Postharvest Storage

A Workshop for Producers and Processors

NORTHEAST SARE
Sustainable Agriculture Research & Education

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Project ONE13-176

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Workshop Outline

- Importance of Food Storage
- Storage Characteristics of Food
- Energy and Heat Transfer
- Components of a Storage System
- Sizing and Design
- Practice Session

Summary

1. Know your target conditions.
2. Provide multiple zones.
   May not be multiple rooms.
3. Informed design, construction and purchase of equipment.
4. Measure your actual conditions.
5. Improve crop selection on the way in.

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Introductions

- You and your farm or business.

- Why is Food Storage Important to you?
- What do you hope to learn from the workshop?
- What have been some of your challenges with storage?

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Importance of Food Storage

- Product quality preservation
- Food safety
- Harvesting & season flexibility
- Food security
- Sunk costs
- Market extension

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Market Access & Economics

- Competitive advantage
  - Market for produce in winter is less saturated
- 2010-2011 winter markets increased 38%
  - 886 in 2010, 1,225 in 2011
- Brattleboro's winter market
  - 18 vendors in 2006, 32 vendors in 2011
- Winter marketing opportunities abound but there is competition
  - Quality is a differentiator

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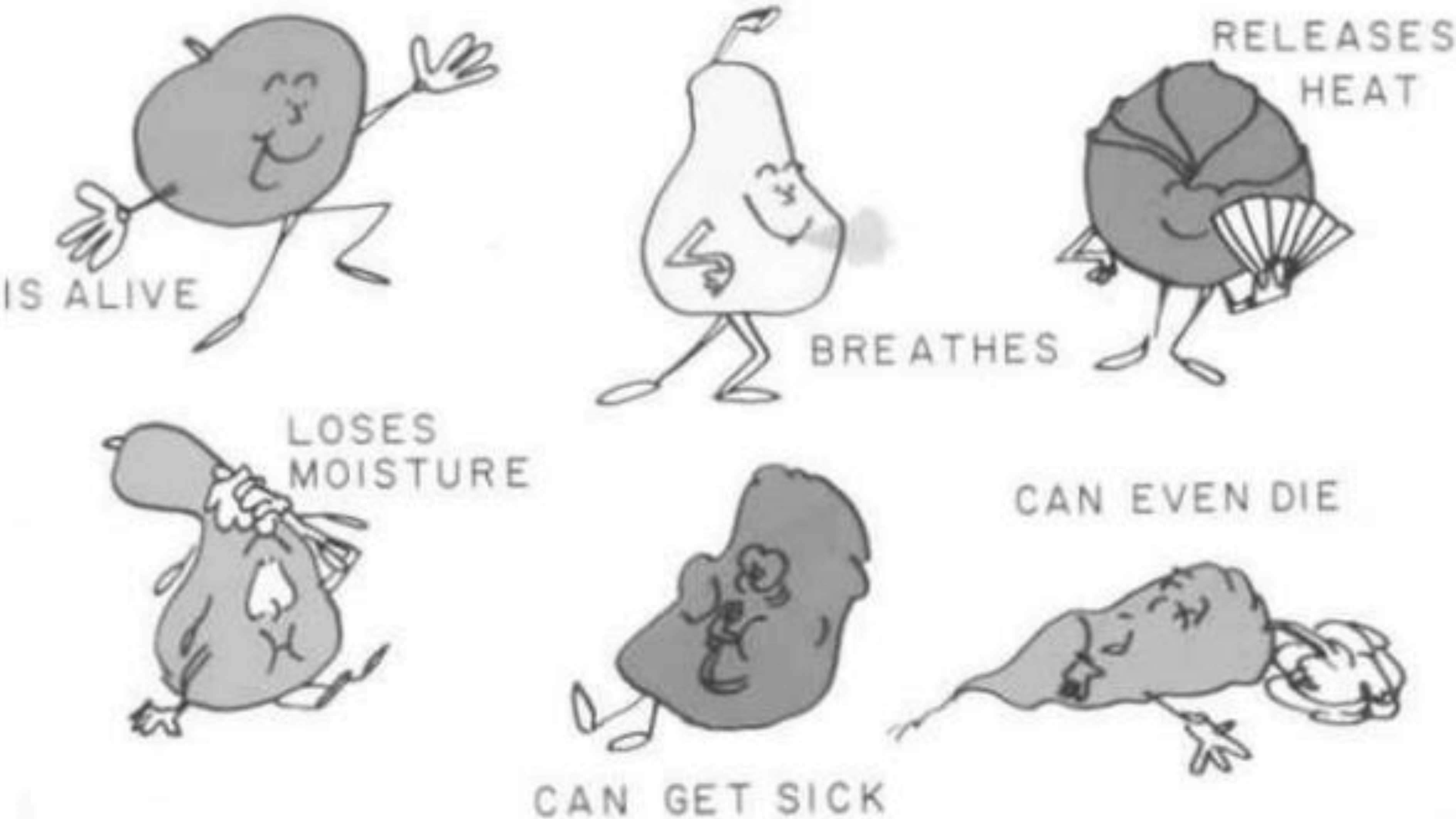
FRESH PRODUCE



Respiration

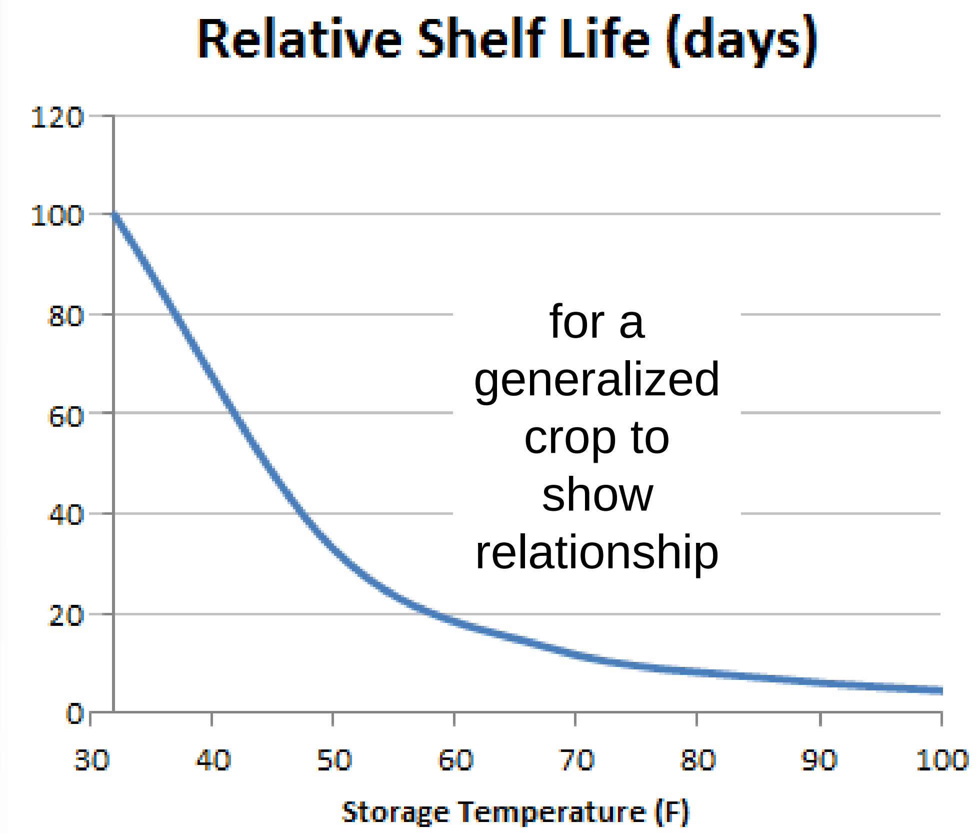
- Crops continue to respire and metabolize post-harvest
  - Through respiration crops use oxygen to break down energy (carbohydrates, fats or proteins)
- Respiration rates of different crops varies:
  - Low rate: Apples, potatoes
  - Moderate: Carrots, Cabbage
  - High rate: asparagus & sweet corn

Respiration

- Respiration leads to:
  - Drying out
  - Decreased food value of crops
  - Less sweetness
  - Less dry weight
  - Creates heat
  - Decreased shelf life, quality & value
- Good news!
  - Respiration & metabolism can be managed

Temperature

- Respiration & Metabolism are highly dependent on temperature.
- By managing temperature you can manage respiration



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Temperature

- General rule:
  - 32-35˚F / 0-2˚C for cool season crops,
  - 47-55˚F / 8-13˚C for warm season crops
  - Varies by crop.
  - See USDA Handbook 66.
- Beware of:
  - Freezing Injury
  - Chilling Injury

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Humidity

- Relative Humidity (RH)
  - Amount of moisture in the air at a given temperature
  - Temperature dependent
    - Warmer air holds more moisture
- Transpiration
    - Crops release moisture into air through respiration
- Manage transpiration by managing RH

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Ethylene

- C_2H_4
- Ripening hormone
- Produced in stored produce (at various rates)
  - plant hormone
  - physiologically active at very low concentrations
    - (0.1 to 10ppm)

Ethylene Scrubber

- Absorbs Ethylene from the air
- Like an air filter for dust, etc.

16”x8”x2” - $50 - www.cjsethylenefilters.com

Storage Crops – Case Studies

Crop	Units	Carrot	Onion	Potato	Cabbage	Squash
Storage Density	lb/ft^3	22	20	42	17	35
Temp	ºF	32 – 34	32	40	32	50
RH	%	98 – 100	65 – 70	99 – 100	98 – 100	50-70
Duration	Months	7 – 9	6 – 9	Up to 12	3 – 6	1-3
Resp. rate at temp	mg CO_2 / kg - hr	10-20	3 (cured)	6 – 18 (cured)	4 – 6	100
	BTU / ton-hr	138	28	110	46	917
Ethylene Prod. Rate	uL / kg-hr	< 0.1	< 0.1	< 0.1	< 0.1	Trace
Ethylene Sensitivity	uL / L	High ~ 0.2	Low > 1500-2000	Low	High ~ 1.0	Low

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Storage Crops – Case Studies

Crop	Units	Carrot	Onion	Potato	Cabbage	Squash
Storage Density	kg/m3	352	320	672	272	560
Temp	ºC	0 – 1	0	4.5	0	10
RH	%	98 – 100	65 – 70	99 – 100	98 – 100	50-70
Duration	Months	7 – 9	6 – 9	Up to 12	3 – 6	1-3
Resp. rate at temp	$\frac{mg\ CO_2}{kg - hr}$	10-20	3 (cured)	6 – 18 (cured)	4 – 6	100
	$\frac{Watt}{tonne}$	44.5	9.0	35.5	14.9	296
Ethylene Prod. Rate	$\frac{uL}{kg-hr}$	< 0.1	< 0.1	< 0.1	< 0.1	Trace
Ethylene Sensitivity	$\frac{uL}{L}$	High ~ 0.2	Low > 1500-2000	Low	High ~ 1.0	Low

GAPS & FSMA

- SOPs & good recordkeeping are critical
- Minimize microbial contamination by using best practices
  - Worker hygiene, sanitation schedules, proper culling of product, temperature monitoring, etc
- Producers need to show that best practices are being used with policies and documentation

Good Agricultural Practices

- Examples of Requirements:
  - Storage areas are clean and free of contamination.
    - Smooth and cleanable surfaces
    - Cleaning schedule
  - Storage areas are used exclusively for food crops and their containers.
  - Produce is stored at least six inches off the floor, depending on the nature of the crop.

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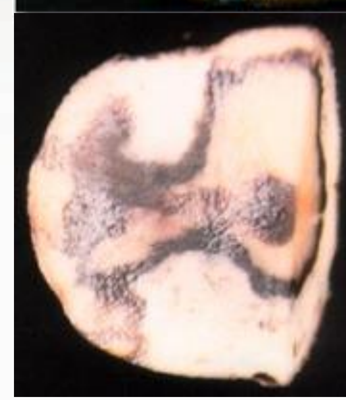
Pathology

- Control begins with seeds, field, harvest, washing and packing.
- Conditions do not improve in storage.
- Take care in proper curing if applicable and maintaining proper storage temps & RH.
- Avoid direct soil contact in storage

Rhizopus Soft Rot on Sweet Potatoes

Potato Affected by Fusarium Dry Rot



Potato Affected by Soft Rot

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And each crop is different

- Recommended storage conditions
  - Temperature
  - Relative humidity
- Ethylene production rate
- Ethylene sensitivity
- Chilling/Freezing Injury
- Variety differences

USDA Handbook 66 – “The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks”
http://www.ba.ars.usda.gov/hb66

Breakout

- Pick a crop
  - Potato
  - Beet
  - Carrot
  - Onion
  - Cabbage
  - Winter Squash

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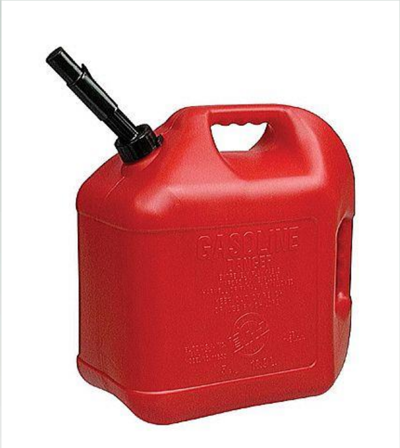
Energy in Food Storage

- Food storage and quality preservation depend on maintaining
  - Temperature
  - Humidity
- Against ambient conditions that differ from the target conditions and which change
- Generally cooling, but may be heating as well.

Energy Basics

- **Energy**: The ability to do work.
  - Can be stored or converted
  - Cannot be created or destroyed
  - Units: kWhr, BTU, Joules, Calories, Cord, Gallons
- **Power**: Energy converted over time.
  - Instantaneous measure
  - Never 100% efficient
  - Units: kW, BTU/hr, Joules/second, Calories/day, Horsepower



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The Rules

a.k.a. the Laws of Thermodynamics.

- **0th Law** – There is such a thing as **thermal equilibrium**. "All heat is of the same kind."
- **1st Law – Energy is conserved**, you can't create or destroy it.
- **2nd Law – Systems seek equilibrium** and will do so on their own. Also, there is no free lunch, **no such thing as 100% efficiency**.
- **3rd Law** – We can't reach absolute zero temperature.

An Innocent Head of Cabbage

- Great example of stored energy.
- We want to remove field heat.
- Assume field temperature of 80 F (27 C).
- Assume storage temperature of 32 degF (0 C).
- 3 lbs (1.4 kg) per head
- 17 lbs/ft3 (272 kg/m3) loading density.
- Specific heat capacity : 0.94 BTU/lb/F (3935 J/kg/C)
  Specific heat capacity is a measure of a material's ability to store thermal energy. Different from dietary energy (i.e. calories).

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Pre-cooling Cabbage

1. What is the temperature change?

2. How much are we cooling?

3. Cooling energy = mass cooled x specific heat x temperature change

4. How quickly are we cooling?

5. Cooling power = Cooling energy / time

Pre-cooling Cabbage

1. What is the temperature change?
   80-32 degF = **48 degF (27 C)**
2. How much are we cooling?
   Let's assume a pallet bin 4'x4'x4' = 64 ft3.
   Multiply by the loading density of 17 lbs/ft3…
   64 ft3 x 17 lb/ft3 = **1088 lbs (492 kg)**
3. Cooling energy =
   mass cooled x specific heat x temperature change
   1088 lb x 0.94 BTU/lb/degF x 48 degF = **49,090 BTU (51.8 MJ)**
4. How quickly are we cooling?
   Let's say **2 hours**.
5. Cooling power =
   Cooling energy / time
   49,090 BTU / 2 hour = **24,545 BTU/hr (7.2 kW)**

Pre-cooling Cabbage

- Now what?
- What does 49,090 BTU and 24,545 BTU/hr tell us?
- Well, if you have a cooler what is the rating of the evaporator? Will it do the job? Needs to be at least 24,545 BTU/hr and if it is keeping other things cool you need to account for that as well.
- If you're considering a hydrocooler or ice machine will you have the capacity?
  - 49,090 BTU is about 340 lbs of ice melting
  - 144 BTU/lb of melted ice

Photo Credit: Paul Sumner. Via UGA.
http://www.caes.uga.edu/Publications/pubDetail.cfm?pk_id=7954

Heat Transfer

- Heat will naturally flow from hot to cold (seeking equilibrium and the "*lowest energy state*").
- This is a blessing and a curse
  - We benefit from this in heating and cooling applications (think furnaces or evaporators)
  - We fight it when trying to keep a greenhouse warm in early spring or a cooler cool in mid summer.

Heat Transfer

- Three modes
  - Conduction – through solids
  - Convection – through fluids (liquid or gas)
  - Radiation – directly from one body to another
- All are proportional to temperature difference
- …and differ by how the heat flow is slowed (or enhanced.)

