

Postharvest Storage

A Workshop for Producers and Processors



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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?

Importance of Food Storage

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

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



IS ALIVE



BREATHES



RELEASES
HEAT



LOSES
MOISTURE



CAN GET SICK



CAN EVEN DIE

Respiration

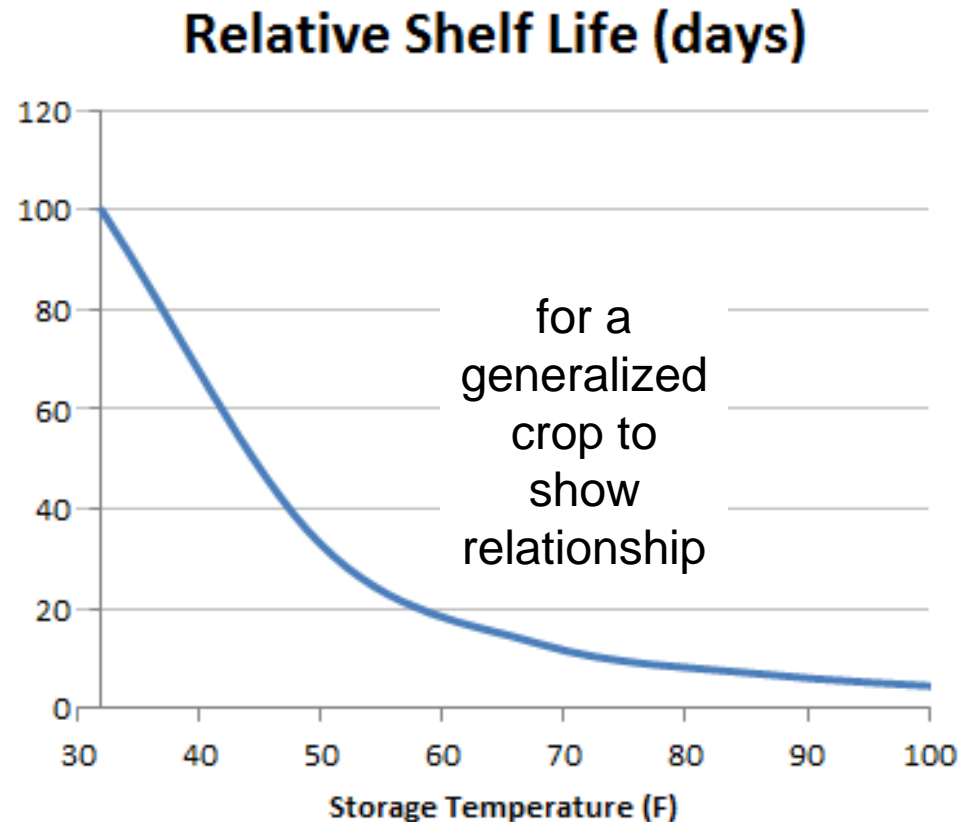
- Crops continue to respire and metabolize post-harvest
 - Through respiration crops use oxygen to break down energy (carbohydrates, fats or proteins)
- Respiration rates of different crops varies:
 - Low rate: Apples, potatoes
 - Moderate: Carrots, Cabbage
 - High rate: asparagus & sweet corn

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



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

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

Ethylene

- C₂H₄
- 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.



Storage Crops – Case Studies



Crop	Units	Carrot	Onion	Potato	Cabbage	Squash
Storage Density	lb/ft ³	22	20	42	17	35
Temp	°F	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	$\frac{\text{mg CO}_2}{\text{kg} \cdot \text{hr}}$	10-20	3 (cured)	6 – 18 (cured)	4 – 6	100
	$\frac{\text{BTU}}{\text{ton} \cdot \text{hr}}$	138	28	110	46	917
Ethylene Prod. Rate	$\frac{\text{uL}}{\text{kg} \cdot \text{hr}}$	< 0.1	< 0.1	< 0.1	< 0.1	Trace
Ethylene Sensitivity	$\frac{\text{uL}}{\text{L}}$	High ~ 0.2	Low > 1500-2000	Low	High ~ 1.0	Low

