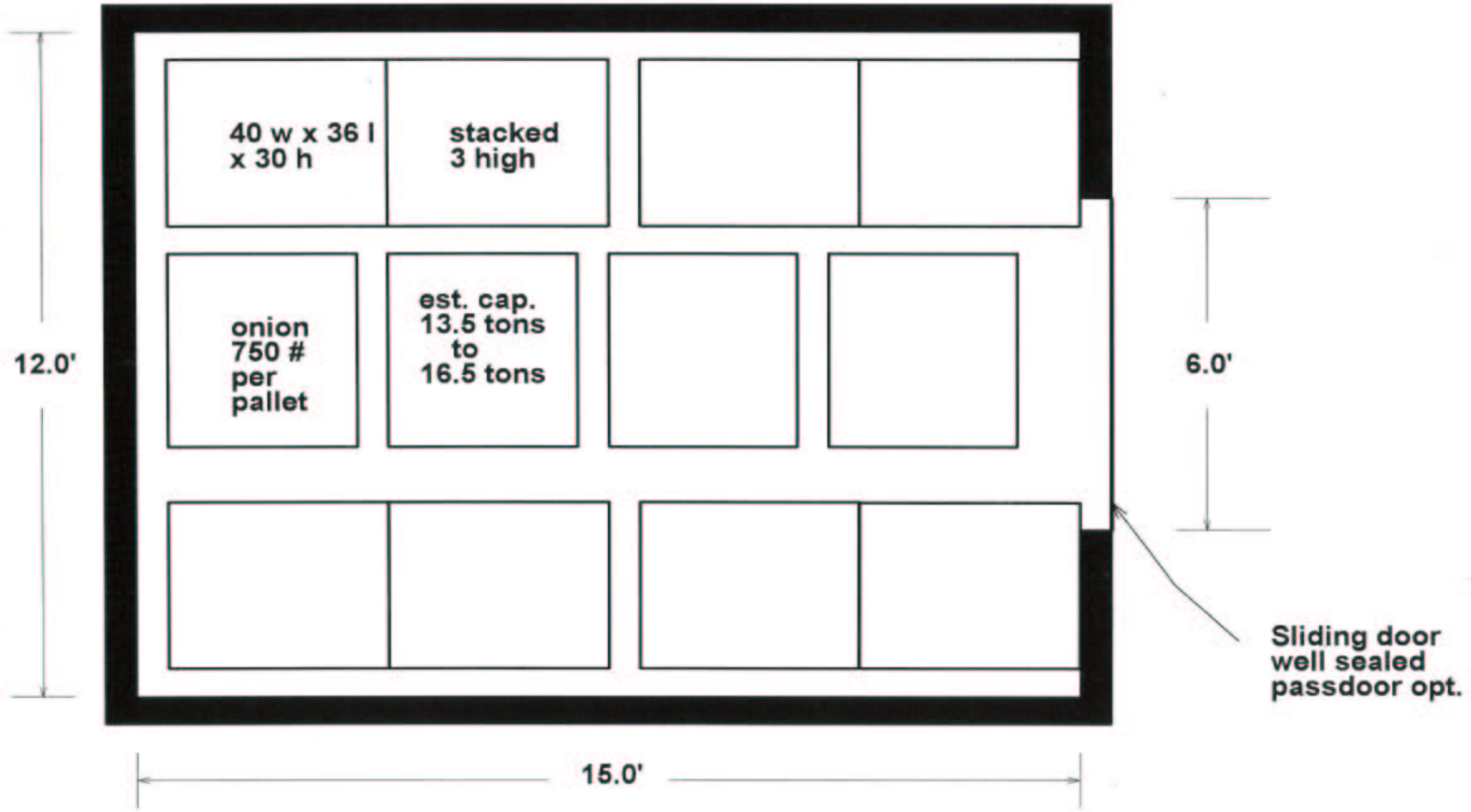
Research Box Example

- Measurements – 12 in. x 12 in. x 15 in. (net inside dimensions) = 2,160 sq. in.
- 2,160 sq. in. / 1,728 c.i. per cu.ft.

  = 1.25 cu. ft.
- Potatoes = 40 lb. / cu. ft.
- 1.25 cu.ft. x 40 pcf = 50 lbs.

Bags on Pallets

Proposed Storage Locker Floor Plan



Ceiling approx. 10 ft.

locker floor plan