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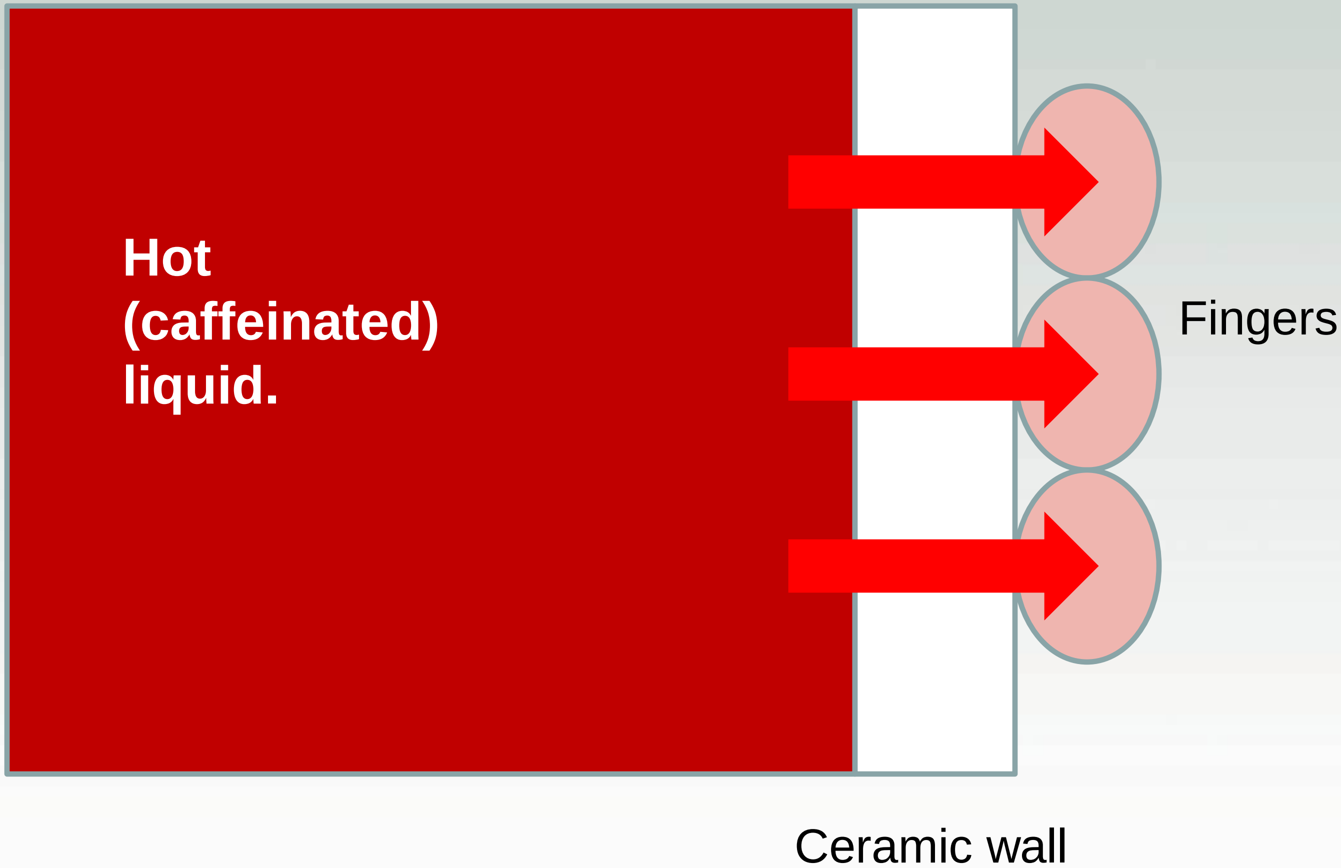
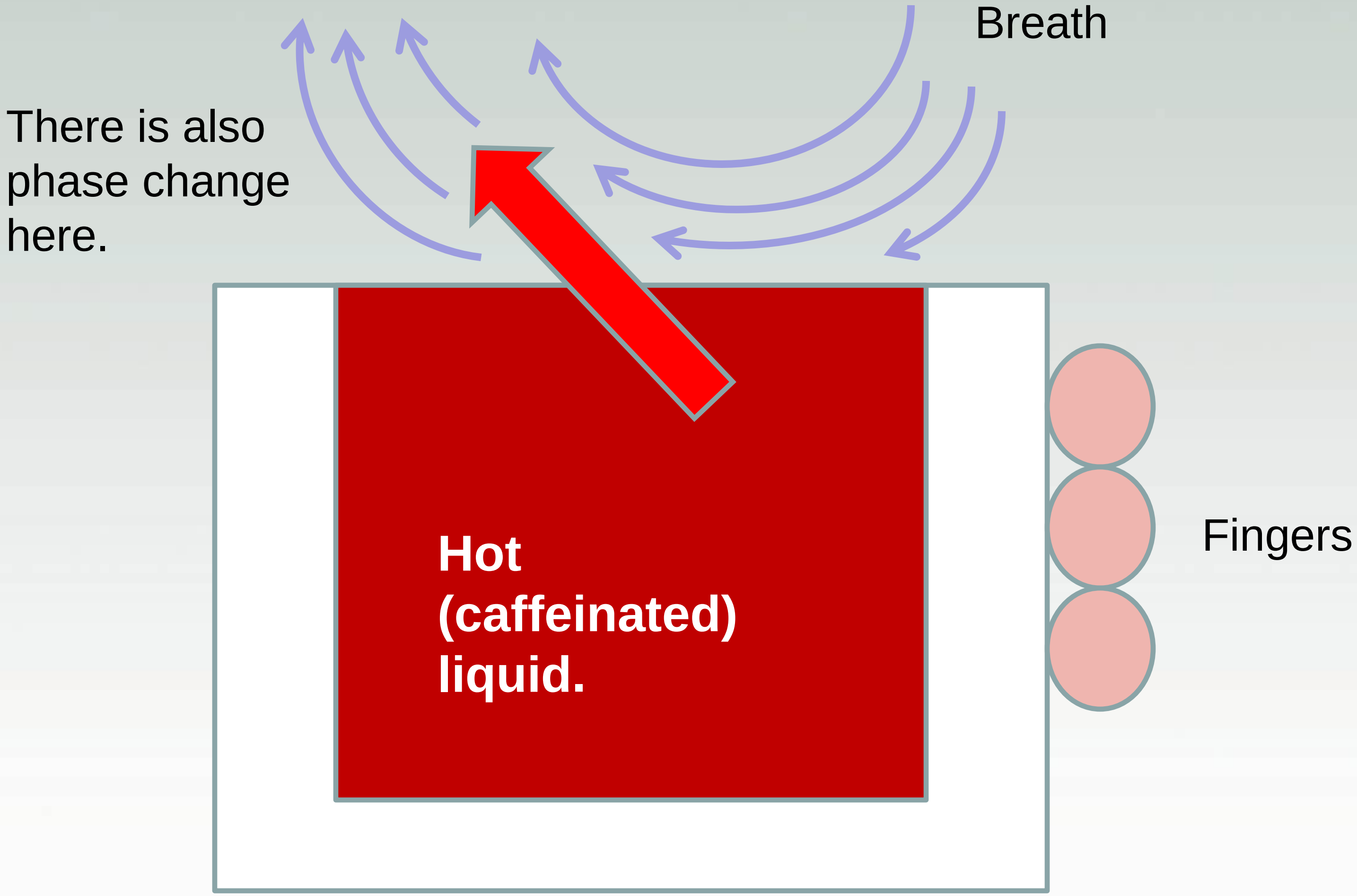
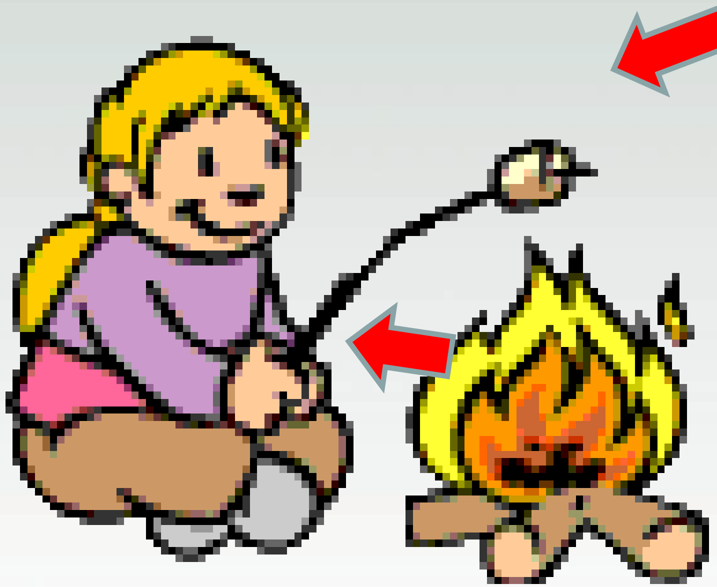
Conduction



Convection


Breath
There is also phase change here.
Hot (caffeinated) liquid.
Fingers

Radiation



No, not the marshmallow!

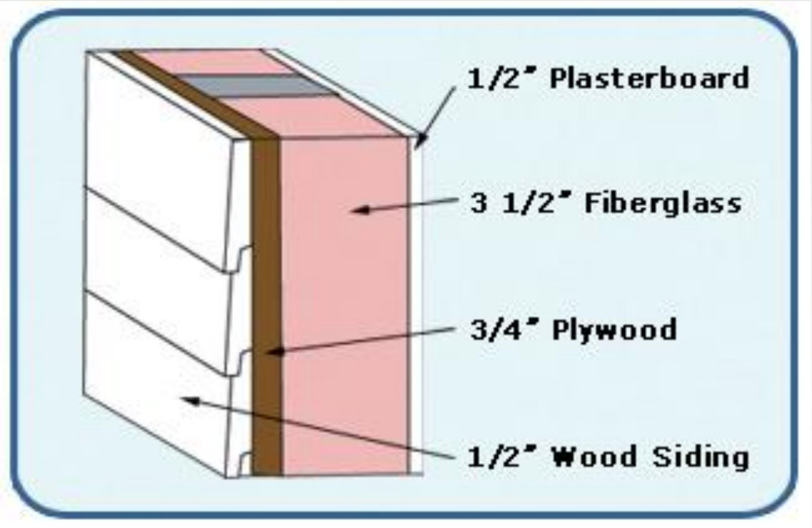
The heat you feel directly from the fire or from the sun.

Heat Transfer

- The way we try to limit heat transfer in food storage is with insulation and sealing.
  - Insulation – retards heat flow through walls
  - Sealing – retards air flow and infiltration between separated spaces
- The ways we try to support heat transfer is with immersion and air flow.

Breakout

- Think about some place where you have an insulated wall or floor or a wall you hope is insulating something.
- List the materials
  - Inside wall surface
  - Cavity material
  - Outside wall surface
  - Etc



Breakout

- Use p. 6 & 7 of handouts to find the R value for each layer of your wall or floor.
- Add them up, multiplying where needed by the thickness.
  - Some are based on “per inch thickness”
  - Some are based on fixed thicknesses.
- Look at the units of measure
  - hr*ft2*F/BTU or hr*m2*C/J

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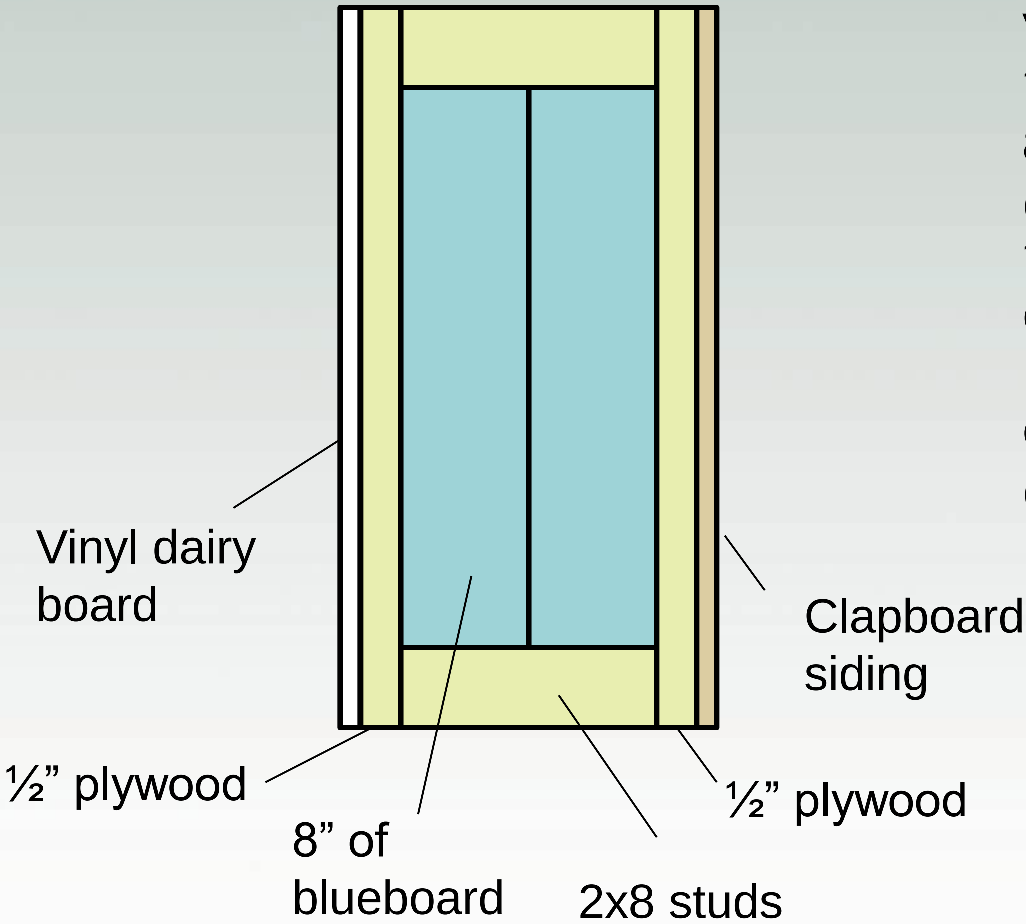

Vinyl dairy board (FRP) =	0.00
½" Plywood =	0.63
8" Blueboard (Expanded Polystyrene) =	32.00
½" Plywood =	0.63
Clapboard Siding =	0.80

Overall R Value (hr-F-ft2/BTU)	34.06

Neglecting heat transfer through studs

What Does R-Value Tell Us?

- The Rate of Heat Loss / Gain =
  Surface Area *times*
  Temperature Difference *all divided by*
  R-Value

$$Q = \frac{\textbf{Area x (Tout – Tin)}}{\textbf{R-value}}$$

BTU/hr

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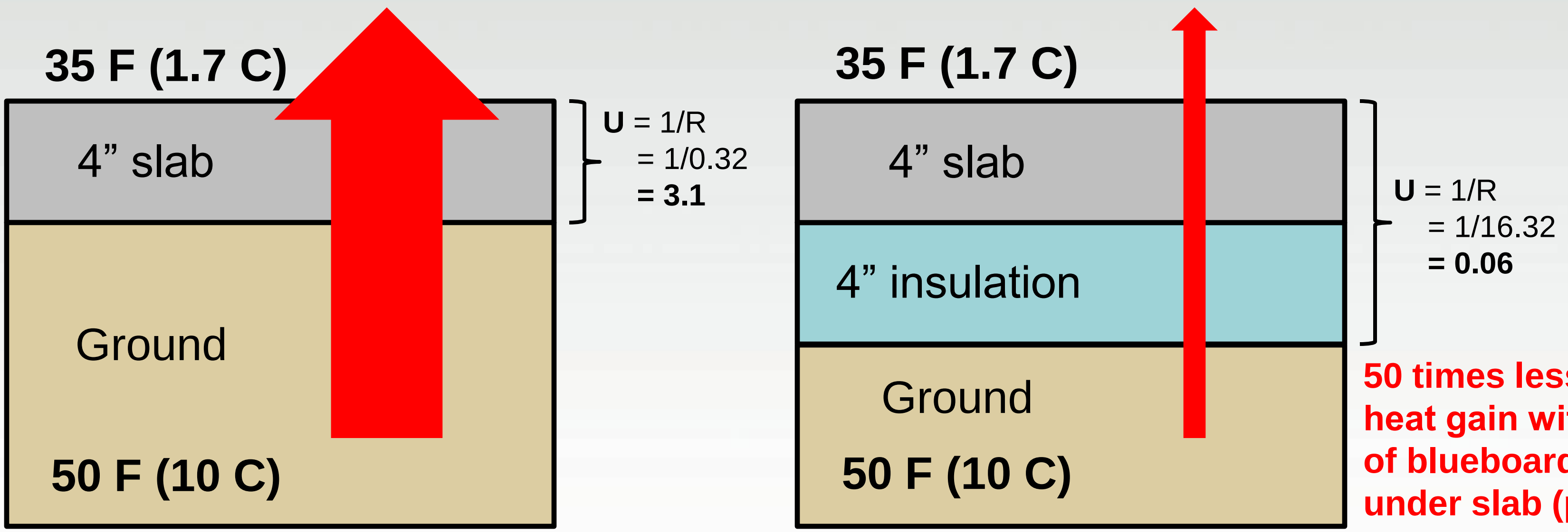
Insulation

- The rate of heat transfer is proportional to the temperature difference and the *overall heat transfer coefficient*.
- Overall heat transfer coefficient ("U") captures how easily heat moves from one body or fluid to another.
  - Conduction – through solids
  - Convection – through fluids
  - Radiation – body to body

Consider Slab Insulation

- Comparing conduction only.
- High R value = Low U value = less heat flow



50 times less heat gain with 4" of blueboard under slab (per square foot of floor).

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Cooler Insulation

- A very common question is, "**How much insulation should I put in my cooler?**"
- Let's take a look at a 10'x20'x8' cooler.
- Assume 90 F (32 C) air and 50 F (10 C) ground
- Assume 34 F (1 C) cooler temp (6 months of use)
- Framed and insulated by grower
- Walls have 4" blueboard insulation.
  - R16 walls, 4 (hr-ft2-F)/BTU per inch
- **Compare 4" slab insulation to no insulation**.

Cooler Insulation

- Roughly **16 times** the energy use with no slab insulation. This accounts for wall and ceiling losses as well.

	With Slab Insulation	**Without** Slab Insulation	
Peak Loss / Evaporator Sizing	2,580	12,380	BTU/hr
Peak Loss / Compressor Sizing	0.3	1.7	HP
Electricity Use (6 months)	288	4,522	kWhr/yr
Operating Costs (6 months)	43	678	$/yr

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Cooler Insulation

- Insulation costs about $0.70 per inch thickness per square foot.
- 4” slab insulation would cost $560 for this cooler
- Our annual savings would be $635.
- Payback <1 year of operation.
- You can insulate above a slab as well, so retrofit is possible.