Storage Crops – Case Studies



Crop	Units	Carrot	Onion	Potato	Cabbage	Squash
Storage Density	kg/m ³	352	320	672	272	560
Temp	°C	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	$\frac{\text{mg CO}_2}{\text{kg} \cdot \text{hr}}$	10-20	3 (cured)	6 – 18 (cured)	4 – 6	100
	$\frac{\text{Watt}}{\text{tonne}}$	44.5	9.0	35.5	14.9	296
Ethylene Prod. Rate	$\frac{\text{uL}}{\text{kg} \cdot \text{hr}}$	< 0.1	< 0.1	< 0.1	< 0.1	Trace
Ethylene Sensitivity	$\frac{\text{uL}}{\text{L}}$	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

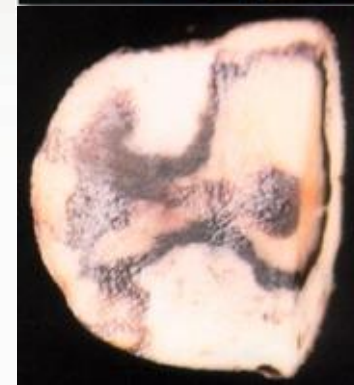
Good Agricultural Practices

- 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.

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

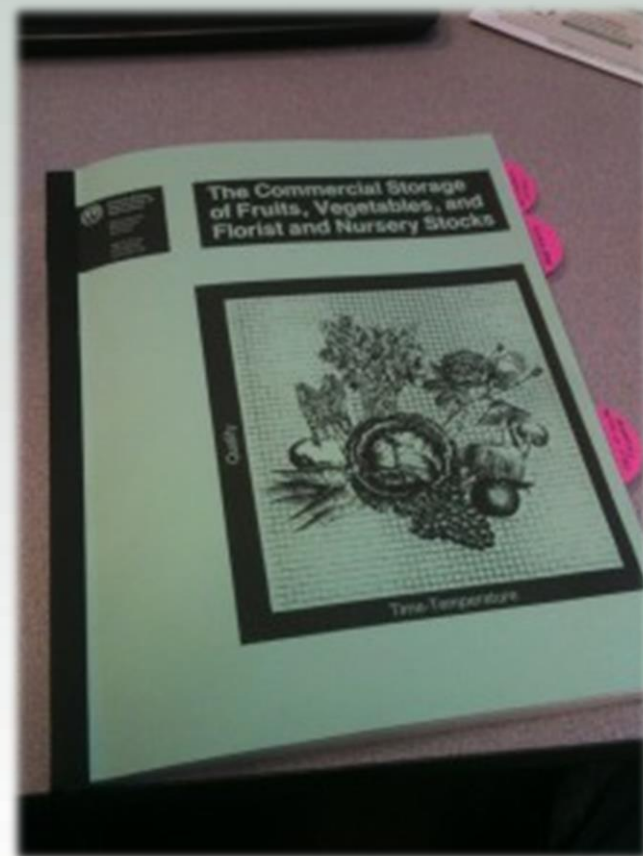
Rhizopus
Soft Rot on
Sweet
Potatoes



Potato
Affected by
Soft Rot

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



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).



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



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

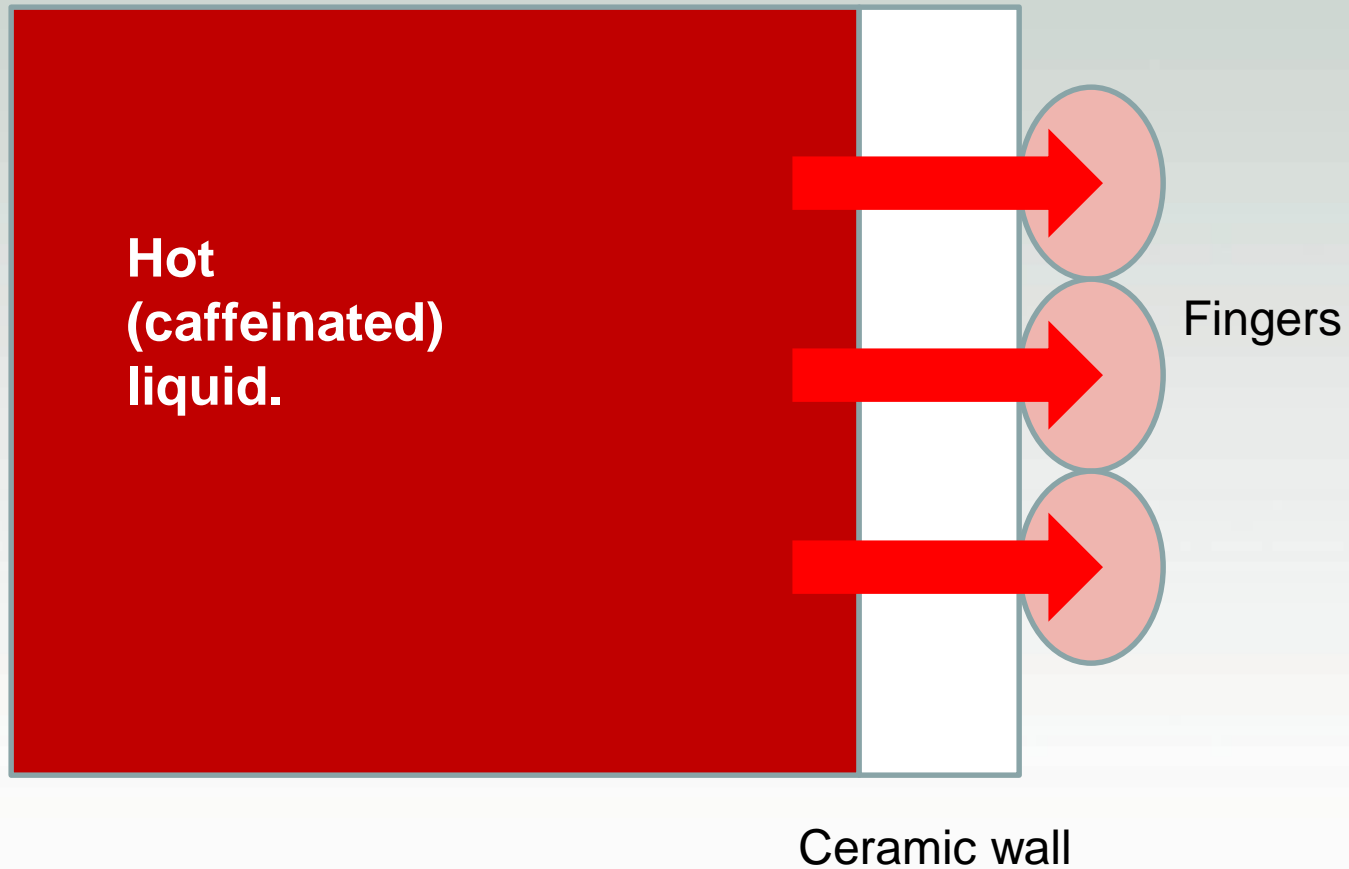
Heat Transfer

- 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

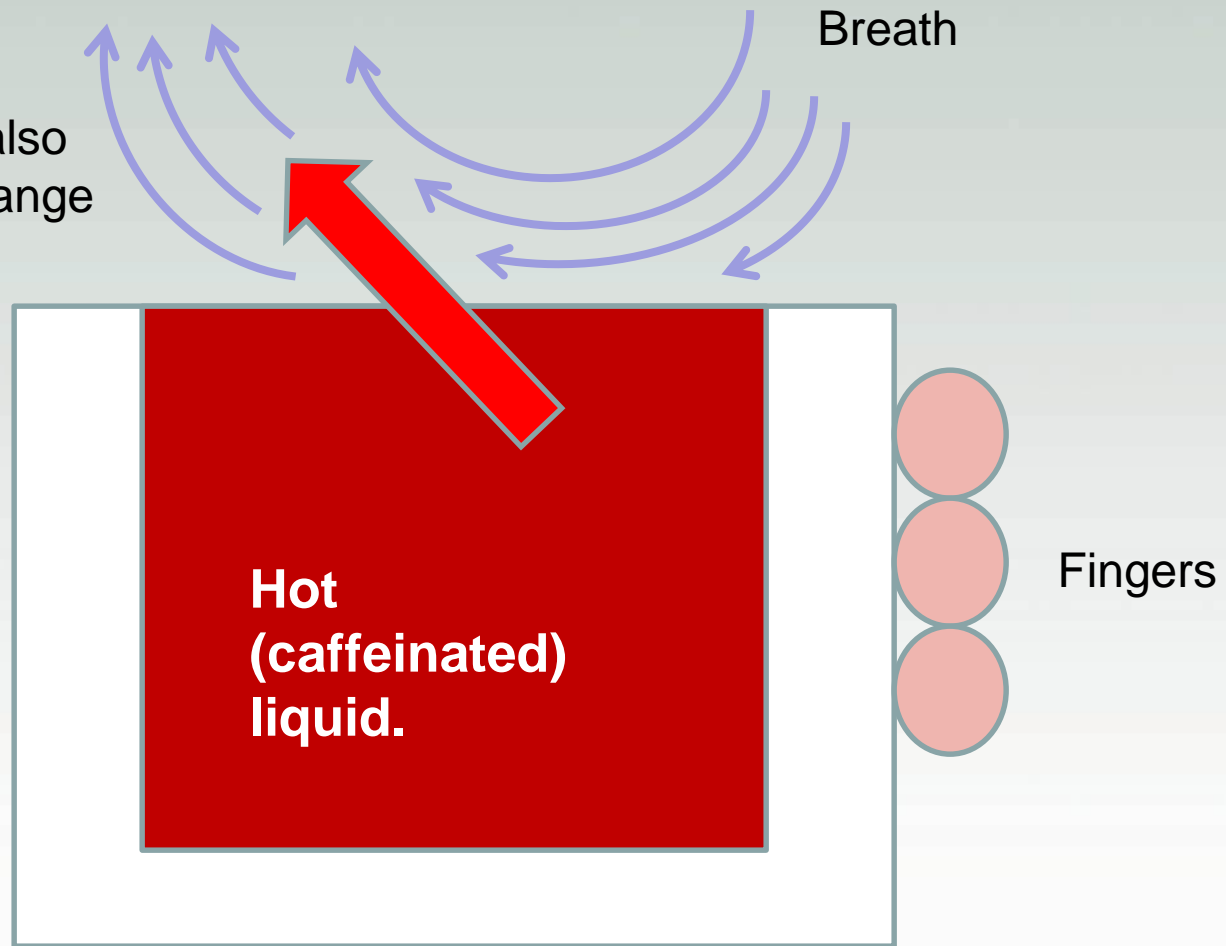
- Three modes
 - Conduction – through solids