Cooler Insulation

- What if everything was the same except wall & ceiling insulation thickness?
- 2”, 4” and 6” insulation in walls:

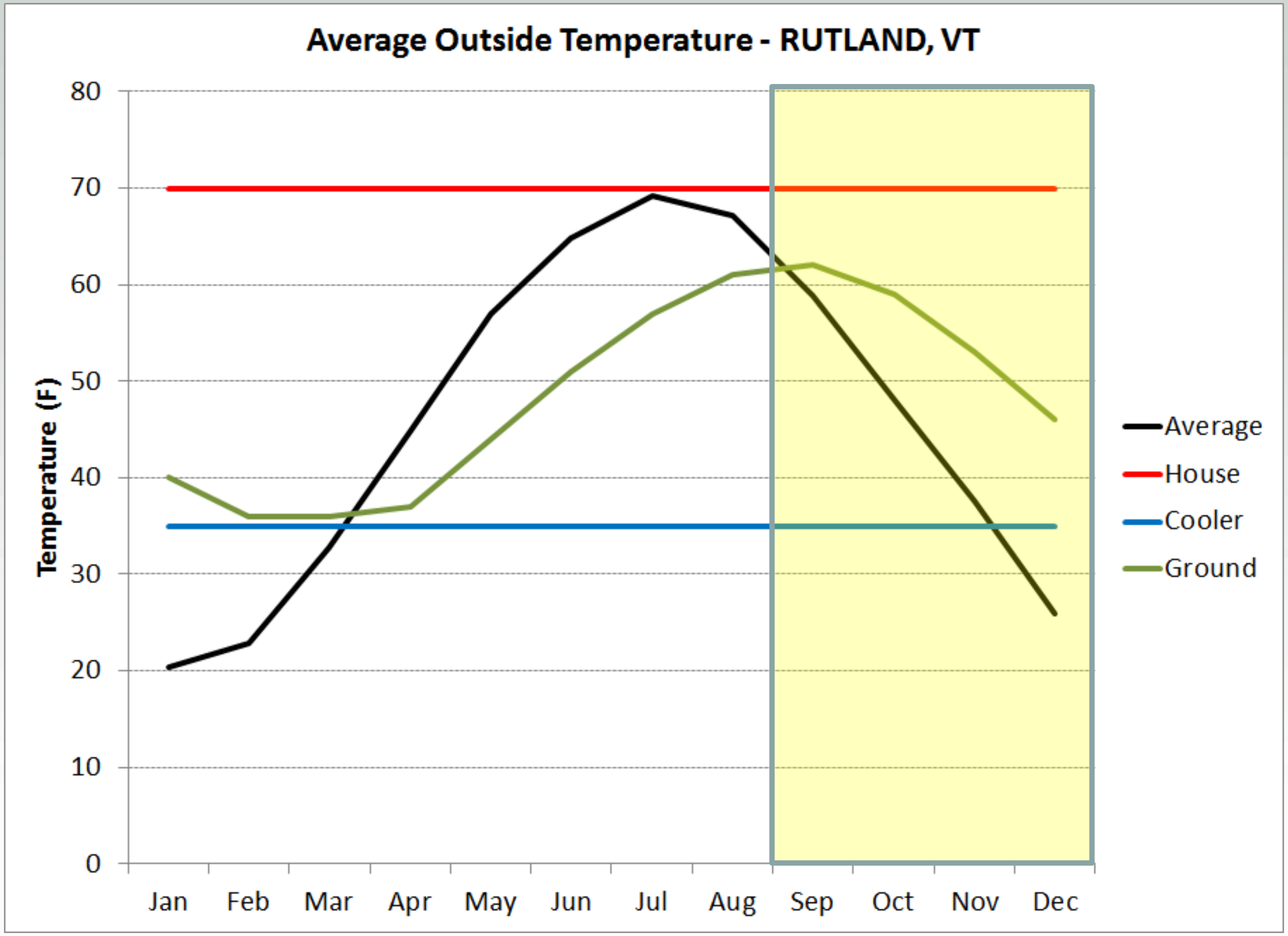
	With 2 inch wall insulation R8	**With** 4 inch wall insulation R16	**With** 6 inch wall Insulation R24	
Peak Loss / Evaporator Sizing	4,960	2,580	1,787	BTU/hr
Peak Loss / Compressor Sizing	0.7	0.3	0.2	HP
Electricity Use (6 months)	1,041	564	405	kWhr/yr
Operating Costs (6 months)	156	85	61	$/yr

Breakout

- Why is slab insulation so signficant?

Why Slab Insulation Has Such an Impact.

- Ground temperature lags air temperature seasonally.
- It is highest right when most growers are seeking long-term storage.
- And stays higher than desired storage temperature.
- Always a load.



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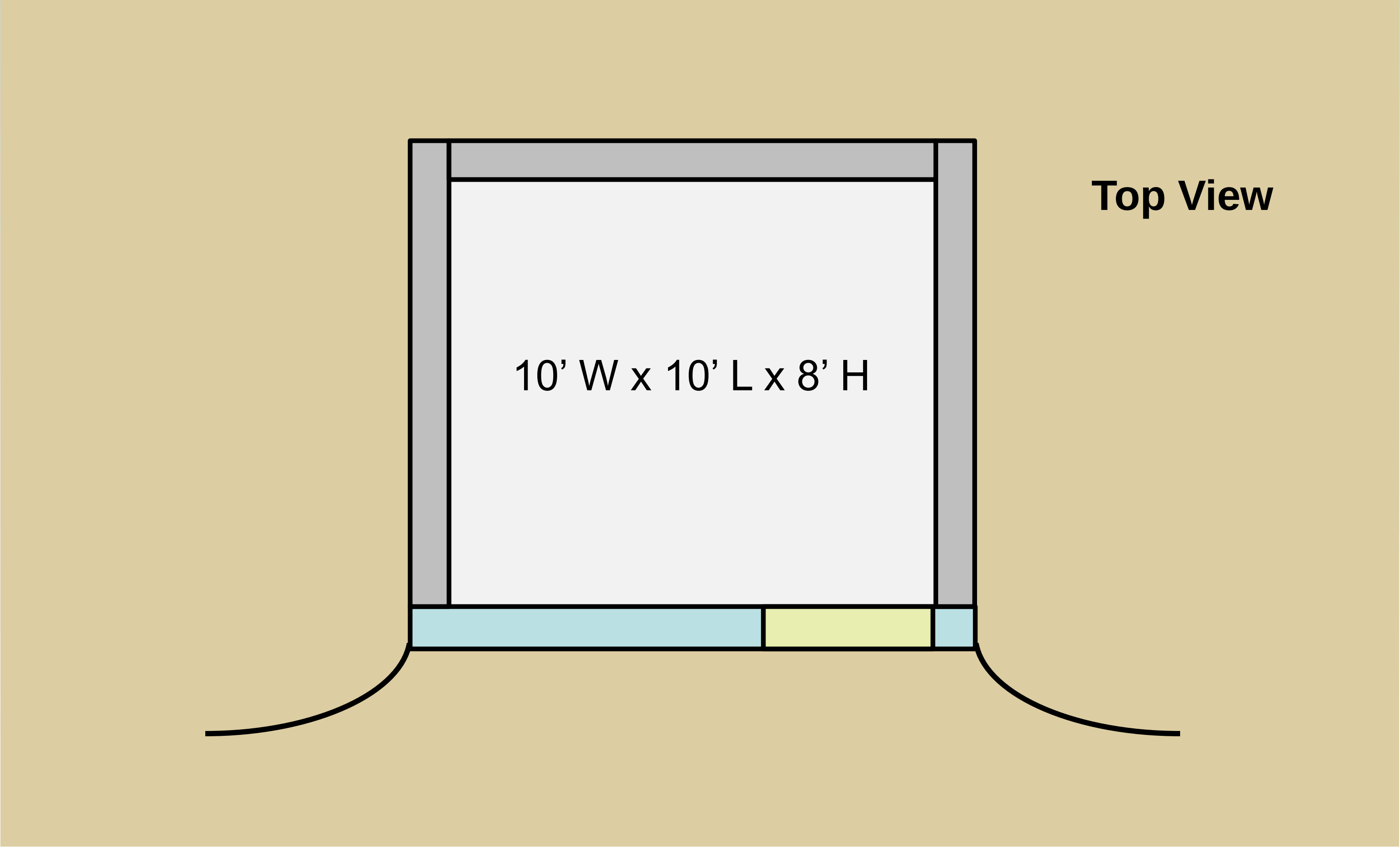
Elliston root cellar, photo credited to http://donjarrl.blogspot.com/2009_07_01_archive.html

Root Cellar



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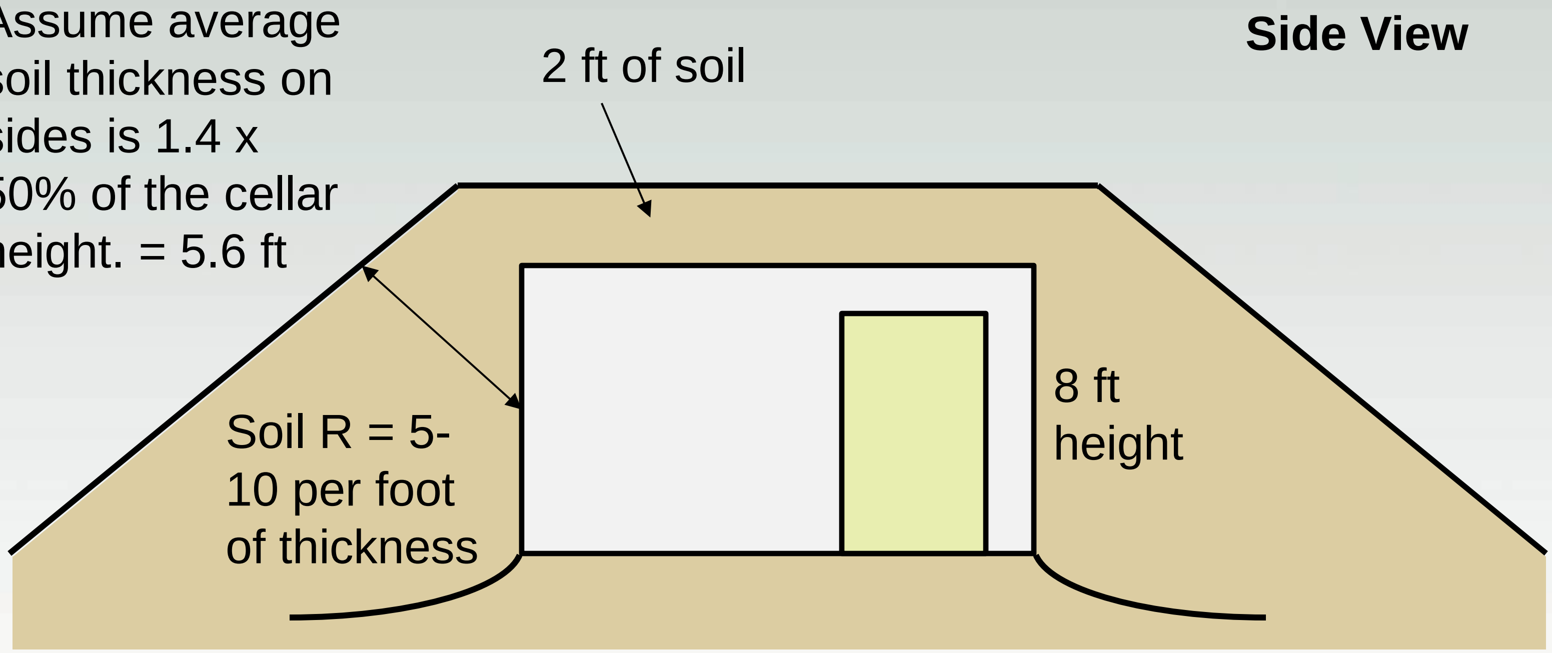
Simplifying assumption: Assume average soil thickness on sides is 1.4 x 50% of the cellar height. = 5.6 ft



Root Cellar

- Outside Temperature: -25 C / -13 F
- Inside Temperature: 2 C / 36 F
- Some other assumptions:
  - 2/3 of volume is taken up by crop
  - Crop is potatoes
  - Neglecting the door
  - Assuming a tight construction (no air exchange)

ΔT = 27 C 49 F

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Heat from Product

- Total Volume: 8x10x10 = 800 ft3
- Product Volume: 67% of 800 = 530 ft3
- Product Mass: 42 lb/ft3 x 530 ft3= 22,512 lbs
  10,186 kg
- **Respiration Rate**:

  110 BTU/ton/hr x 22,512 lbs / 2000 lbs/ton

  = **1,238 BTU/hr**

  363 Watts

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Heat from Ground

• Ground Temperature:	7 C / 45 F
• Inside Temperature:	2 C / 36 F
	ΔT = 5 C / 9 F
• Heat Gain Coefficient:	0.3 BTU/hr/ft2/F
• Floor Area:	100 ft2
• **Heat gain from Ground:**	**270 BTU/hr** **79 Watts**

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Heat Loss Through Roof

- 2 feet deep soil
- Assume lower R value of 5 ft2-hr-F/BTU per foot
- R = 2 x 5 = 10
- A = 10 ft x 10 ft = 100 ft2
- A/R = 100 / 10 = **10 BTU/hr-F**
- **490 BTU/hr or 144 Watts**

Heat Loss Through Berm

- 5.6 feet of soil
- Assume lower R value of 5 ft2-hr-F/BTU per foot
- R = 5.6 x 5 = 28
- A = 8 ft x (10 + 10 + 10 ft) = 240 ft2
- A/R = 240 / 28 = **8.6 BTU/hr-F**
- **420 BTU/hr or 123 Watt**

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Heat Loss Through Front Wall

- Assume 6” Blueboard Wall
- R value of 4 ft2-hr-F/BTU per inch
- R = 6” x 4 = 24
- A = 8 ft x 10 ft = 80 ft2
- A/R = 80 / 24 = **3.3 BTU/hr-F**
- **163 BTU/hr or 48 Watt**

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All Together Now…

- Heat Gains
  - Product +1238 BTU/hr
  - Floor +270 BTU/hr
- Heat Loss
  - Roof -490 BTU/hr
  - Soil Berm -407 BTU/hr
  - Front Wall/Door -161 BTU/hr
- **Surplus Heat 435 BTU/hr (127 Watt)**

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That's a lot of potatoes

- What if we were only **10% full**
- 3,360 lbs or 1,520 kg of potatoes
- 185 BTU/hr or 54 Watts from product
- Net heat needed is **619 BTU/hr or 181 Watts**
- A small space heater on a thermostat.

Energy & Heat Tranfer

- Introductory Thermodynamics
  - Matter & Temperature
  - Intro to Psychrometrics—Humidifying & Drying
    - The “Triple Point”
    - Water’s Phase Change Properties
    - Adding Humidity to a Potato Room
- Heat Transfer Modes

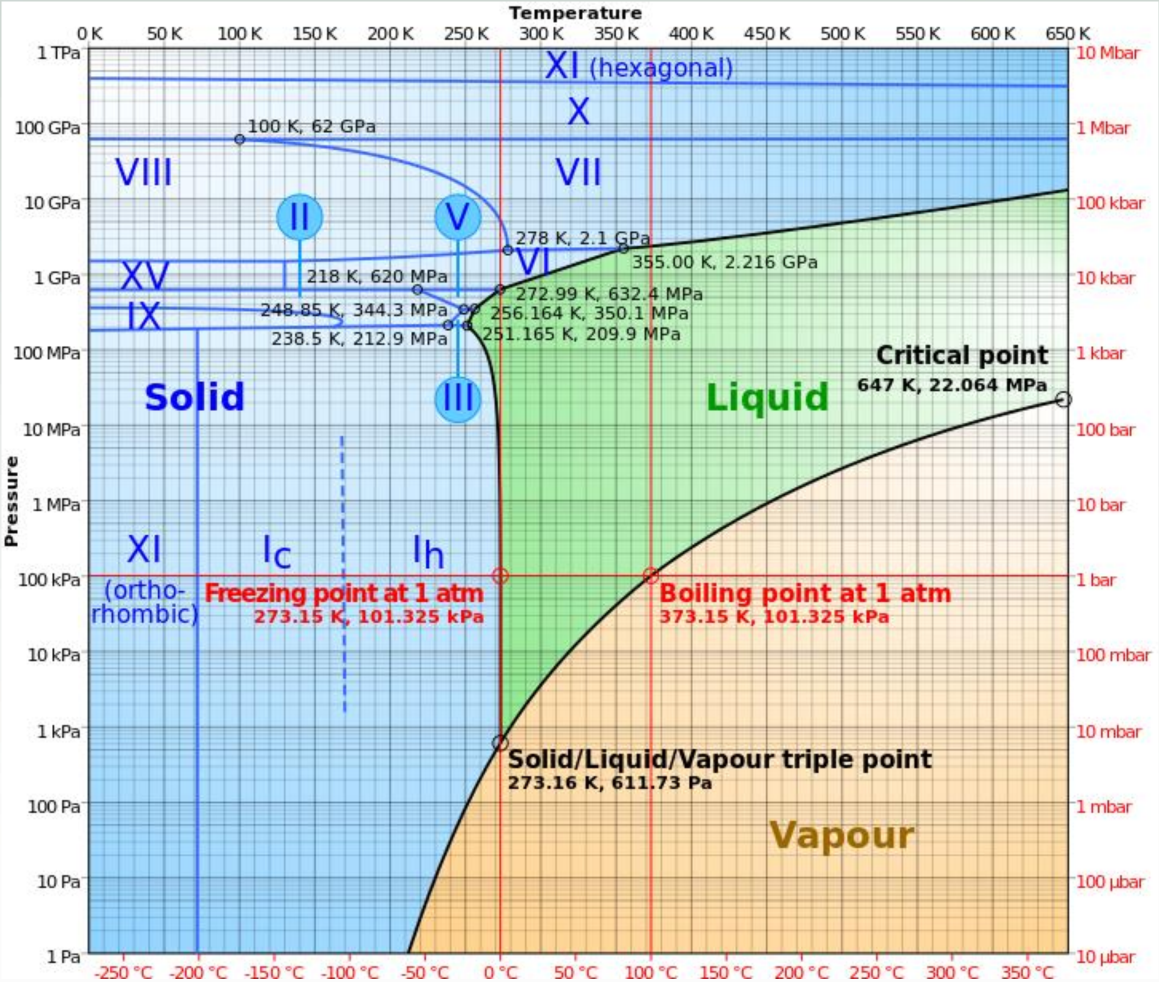
Humidifying and Drying

- What is actually happening?
- Depends on water changing "phase"
  - Liquid
  - Vapor
- That requires air, energy flow, and temperature

Water's Phase Change

- What we think we know…
  - Water freezes at 32 F and 0 C
  - Water boils at 212 F and 100 C
- It is true….but…
- Only at standard atmospheric pressure!
- How is there water vapor in air?

Sorry… it's a bit more complicated



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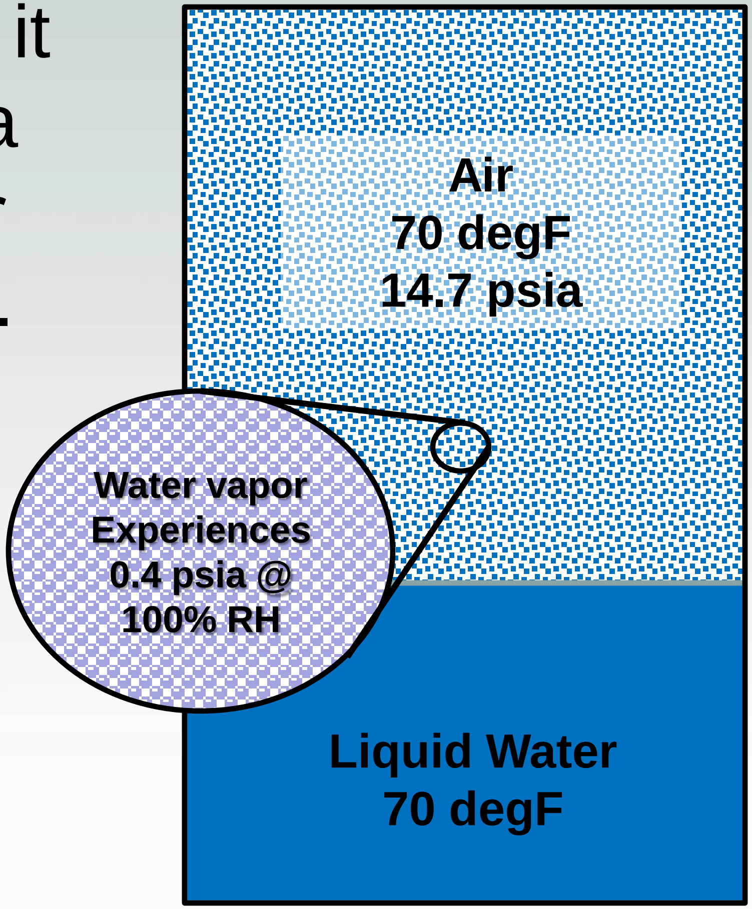
Water and Air Mixtures

- When water vapor is in air, it behaves as though it is at a "**partial pressure**" or lower pressure than atmospheric.
- Meaning, it is vapor even though it isn't at 212 F.
- This allows for "**humidity**" below 212 F.
  - And most of the weather systems we deal with.



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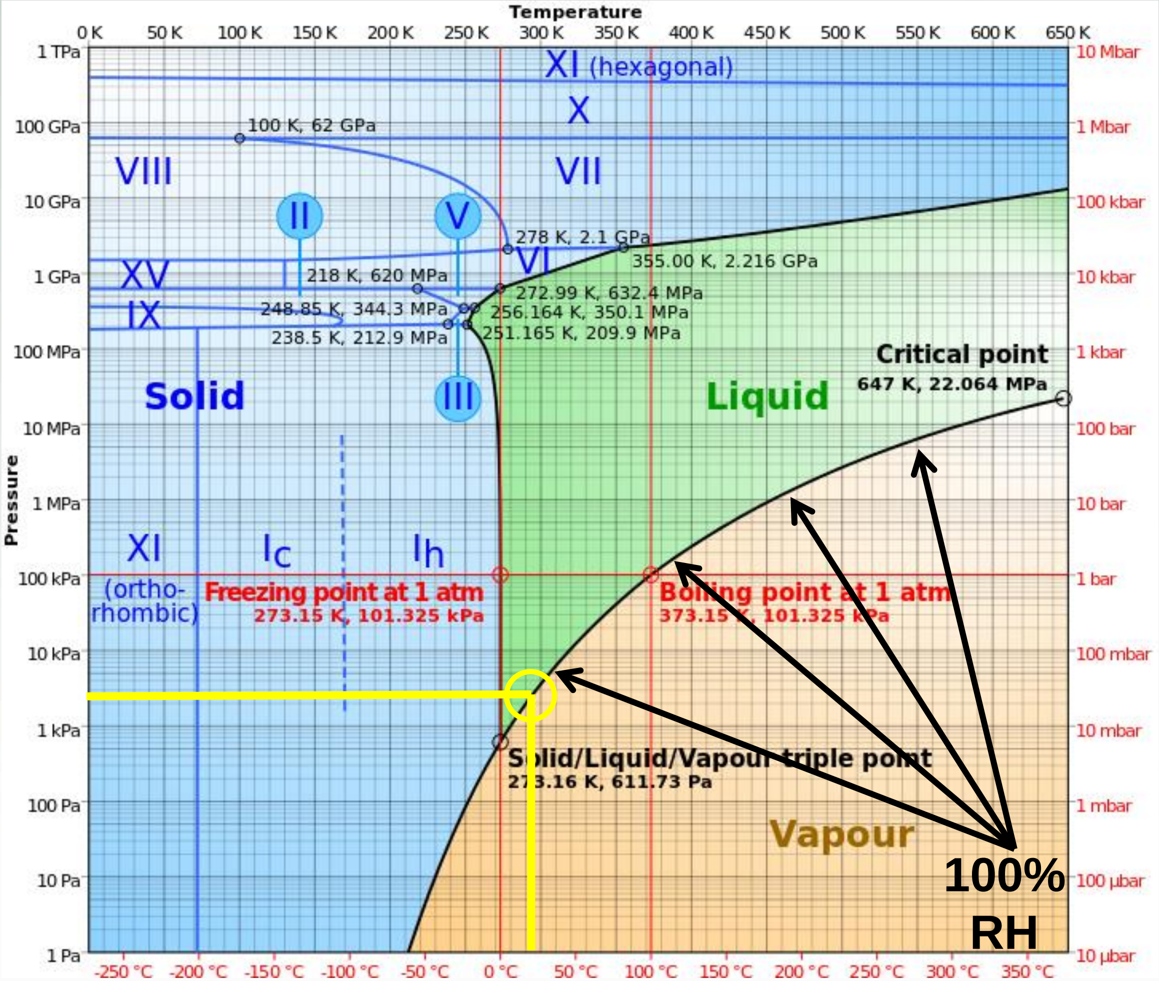
Water and Air Mixtures



Relative Humidity

- The degree to which air is "saturated" with water vapor at a certain temperature and barometric pressure.
- Since barometric pressure is relatively constant, RH is really a function of temperature.
  - For *most* agricultural applications
  - Pressure's influence is the basis of vacuum cooling, however…

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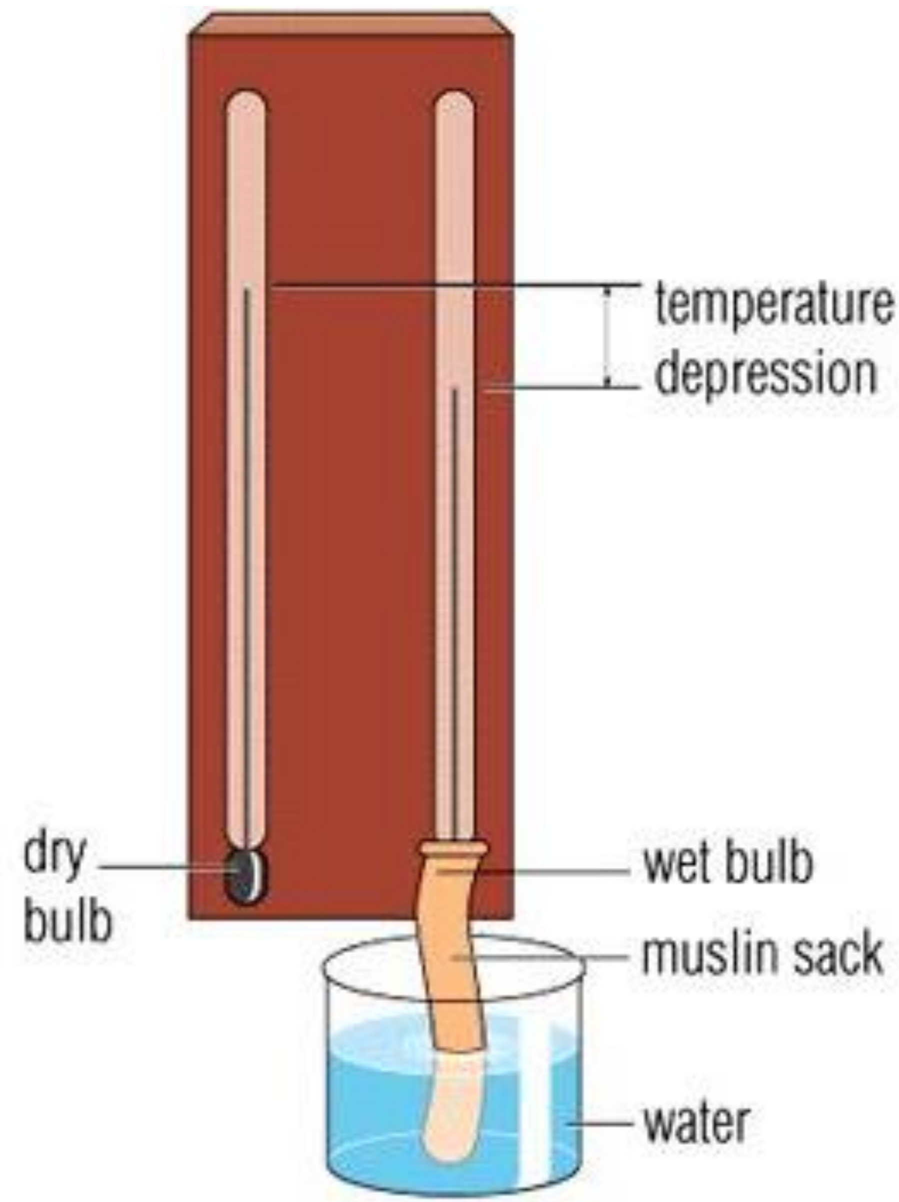
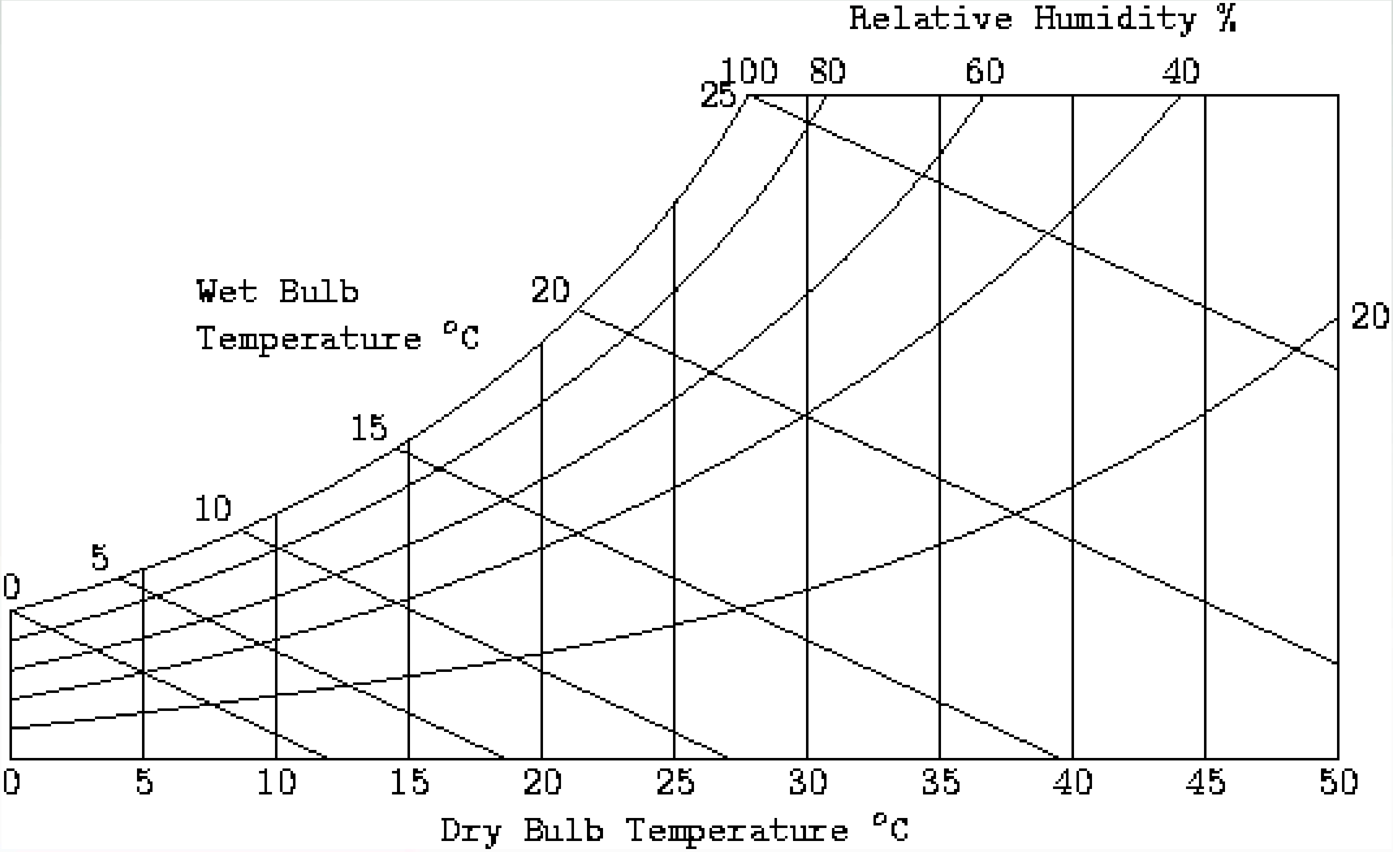
- We don’t actually measure Relative Humidity (RH)
- We measure
  - Dry Bulb Temperature, and
  - Wet Bulb Temperature
- RH is a calculation based on these two temperatures.



Psychrometric Charts

- Relate Dry Bulb T, Wet Bulb T and RH.



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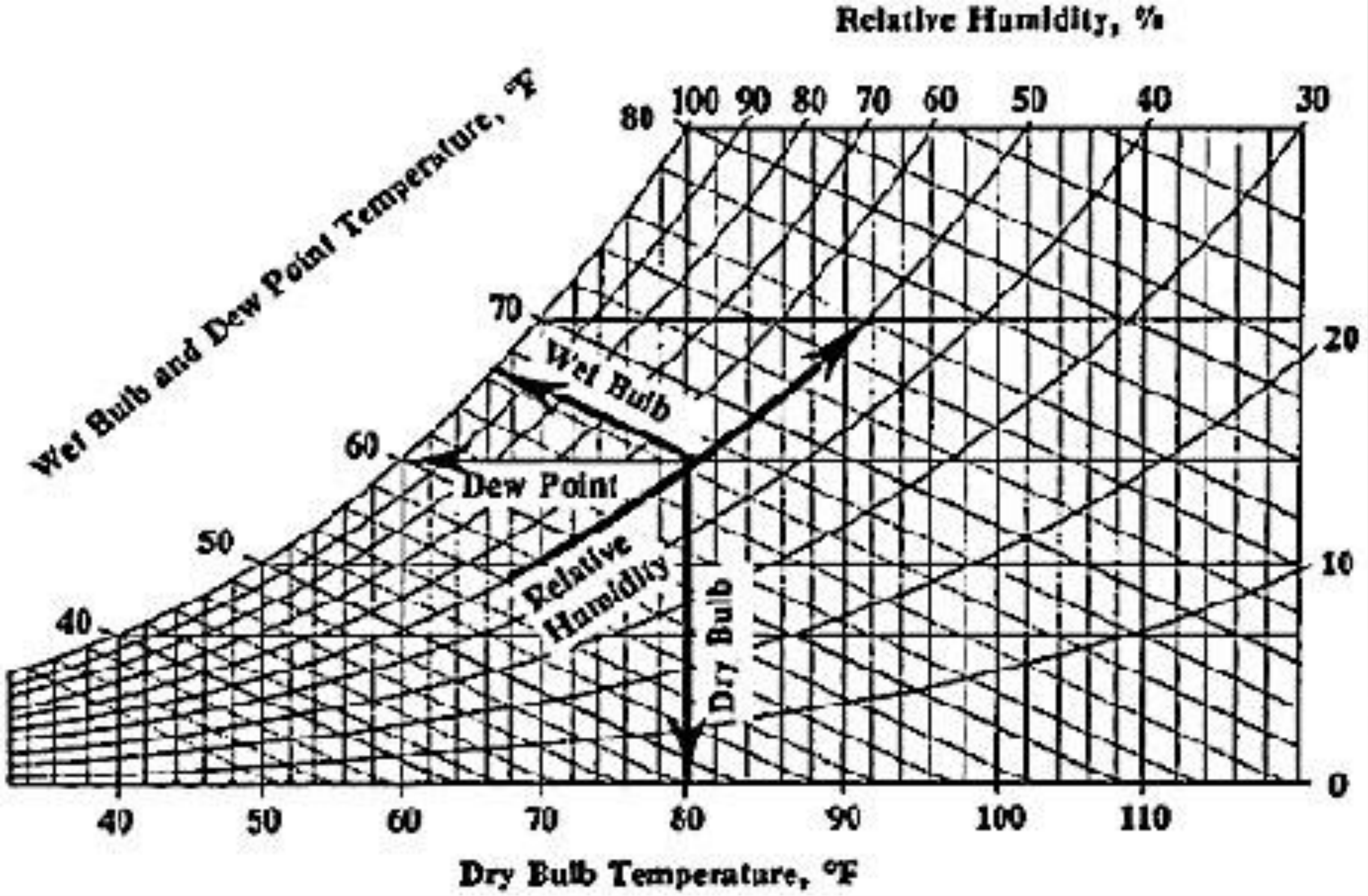
Psychrometric Charts



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Humidity Sensors

- Humidity: 10 to 99% RH
- Temperature: 14 to 140°F (-10 to 60°C)
- Accuracy: **±5%RH**; ±1.8°F, ±1°C

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Sling Psychrometer

QA Supplies
Norfolk, VA, USA
www.qasupplies.com

Vented Psychrometer

Gorman Industries
South Melville, PE, Canada
www.gormancontrols.com

Breakout

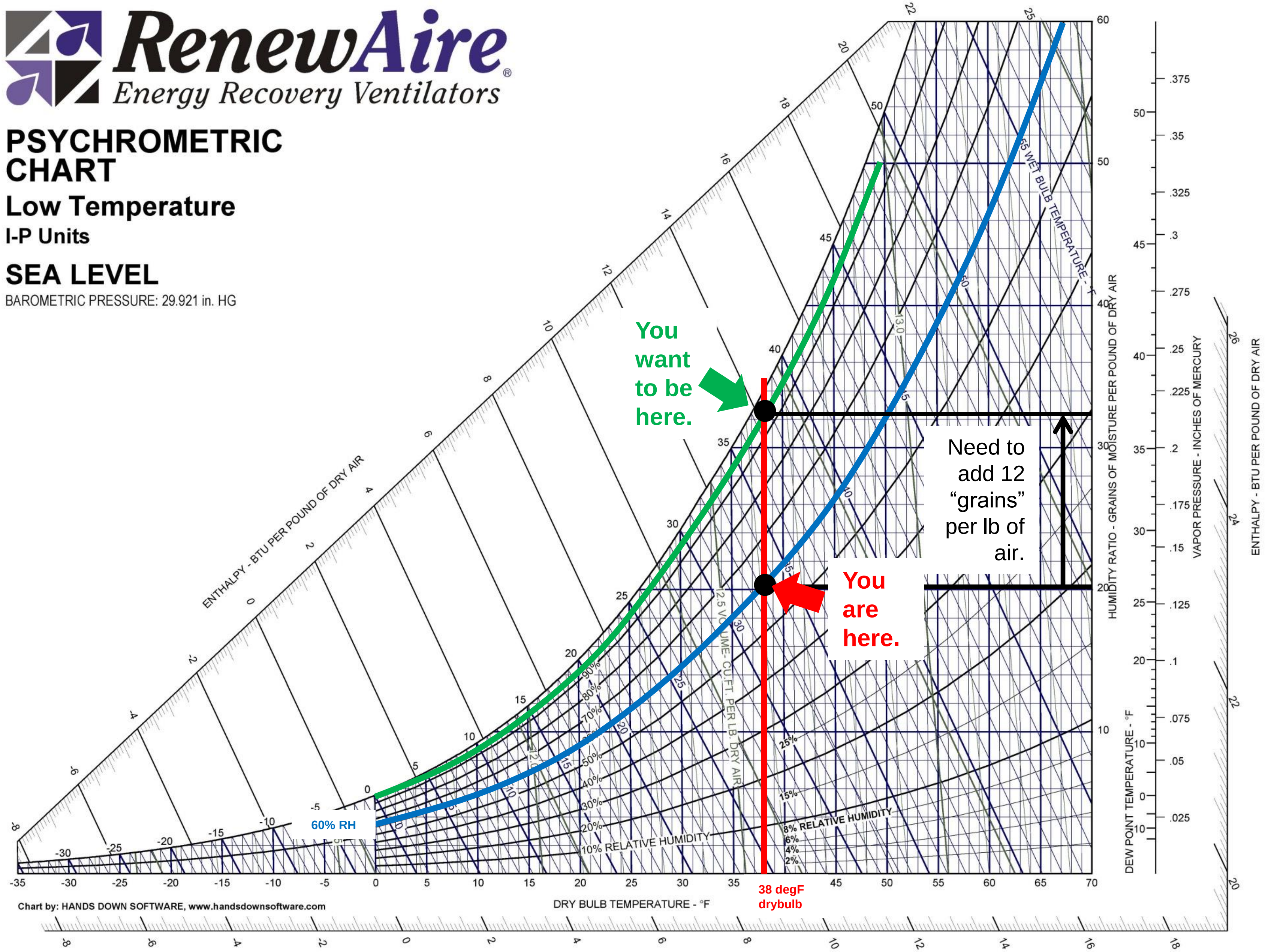
- How is everyone measuring humidity?