 - Convection – through fluids (liquid or gas)
 - Radiation – directly from one body to another
- All are proportional to temperature difference
- ...and differ by how the heat flow is slowed (or enhanced.)

Conduction

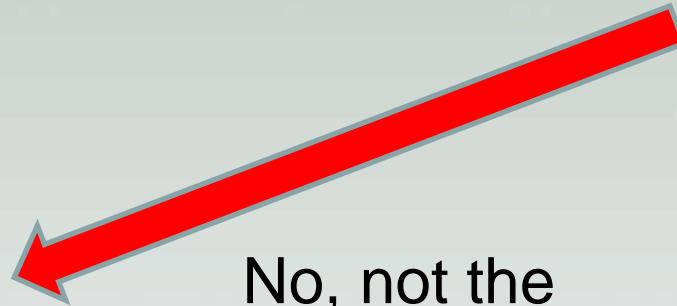


Convection

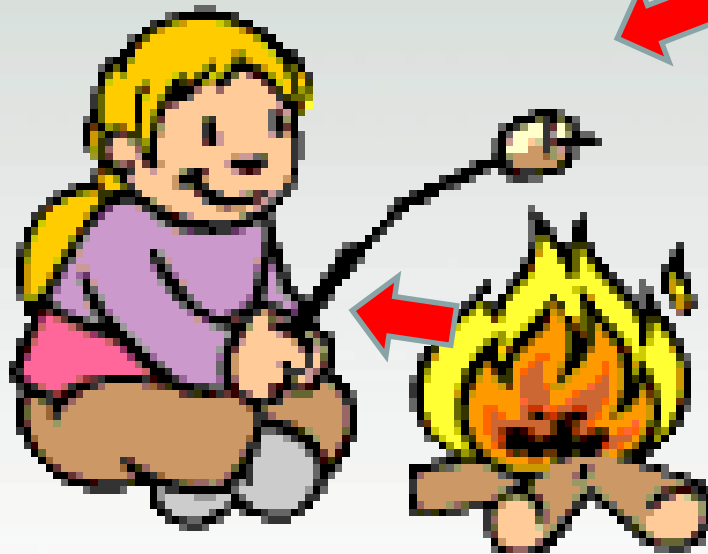
There is also phase change here.