Humidity in Potato Room

- Our target temperature is 38 degF.
- Target RH is 95%
- Room (10’x20’x8’) is at 38 degF and 60% RH.
- **How much water do we need to add?**

Humidity in Potato Room

- Room is 10’x20’x8’ = **1600 ft3**
  - Mass of air in room is **126 lbs**
- Temperature (Dry-Bulb) = **38 degF**
- Current RH = **60% RH**
- {How was this measured?}
- Target RH = **95% RH**
- Let’s plot it on the psychrometric chart.



1 grain = 0.000143 lbs

Humidity in Potato Room

- "Grains"?
  - Unit of measure for mass.
  - About 0.000143 lbs per grain. Handy when dealing with amounts of water in air.
- When converted, we need to add
  - 0.0017 lbs water per lb of air
  - We know our room has 126 lbs of air
  - So we need to add 0.22 lbs of water
    - Or 3/100th gallon = **3.3 fluid ounces**

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Humidity in Potato Room

- What does this mean?
- 3.3 fluid ounces isn't much water
- Some water vapor is produced through respiration.
- In this case, the naturally evolved water vapor is likely sufficient to raise the RH.

Measuring Humidity

Sling Psychrometer

Wet Bulb

Dry Bulb

Break

Workshop Outline

- Importance of Food Storage
- Storage Characteristics of Food
- Energy and Heat Transfer
- **Components of a Storage System**
- Sizing and Design
- Practice Session

Structure and Materials

- Sound
- Durable
- Moisture tolerance
- Reusable?
- Portable?




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Alternatives

- Overseas shipping container
- Refrigerated tractor-trailer

Inside the overseas shipping container at Kilpatrick Family Farm, Middle Granville, NY

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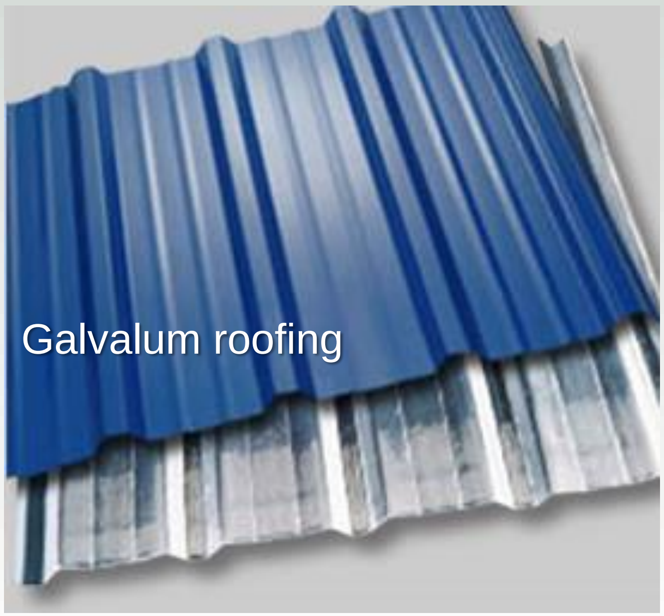
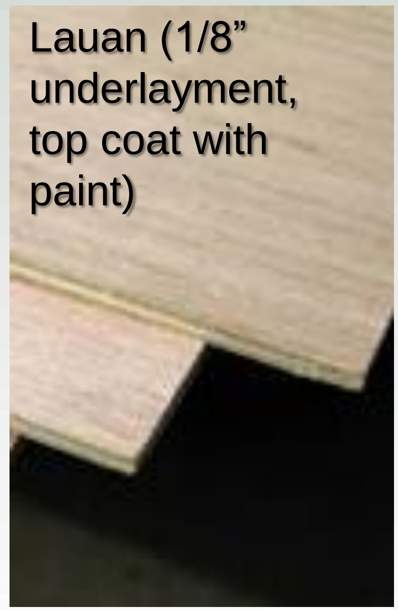
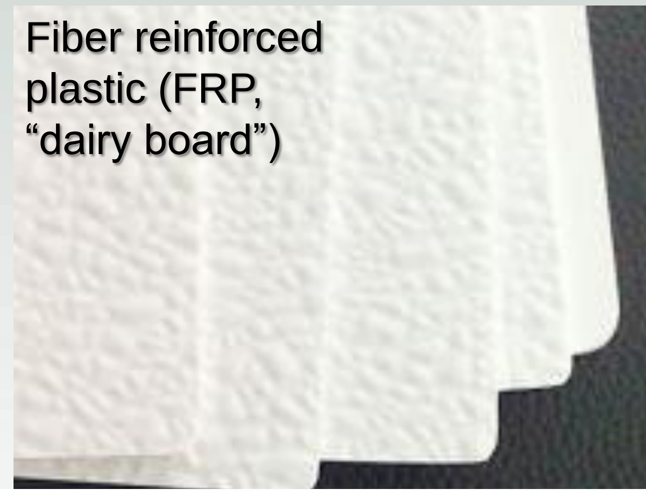
Structure and Materials

“Smooth and cleanable”







Structure and Materials

Practices to avoid

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Materials

- There are many options!
  - Pre-fabricated or homemade?
  - New or used?
  - Pros and Cons for each
  - Cost considerations
- Should be dictated by:
  - Your budget (including labor)
  - Existing infrastructure
  - Your short & long-term plans for the farm
  - What you're storing

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Framing

- Beware of thermal conductors & thermal bridges
  - Staggered stud walls are an option
- Framing with metal vs. wood
  - Must be structurally sound
- Buying a prefabricated box (e.g. pre-fab shed)

Materials

- **Interior materials should be:**
  - smooth;
  - impervious;
  - free of cracks and crevices;
  - nonporous;
  - nonabsorbent;
  - non-contaminating;
  - nonreactive;
  - corrosion resistant;
  - durable and maintenance free;
  - nontoxic;
  - easily cleanable.

Materials

- Examples of good materials to use for interiors:
  - Fiberglass Reinforced Plastic (FRP) (dairy board)
  - Luon (sealed or painted)
  - Sheet Metal
  - Recycled metal roofing or vinyl siding materials
- What not to use
  - Uncoated wood
  - Unsealed spray foam




Avoid Bare Wood & Liquid Water

Options for Insulation

- Pre-Fabricated Box or Individual Panels
- Structural Insulated Panels
- Homemade panels
- Rigid insulation board
- Cellulose Insulation
- Spray Foam
- Other options:
  - Overseas Shipping Containers
  - Refrigerated Tractor-Trailer

Pre-Fabricated Box

Federal Regulations require R-25 for cooler walls and ceilings for prefab box

- Advantages
  - Essentially a plug & go model
  - Easiest to install
  - Potentially moveable
  - Can find used
- Disadvantages
  - Most costly
  - May not be able to find a prefabricated box that perfectly meets specifications
  - Not custom-adapted

Structural Insulated Panels

- Pre-fabricated insulated panels that can be used for cooler siding
- Can be load-bearing
- Can be used for roof-insulation
- Make sure food-safe materials are used

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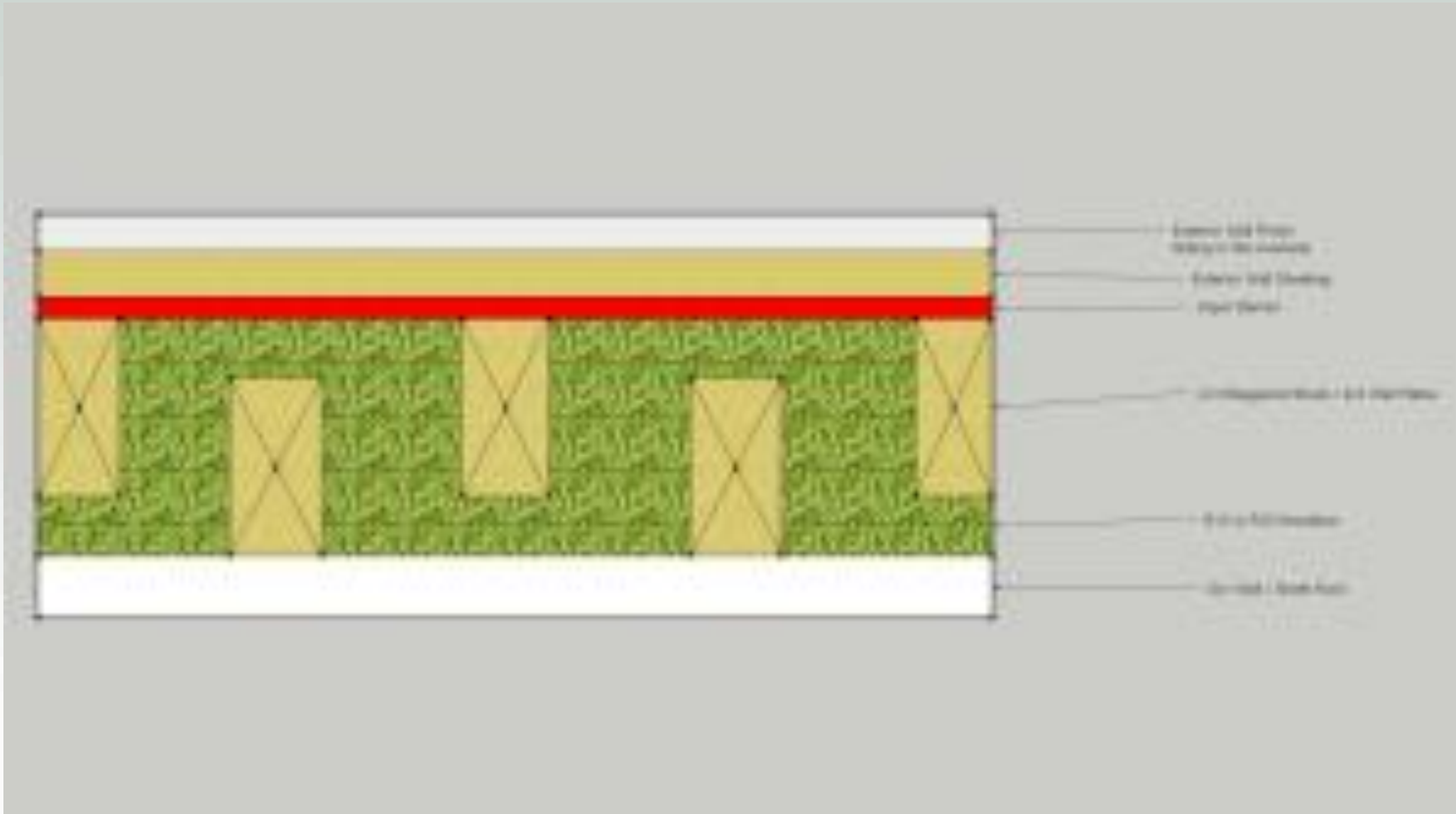
Homemade Panels

- Mimic structural insulated panels in construction
  - Foam board sandwiched between exterior building materials
  - R-value is dependent on what you create
  - Higher labor costs
  - Build it tight

Staggered Stud Walls



Rigid Insulation Boards

- “Blue board”
  – Polystyrene
  – R 4/inch
  – $0.62 /ft2-inch thickness
- Tuff-R
  – Polyisocyanurate
  – R 6.5/inch
  – $0.66 /ft2-inch thickness

Cellulose Insulation

- Inexpensive, recycled materials
- High R-value
  - 3.8 /inch
- Moisture management is essential

Fiberglass Insulation

- Questionable sustainability
- R 3.1-4.3/inch
- Not recommended for cooler applications due to moisture issues.

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Spray Foam

- Polyurethane spray foam
  - Creates a tight seal, is versatile & inexpensive
  - High-density foam is best
  - Can create r-value of 50 or higher
    - 6.25 per inch of insulation
  - Not smooth or cleanable
  - Flammability
  - Sealing spray foam
    - *Make sure it can withstand cooler conditions.*
    - *Ames Rubber – has worked for several growers*

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Where to Insulate

- Floor
  - Different than insulating a home or barn
  - Floor needs to be insulated if storage is over or under 45°—even if it's in a basement!
  - Uninsulated floor is a cold sink or a heat source
  - Doesn't have to be framed out
- Roof needs to be insulated
  - Different than in a home where you're trying to keep rising heat in

Cost Comparison

- Pre-Fabricated Box or Individual Panels (new vs. used)
- Structural Insulated Panels
- Homemade panels
- Spray Foam
- Other options:
  - Overseas Shipping Containers
  - Refrigerated Tractor-Trailer (“Reefer”)

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Sealing

- Caulking during construction
- Overlapping foam board, don’t cut to fit between studs
- Has to be tight or you’re wasting money!
  - Both temperature and humidity implications

Drainage

- Lots of moisture collects on the floors in coolers
  - Build entire cooler slanted towards the door (or drain)
  - Incorporate a drain into the cooler
- Route condensation line intentionally.

Lighting

- Shatter-proof, shatter-resistant, or with a protective guard
- Must work in low temps/high humidity and turn on quickly
  - Compact fluorescent bulbs aren't great
- Should be bright enough to be able to see
  - think efficiency!

Access: Doors and Sealing

- Doors
  - – Home built or pre-fabricated?
  - – Must seal-up tight! Hard to perfect
- Swing vs. Sliding vs. Overhead
- Plastic Curtains
- Weather Stripping

Sliding cooler door with plastic curtains at Jericho Settlers Farm

Doors and Sealing

- Check door seals and latches - adjustable

Structure and Materials

- Sealing –
  - daylight test
  - (or dog/cat test).

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Containers

- Storage bins/pallet sizing
- Consider: Wood vs. Plastic, Maneuverability, Stackability, Airflow & circulation


Photo Credit: Brookfield Farm


Photo Credit: MacroPlastics


Photo Credit: Monte Package Company


Photo Credit: Orbis

Winter Wash Station

- Many farms need to incorporate wash stations into winter storage systems
- Consider:
  - Will you be washing crops going into or coming out of storage
    - Does there need to be space to wash crops indoors?
  - Is there a creative way to combine a wash station with another storage area that needs humidity?

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Washing

- Staining: Depends on soils types, crop variety, & maybe timing of harvest
- Disease
  - Washing can help prevent infiltration of crop disease, or it can help disease enter crop
- Storability of crop

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http://extension.umass.edu/vegetable/projects/umass-carrot-storage-trials

Rodent & Pest Control

- New construction vs. Retrofit
- Bait & traps
  - OMRI approved D3 rodenticide
  - Must have strict schedule for checking traps!
- Tight envelope excludes pests
  - Wire mesh / hardware cloth
- Some storage bins help exclude rodents
- Cement curb

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Managing Zones

- Innovations to incorporate multiple zones into a single space
  - Adapted packaging
- Red Fire Farm
  - Plastic wrapped pallets with wet burlap & water reservoirs
  - Consider ethylene—how long will product be in storage?
  - Watch for hot spots during storage

Innovation at Red Fire Farm

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1 3/4 BU.
1 3/4 BU.
ROMAINE
VERMONT'S
BIG HAWK
BRAND
CERTIFIED ORGANIC
NET WT. 25 LBS. (11.35Kg)
WESTMINSTER ORGANICS
U.S. No. 1

Breakout

- What have you built or what do you have planned?

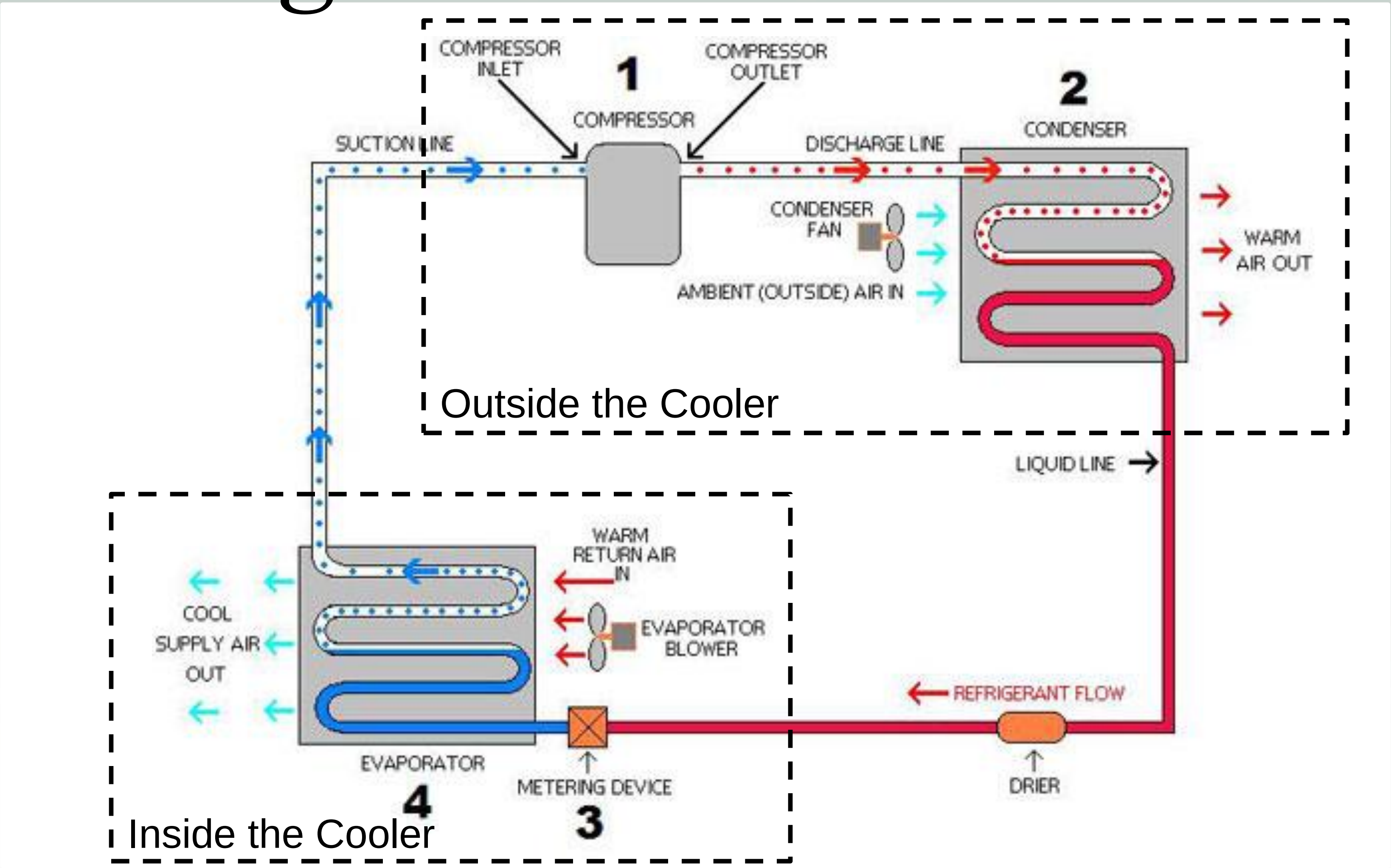
- What construction details are you considering?

Intro to Refrigeration

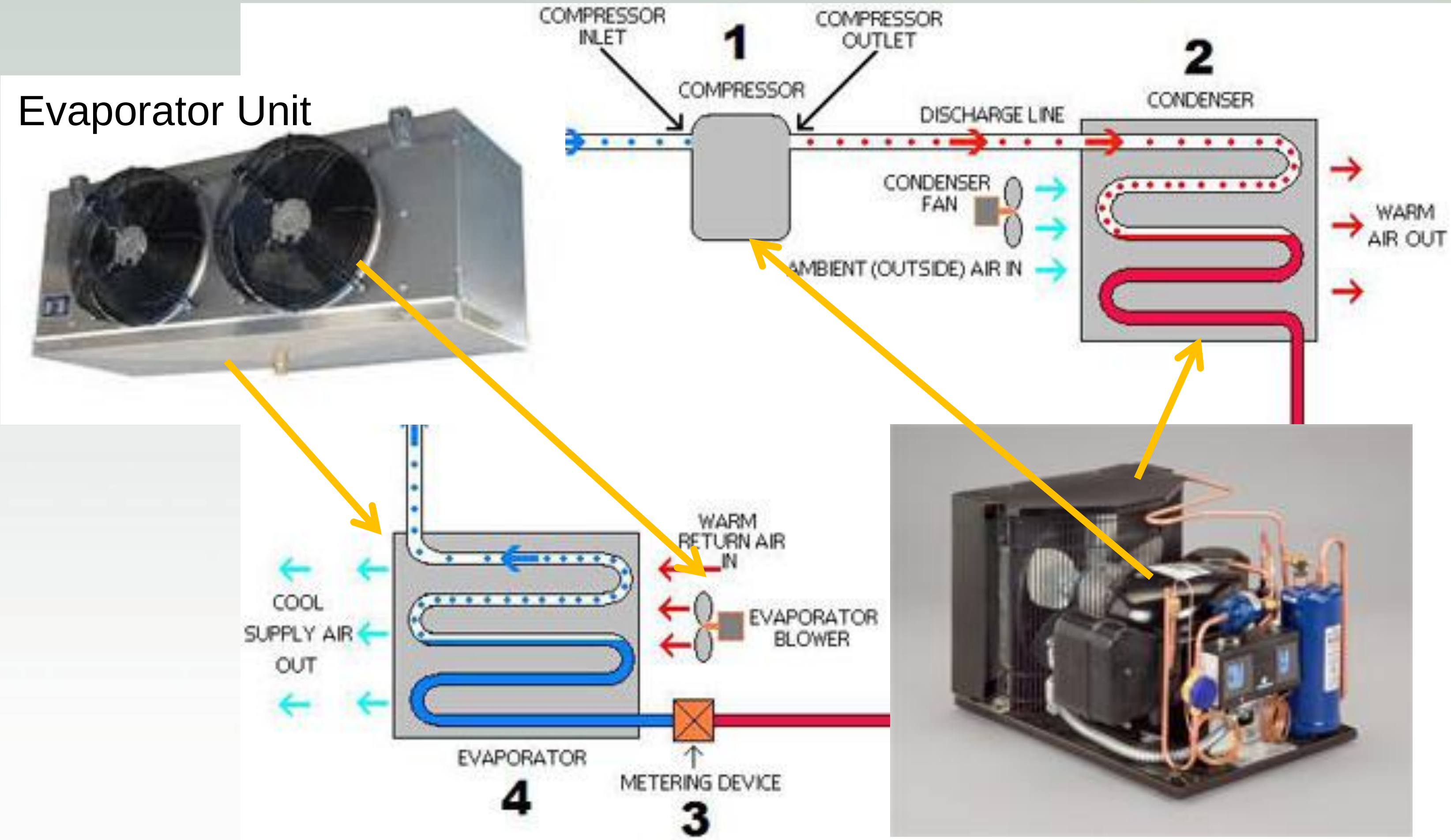
- Mechanical Refrigeration is a pumping system.
- We use the phase change of a refrigerant to move heat from one location (low temperature) to another (high temperature.)
- Yes, we are moving heat from cold to hot.

Intro to Refrigeration

Refrigeration



Refrigeration

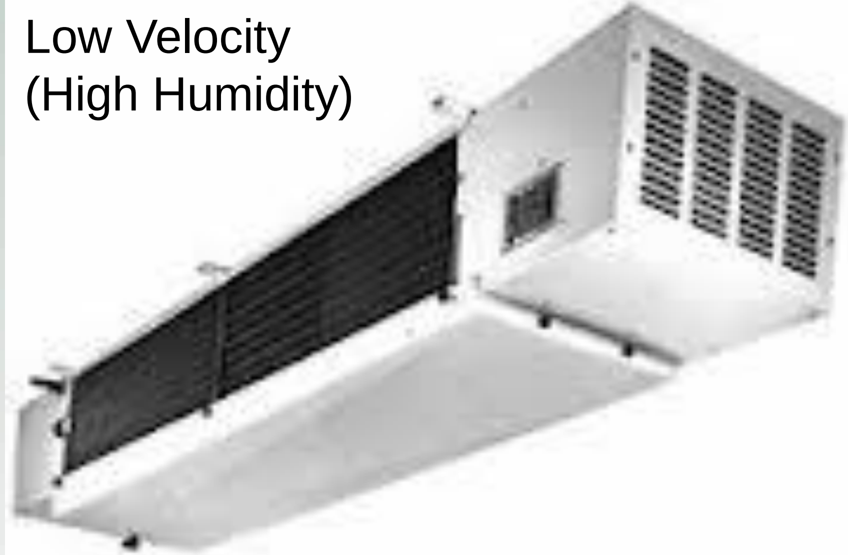


Compressor / Condenser Unit

Evaporator Options

Standard

Low Velocity
(High Humidity)



Plates

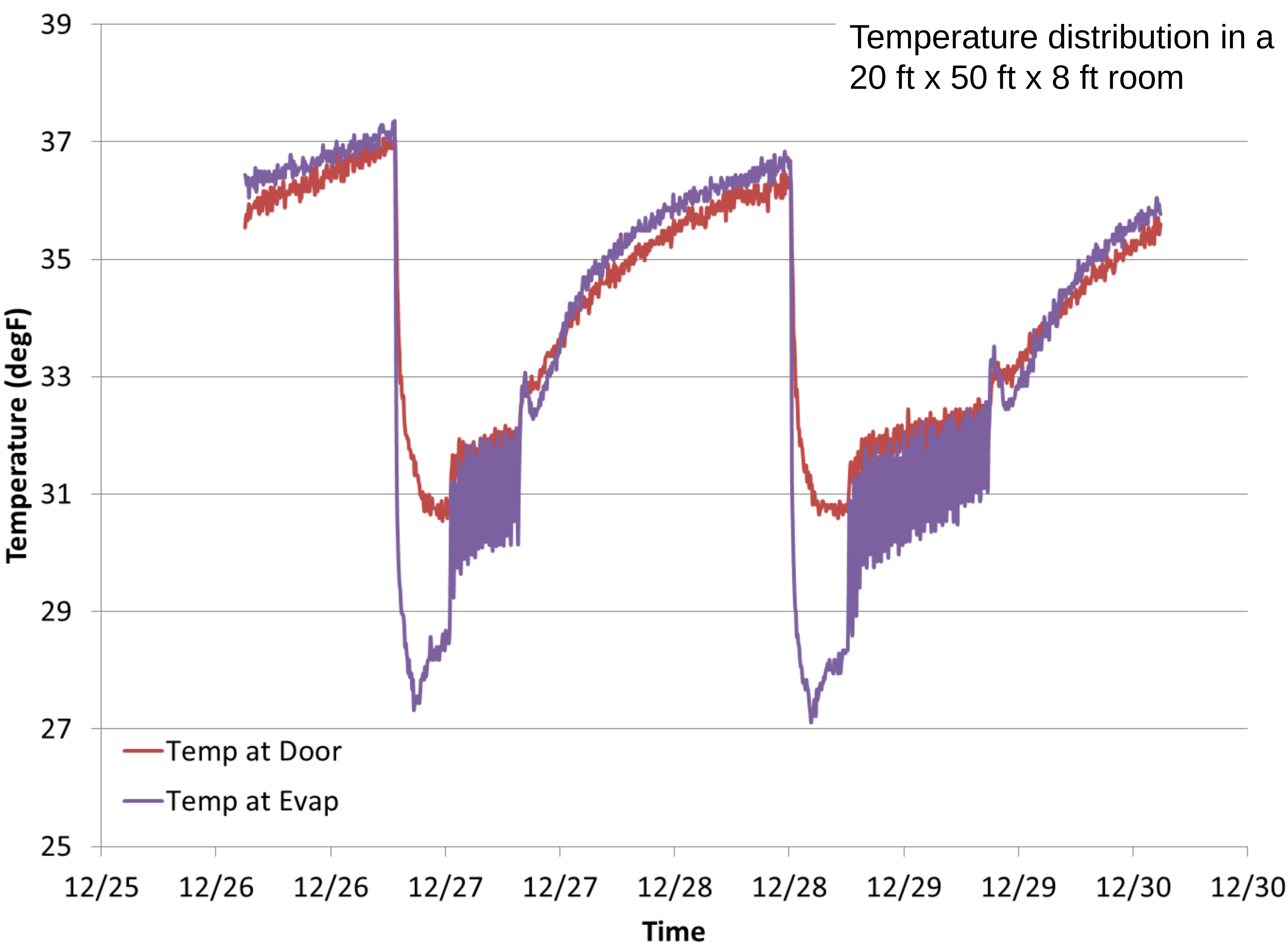
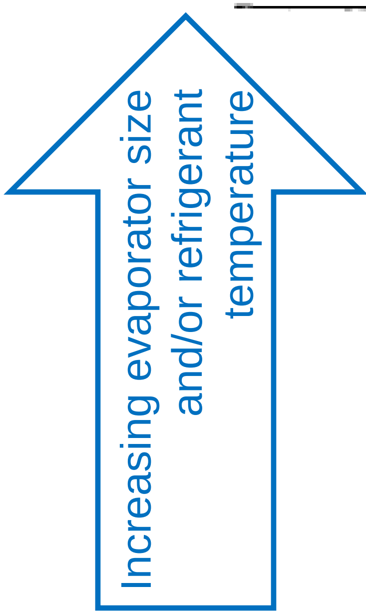

Temperature distribution in a
20 ft x 50 ft x 8 ft room
39
37
35
33
31
29
27
25
Temperature (degF)
Temp at Door
Temp at Evap
12/25
12/26
12/26
12/27
12/27
12/28
12/28
12/29
12/29
12/30
12/30
Time

Table 3. Minimum Relative Humidity Levels[1] Developed at Various Storage and Evaporator Discharge Temperatures



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

From NRAES-22 – "Refrigeration and Controlled Atmosphere Storage for Horticultural Crops. J. A Bartsch & G. D. Blanplied. 1984.

CoolBots™

- Adapt an air conditioner for use as a refrigeration system.
- Air conditioners are basically “packaged” refrigeration systems run at higher temperature.
- Build a “good box” first.

CoolBots™

- Pro's
  - Low initial cost
  - Easy to retrofit into existing spaces with basic construction
  - Potential efficiency benefit
- Con's
  - Slow to "pull down" temperature
  - Slow to recover from rises in temp
  - Can not freeze, only cools down to 35 ºF

www.storeitcold.com – Has loads of info and is very clear.

CoolBot vs. Conventional

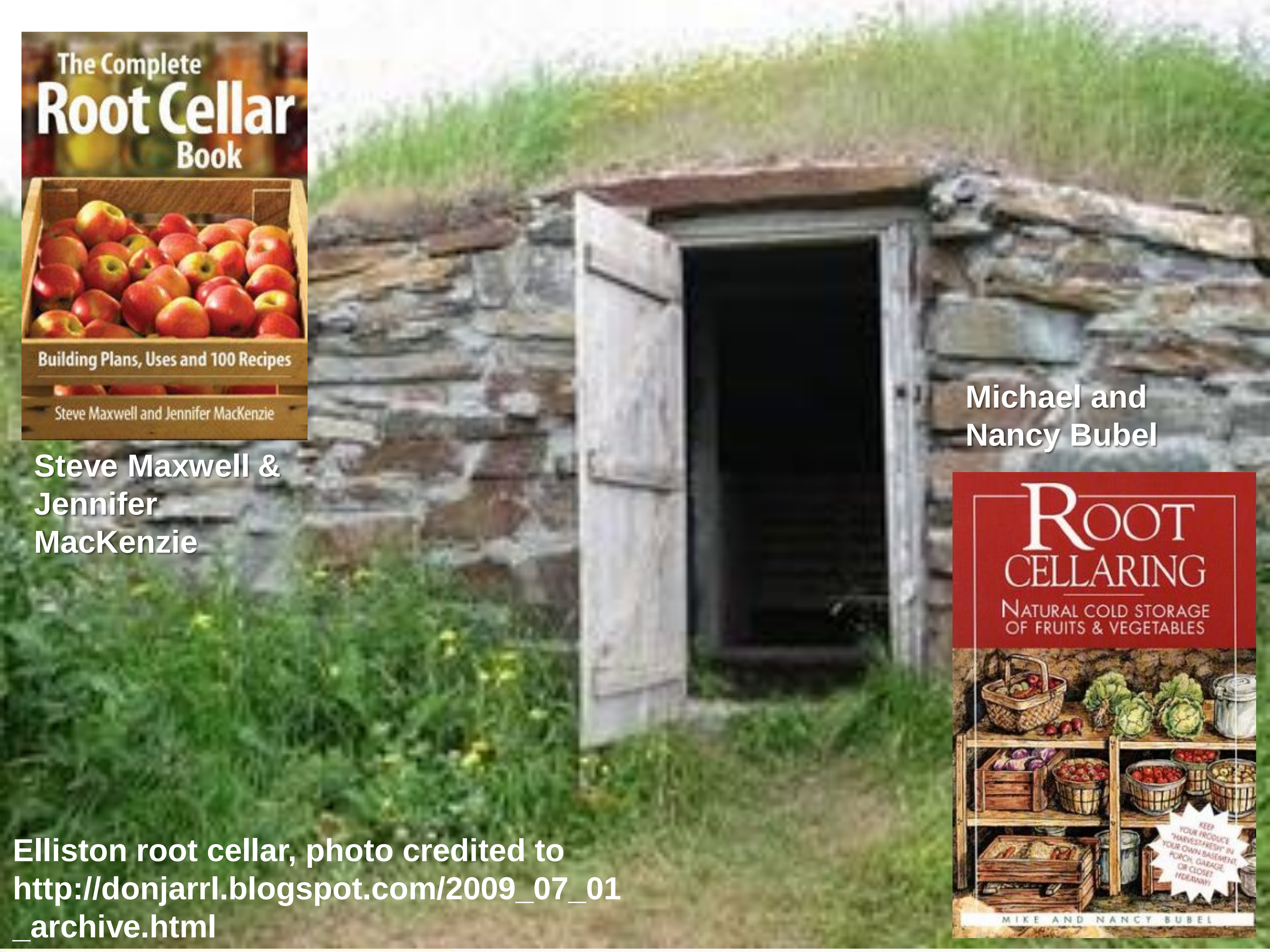
- 2009 NYSERDA Study
  http://storeitcold.com/coolbot%20Report%20May09.pdf
- 8'x10' storage room - Albany, NY conditions
- Cooled to 35 F
  - with evap fan controls
    - Conventional is 74 kWhr/yr more efficient ($10/yr)
  - without evap fan controls
    - CoolBot is 230 kWhr/yr more efficient ($30/yr)
- Coolbot cost $750 (net of cold room)
- Conventional cost $4,400 (net of cold room)

Geothermal

- What most people mean by “root cellar.”
- Passive thermal and humidity control using the ground as the source and sink
- Active thermal – piped air through ground.
- Soil contact should be avoided in storage.
- “Geothermal” sometime used to mean “Ground Source Heat Pump.”