Radiation



No, not the
marshmallow!



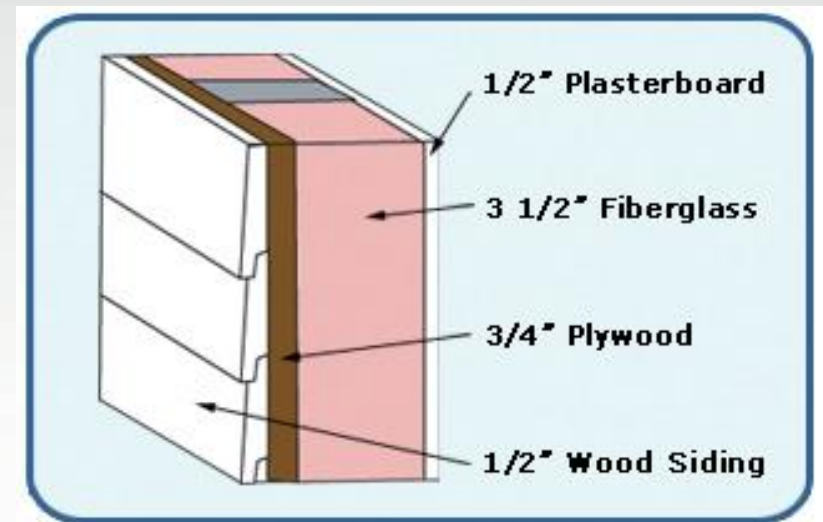
The heat you feel
directly from the
fire or from the
sun.

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.