Root Cellars

- Air Exchange
  - Helpful for shoulder months
  - Need positive shutoff to avoid passive ventilation when not wanted
  - Double thermostat design with a small fan
- Rodent Control
- Moisture and Condensation Plan



Steve Maxwell & Jennifer MacKenzie

Michael and Nancy Bubel

Elliston root cellar, photo credited to http://donjarrl.blogspot.com/2009_07_01_archive.html


BUS
STOP

Heating

- Generally required for winter squash, pumpkins, etc.
- Same basic principles related to storage space / room.
- Air flow and circulation
- Heater controls

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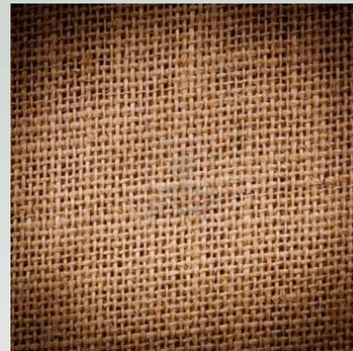
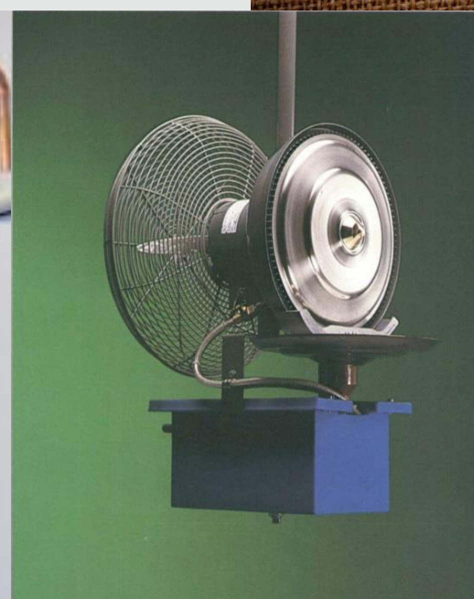
Humidification

Humidification

- Generally required for root veg storage

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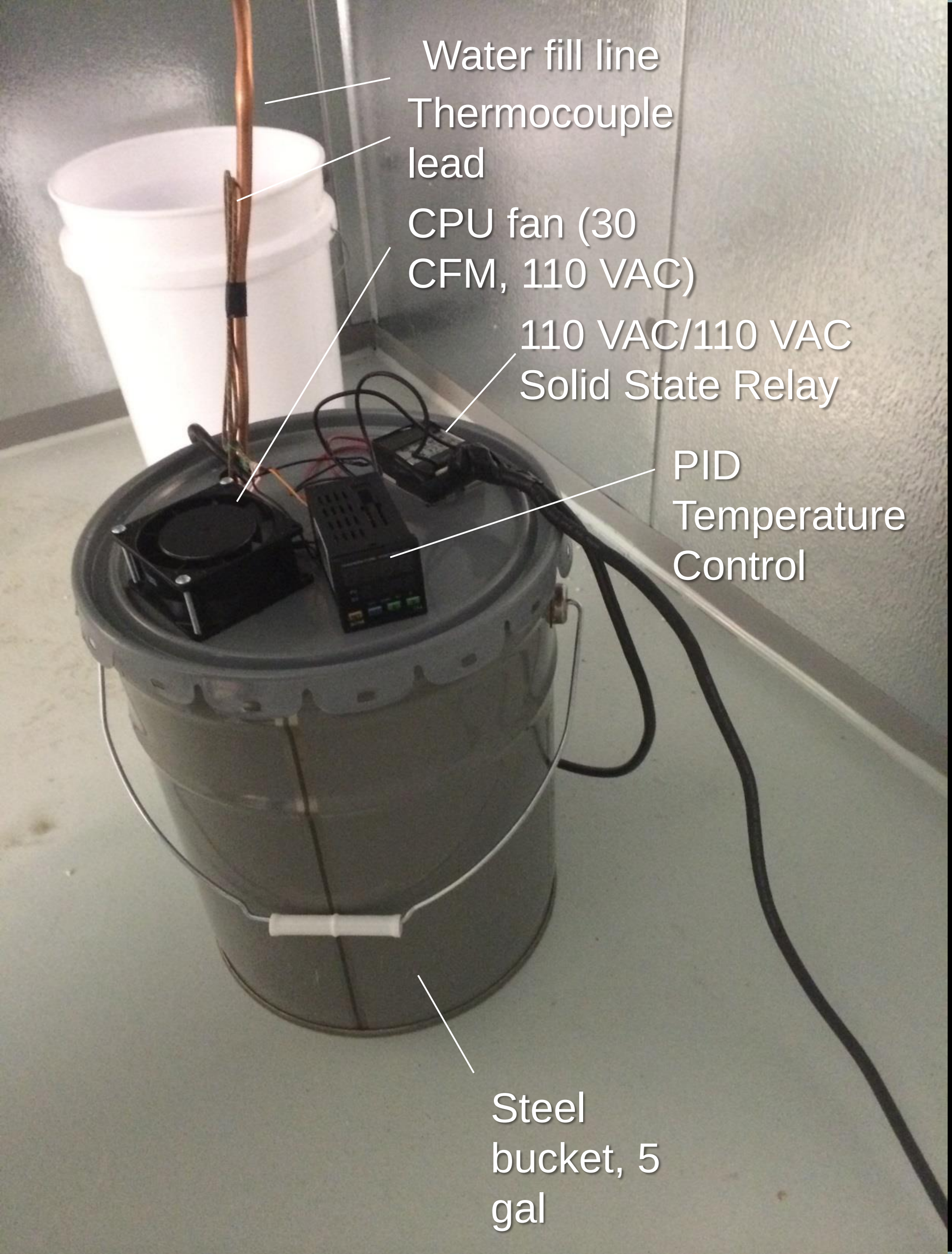

www.FarmHack.net

http://farmhack.net/tools/auto-fill-high-output-temperature-controlled-humidifier#wiki


Toilet fill valve
Tank deicing heater

Drying

- Generally not an issue in storage.
- “Curing” is a method of prolonging storage life and prevent disease in storage
  - Essentially control drying
  - Reference Handbook 66 for conditions.
- If storage area is high RH relative to desired conditions, consider controlled outside air exchange.

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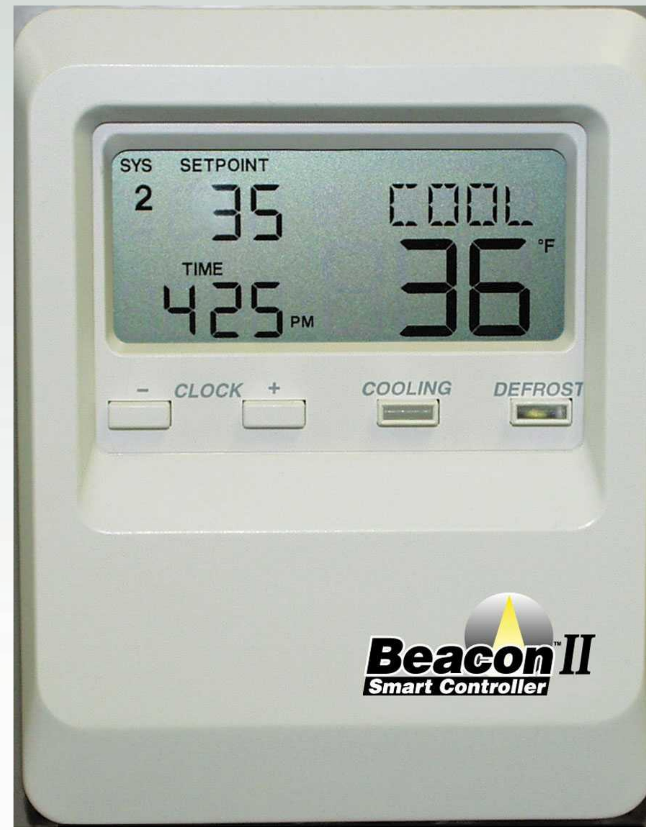
Workshop Outline

- Components of a Storage System
  - Creating a Structure or Box
  - Cooling
  - Heating
  - Ventilation & Air Flow
  - Humidification & Drying
  - Controls
  - Lighting
  - Monitoring

Controls - Thermostats

- Control a load based on temperature



Controls - Thermostats

- Dramm – Accurate to 1 degC (2 deg F)
  - Same model as greenhouse ones.
  - Single and dual stage
  - For heating and cooling
    - Different set of contactors.

Controls - Humidistats

- Control a load based on measured (or calculated) RH

Controls – Expandable Systems

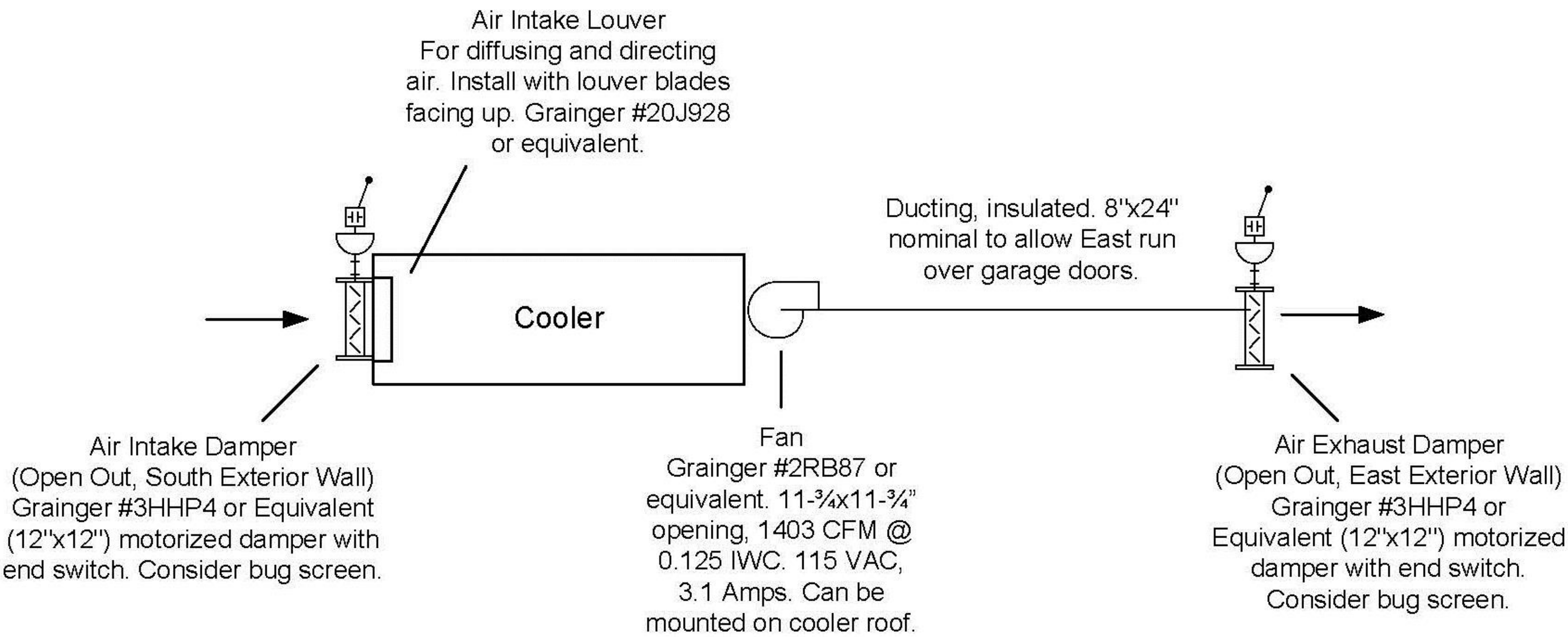
- Combined Temp and RH
- Modular and expandable
- Modulated outputs as well as On/Off

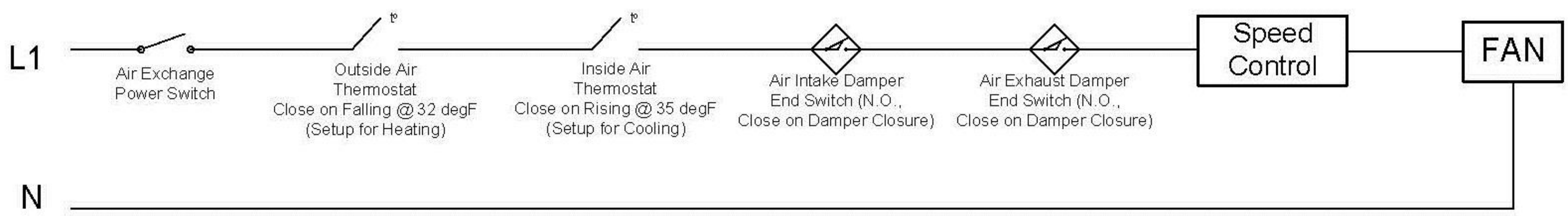
Ventilation & Airflow

- Seeking to have a well mixed storage space.
- Avoid hot spots
- Avoid high moisture
- Strip ethylene.
- 3-5 volume changes per day is rule of thumb.
- Higher for curing or pre-cooling.

Remember that a thermostat is simply a switch

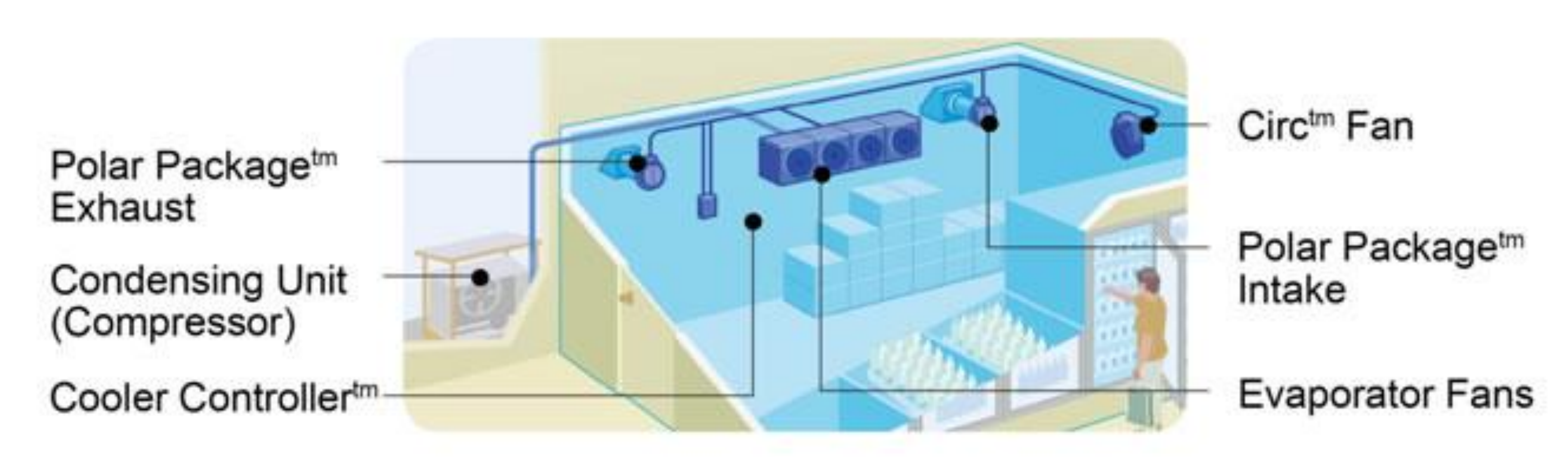
From Stephen Belyea


Air Intake Louver
For diffusing and directing air. Install with louver blades facing up. Grainger #20J928 or equivalent.
Cooler
Ducting, insulated. 8"x24" nominal to allow East run over garage doors.
Air Intake Damper
(Open Out, South Exterior Wall) Grainger #3HHP4 or Equivalent (12"x12") motorized damper with end switch. Consider bug screen.
Fan
Grainger #2RB87 or equivalent. 11-¾x11-¾" opening, 1403 CFM @ 0.125 IWC. 115 VAC, 3.1 Amps. Can be mounted on cooler roof.
Air Exhaust Damper
(Open Out, East Exterior Wall) Grainger #3HHP4 or Equivalent (12"x12") motorized damper with end switch. Consider bug screen.


L1
N
Air Exchange Power Switch
Outside Air Thermostat Close on Falling @ 32 degF (Setup for Heating)
Inside Air Thermostat Close on Rising @ 35 degF (Setup for Cooling)
Air Intake Damper End Switch (N.O., Close on Damper Closure)
Air Exhaust Damper End Switch (N.O., Close on Damper Closure)
Speed Control
FAN

Controls - FreeAire™

- Uses cold outdoor air to refrigerate.
- Reduces compressor run time
- Reduces evaporator fan load
- Install involves other efficiency upgrades.



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Controls

- Never trust your thermostat or humidistat
  - Precision and accuracy are different things.
- Always have a secondary, trusted measurement
  - Sling psychrometer is best.
- Check your **actual** conditions regularly

Workshop Outline

- Components of a Storage System
  - Creating a Structure or Box
  - Cooling
  - Heating
  - Ventilation & Air Flow
  - Humidification & Drying
  - Controls
  - Lighting
  - Monitoring

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Measure and Monitor

- "The measured variable improves."
- Temperature ***<u>AND</u>*** Relative Humidity
- Don't assume you have the conditions you want. **Measure**.
- **Low tech** – wall sensors, daily checks, log book
- **High tech** – remote monitoring, email alerts
- Calibration and certification

USB Data Loggers

DATA-Q www.dataq.com

EL-USB-2+ USB Data Logger
Measures ambient temperature and humidity
Higher accuracy than EL-USB-2
Automatically calculates dew point
-35 to +80 °C (-31 to +176 °F) temp measurement range
±0.3 °C (±0.6 °F) overall temp accuracy
0-100% RH measurement range
±2.0% overall RH accuracy (20-80%RH)
2 User-programmable temp alarm thresholds
2 User-programmable RH alarm thresholds

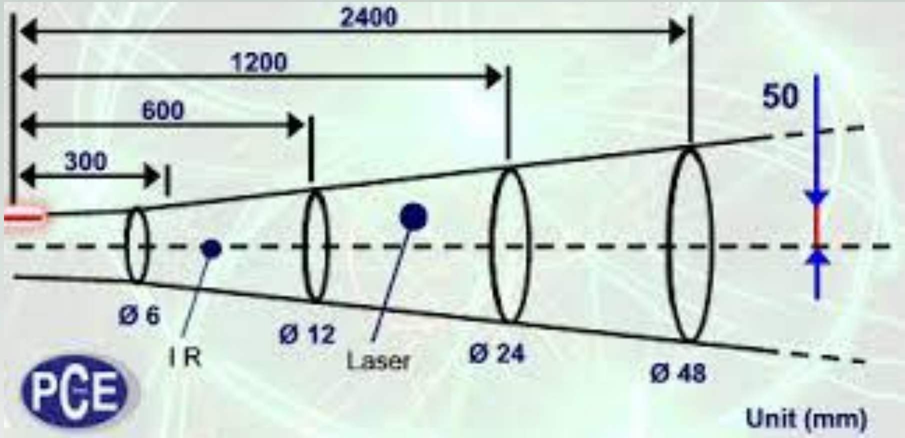
5 minute readings = 56 days storage
1 minute readings = 11 days storage
Download data to computer

$125 (RH +/-2%)

$99 (RH +/-3%)

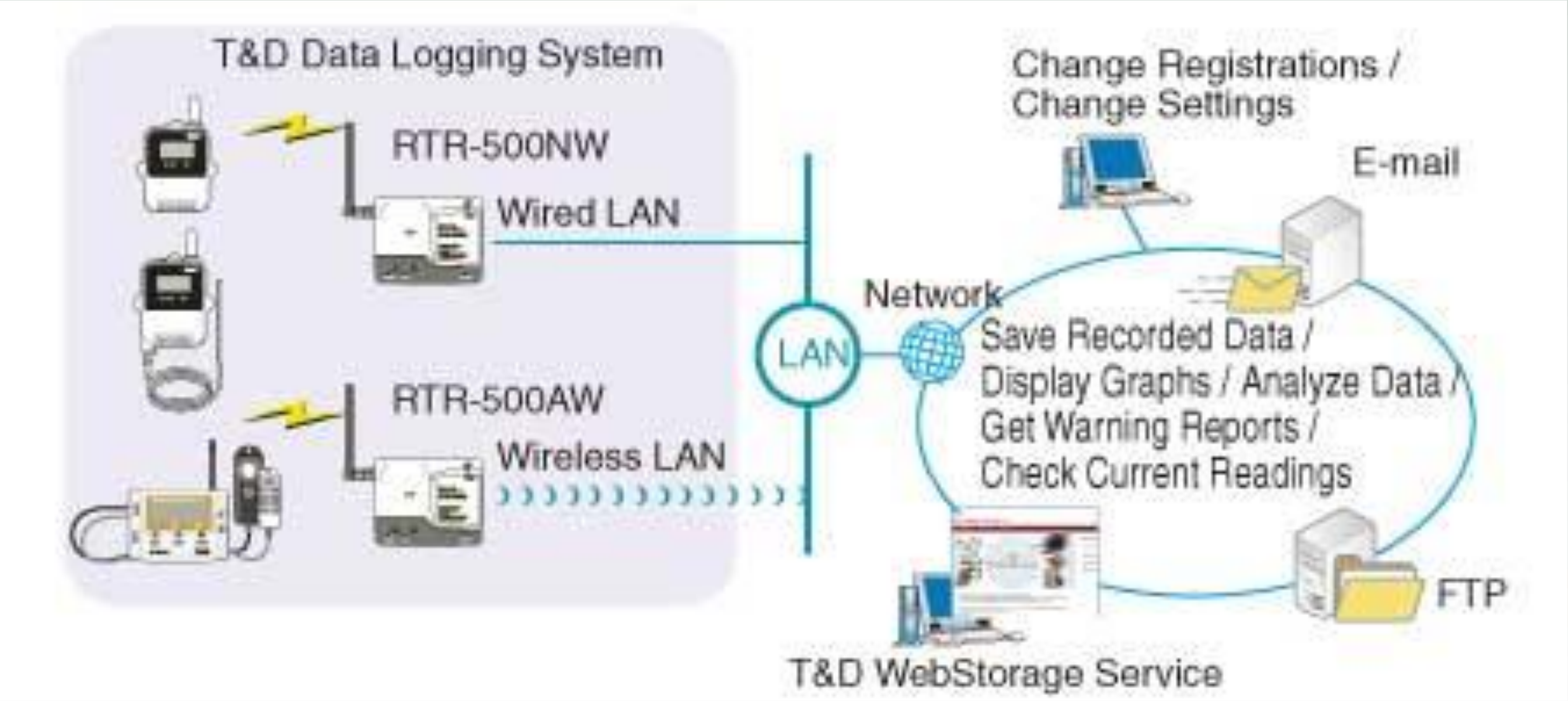
$82 (RH +/-3%)

Infrared Thermometer



$20-100

Remote Monitoring



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Remote Monitoring

- $400-$2000 for a typical install.

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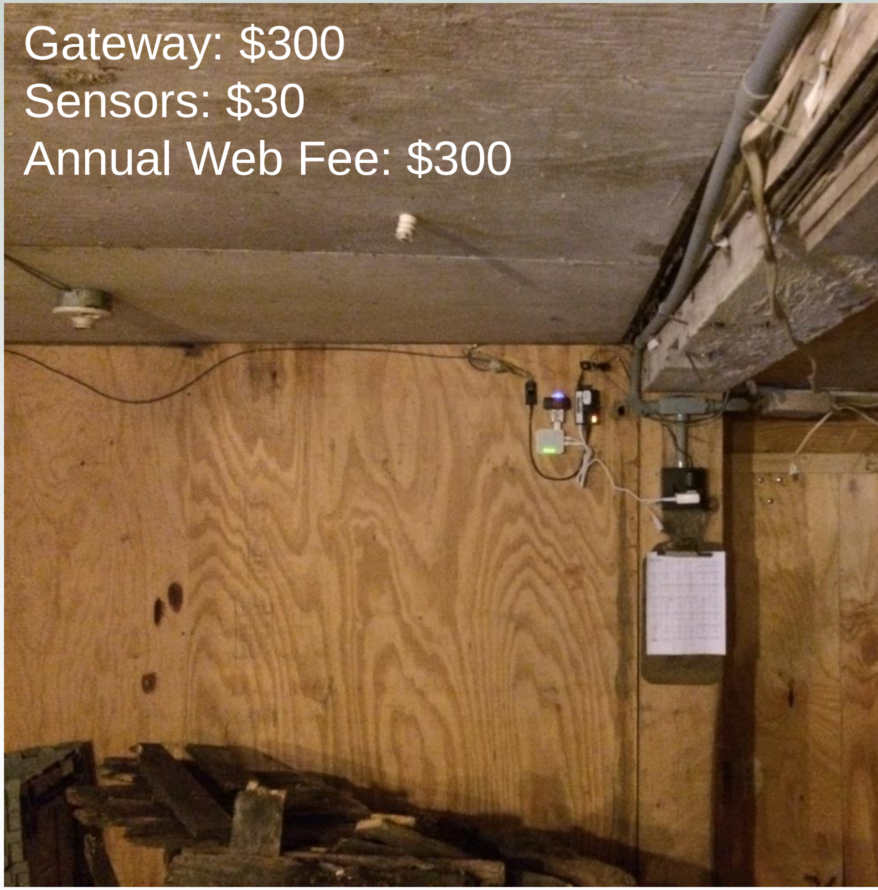
Sensaphone

- Several models
- 400 – 4 inputs
- 800 – 8 inputs
- $460 for the control
- $32 per sensor

Mojyle

Gateway: $300
Sensors: $30
Annual Web Fee: $300



Break

Sizing & Design

- Summary Review
- Design Approach
  - Space Requirements
  - Cooling Load Calculation
  - Equipment Selection
- Design Charrette / Consults

Summary

1. Know your target conditions.
2. Provide multiple zones.
   May not be multiple rooms.
3. Informed design, construction and purchase of equipment.
4. Measure your actual conditions.
5. Improve crop selection on the way in.

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Sizing & Design

- Principles Review
- **Design Approach**
  - Space Requirements
  - Cooling Load Calculation
  - Equipment Selection
  - Siting
- Design Charrette

Space Requirements

- List your storage crops
  - And quantity
- Check your loading density
- Group by temperature and RH

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Cooling Load Calculation

- Space dimensions
  - Product storage is 2/3 of overall space
- Sketch the cooler
- Consider insulation thickness

Cooling Load Calculation

- Load calculation
  - Ambient heat gain
  - Slab heat gain
  - Respiration
  - Door/Infiltration
  - Precooling

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Equipment Selection

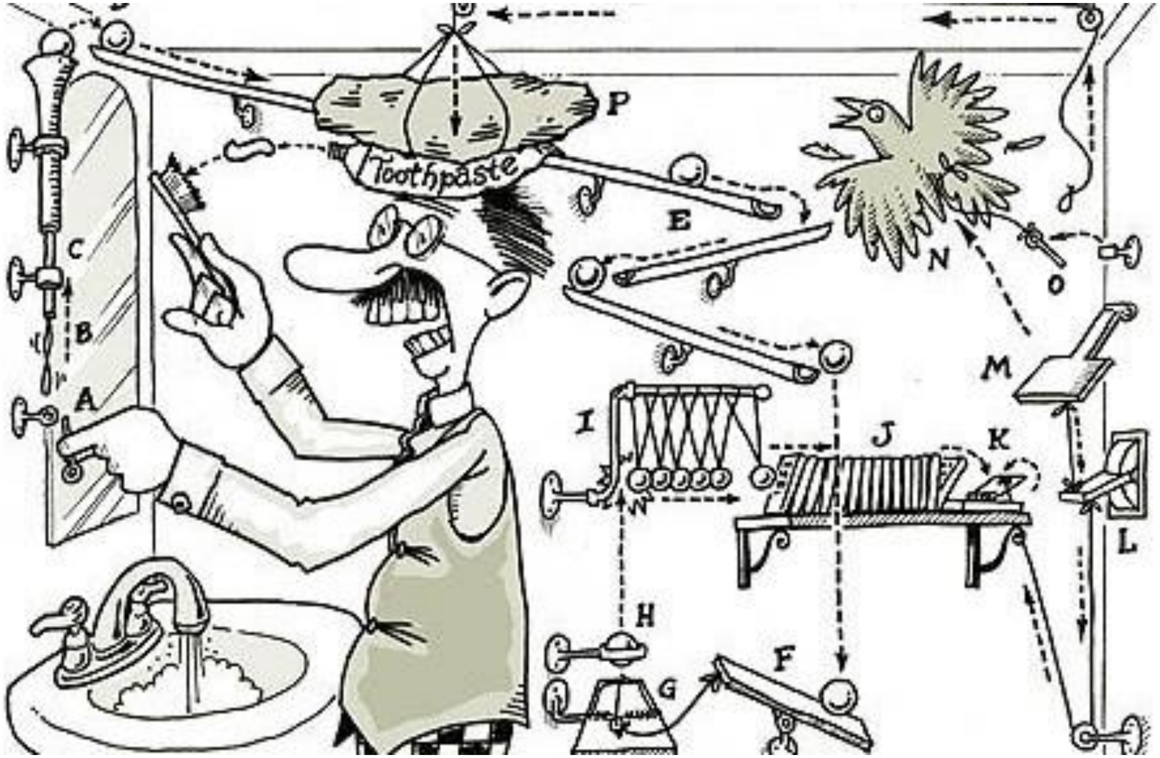
- Air Exchange
- Evaporator
- Compressor/Condenser
- CoolBot

Siting

- Retrofit or new construction?
- Retrofit considerations
  - Structural integrity of existing structure
  - Accessibility & efficiency
- New construction
  - Where to put it? Out of direct sunlight! Shade of a tree or barn is nice
  - Efficiency as a piece in the whole farm system

“The **perfect** is the **enemy** of the **good**.”

- Voltaire



Sizing & Design

- Principles Review
- Design Approach
- **Design Charrette / Consults**

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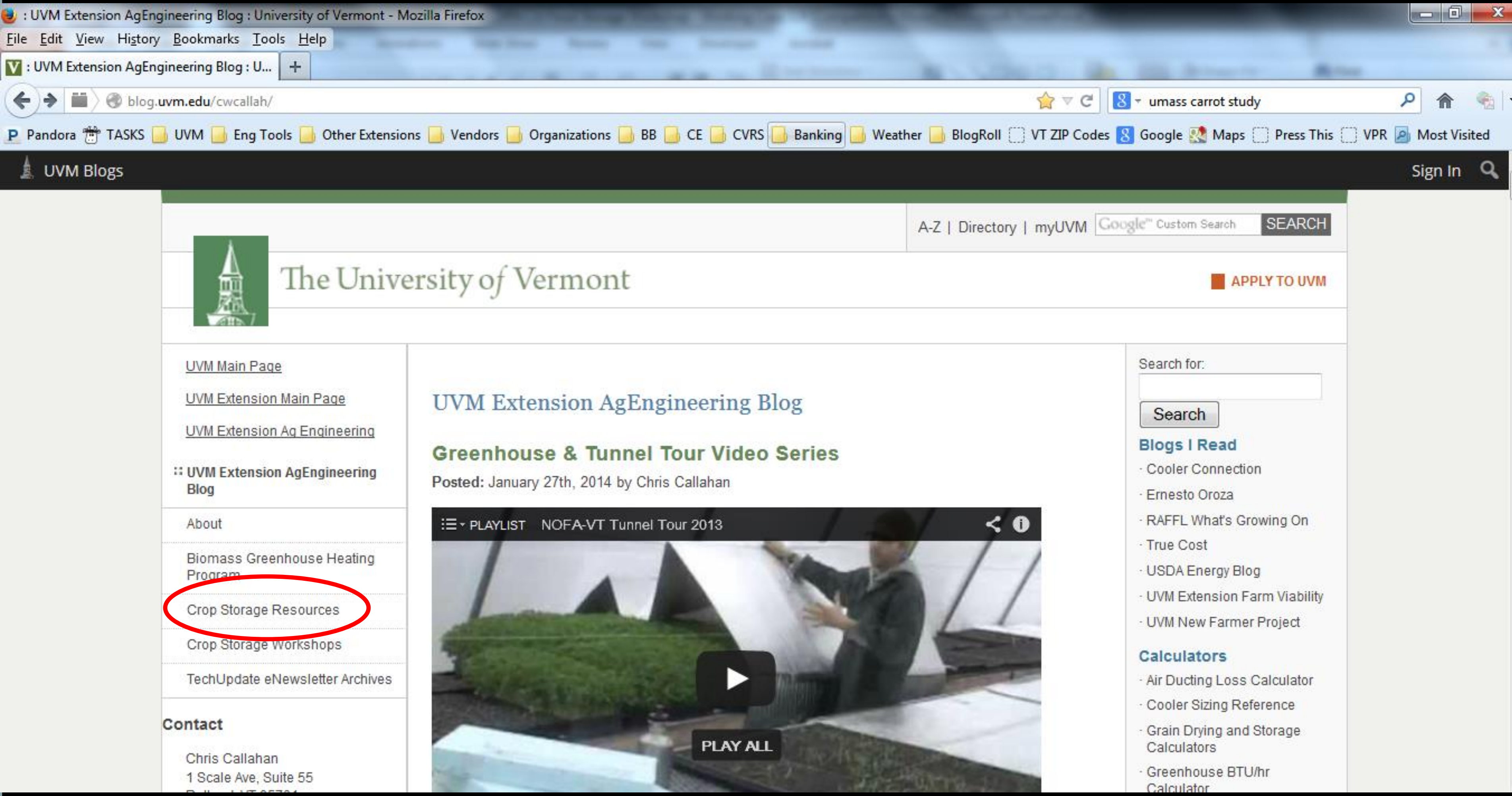

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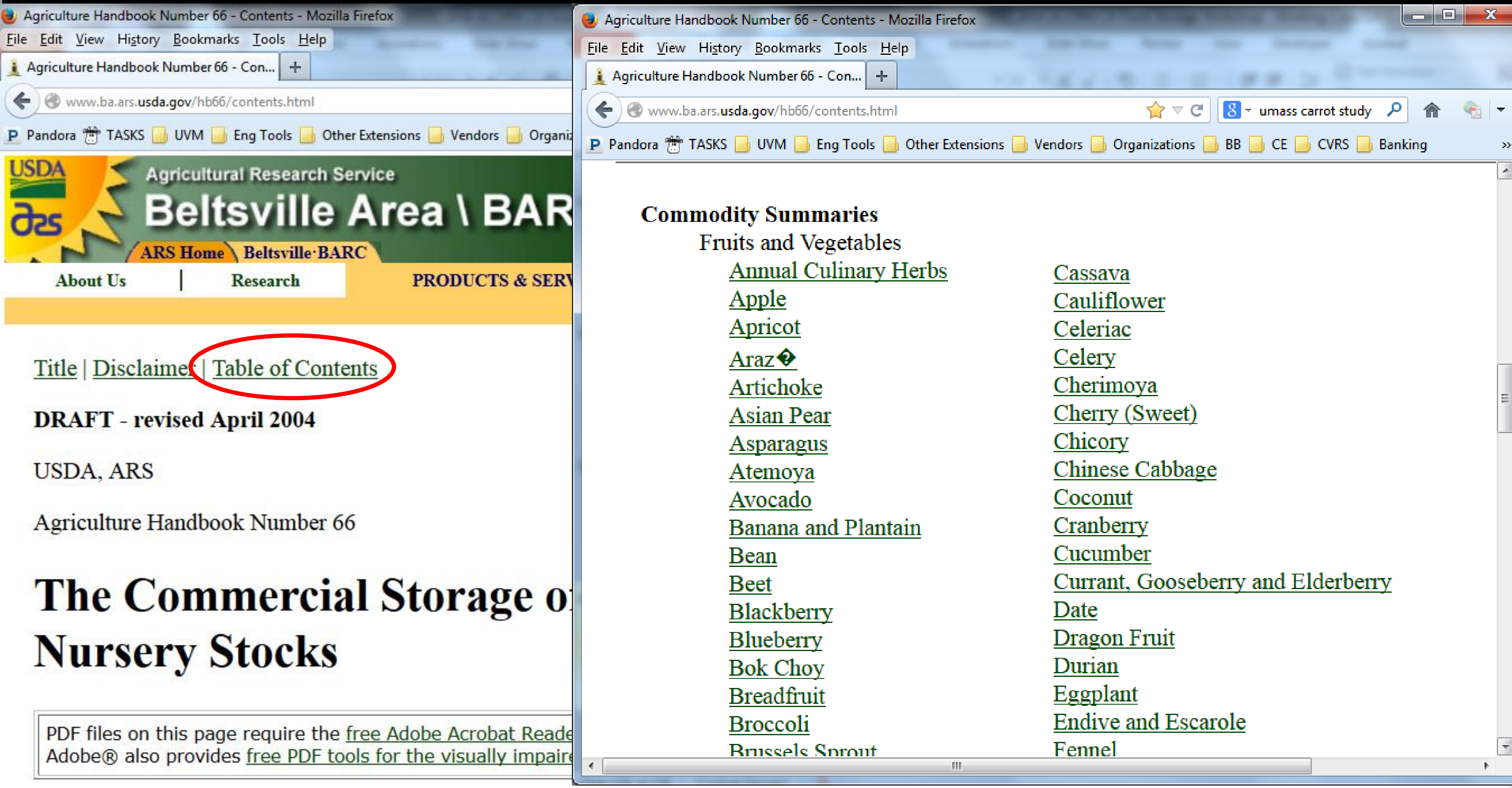

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