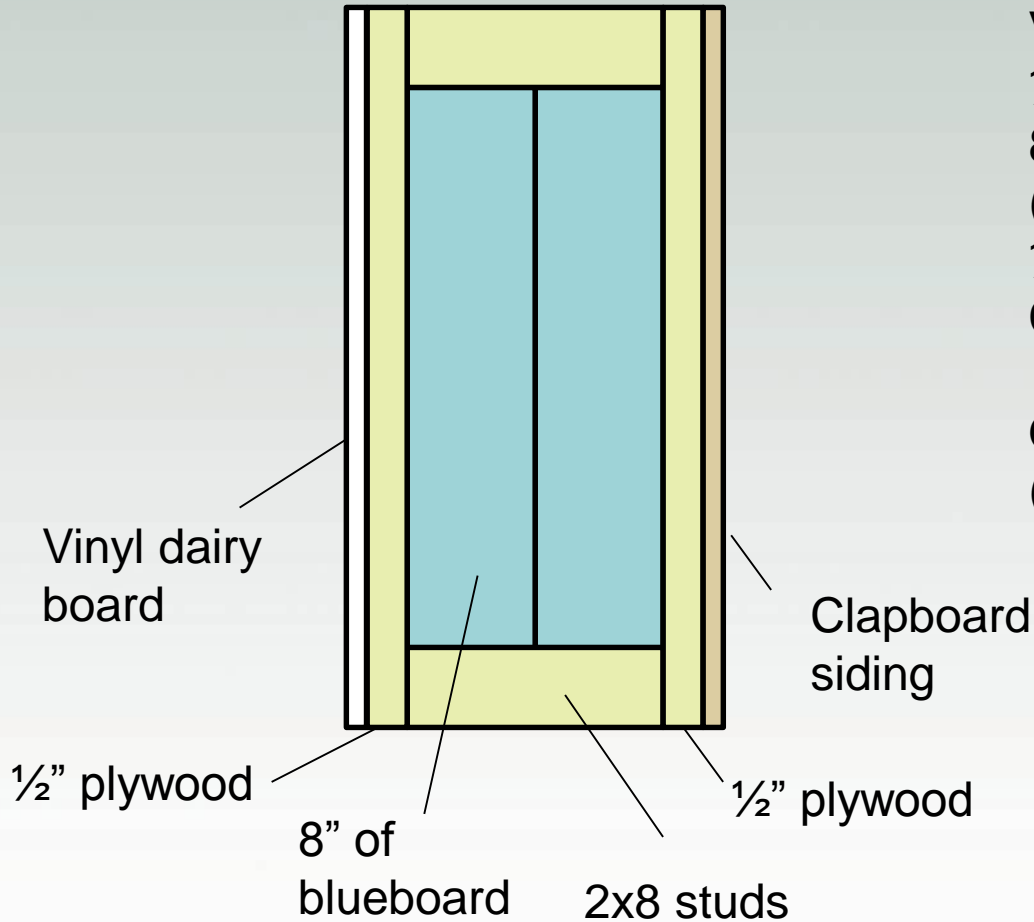
Breakout

- 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
 - $\text{hr} \cdot \text{ft}^2 \cdot \text{F} / \text{BTU}$ or $\text{hr} \cdot \text{m}^2 \cdot \text{C} / \text{J}$



Vinyl dairy board (FRP) =	0.00
1/2" Plywood =	0.63
8" Blueboard (Expanded Polystyrene) =	32.00
1/2" Plywood =	0.63
Clapboard Siding =	0.80

Overall R Value (hr-F-ft ² /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

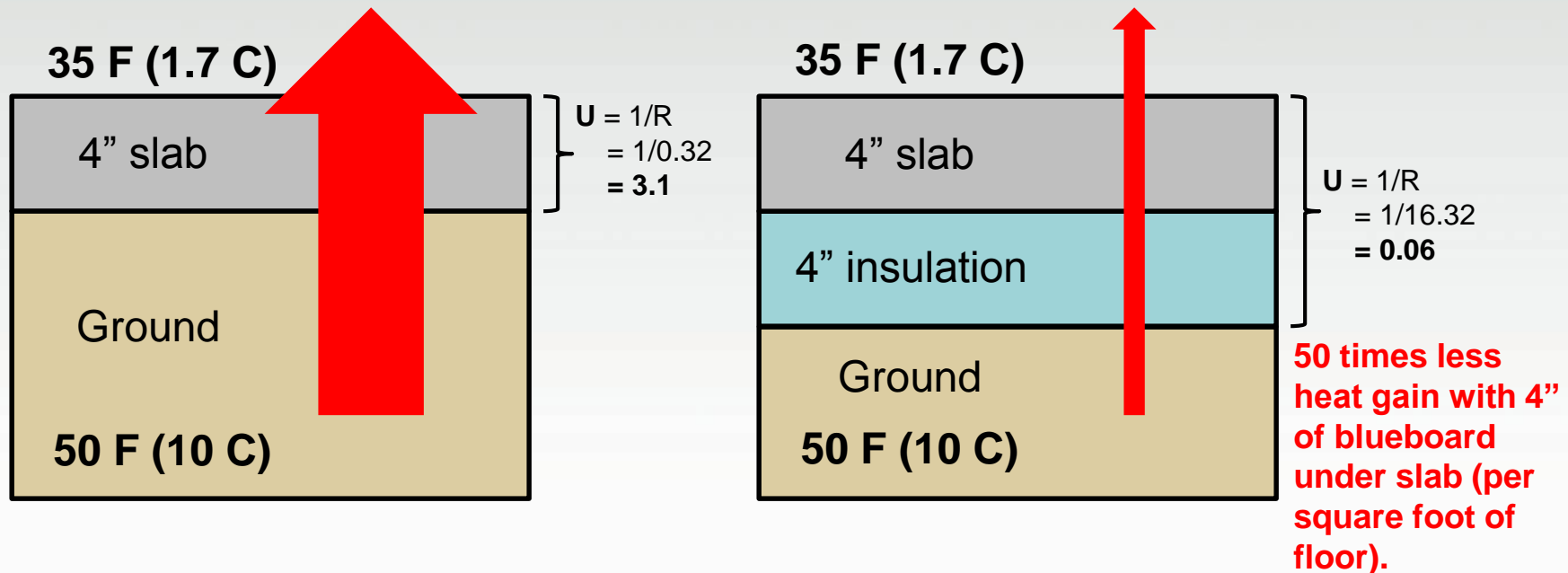
$$Q = \frac{\text{Area x (T}_{\text{out}} - \text{T}_{\text{in}})}{\text{R-value}} \quad \text{BTU/hr}$$

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



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

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:

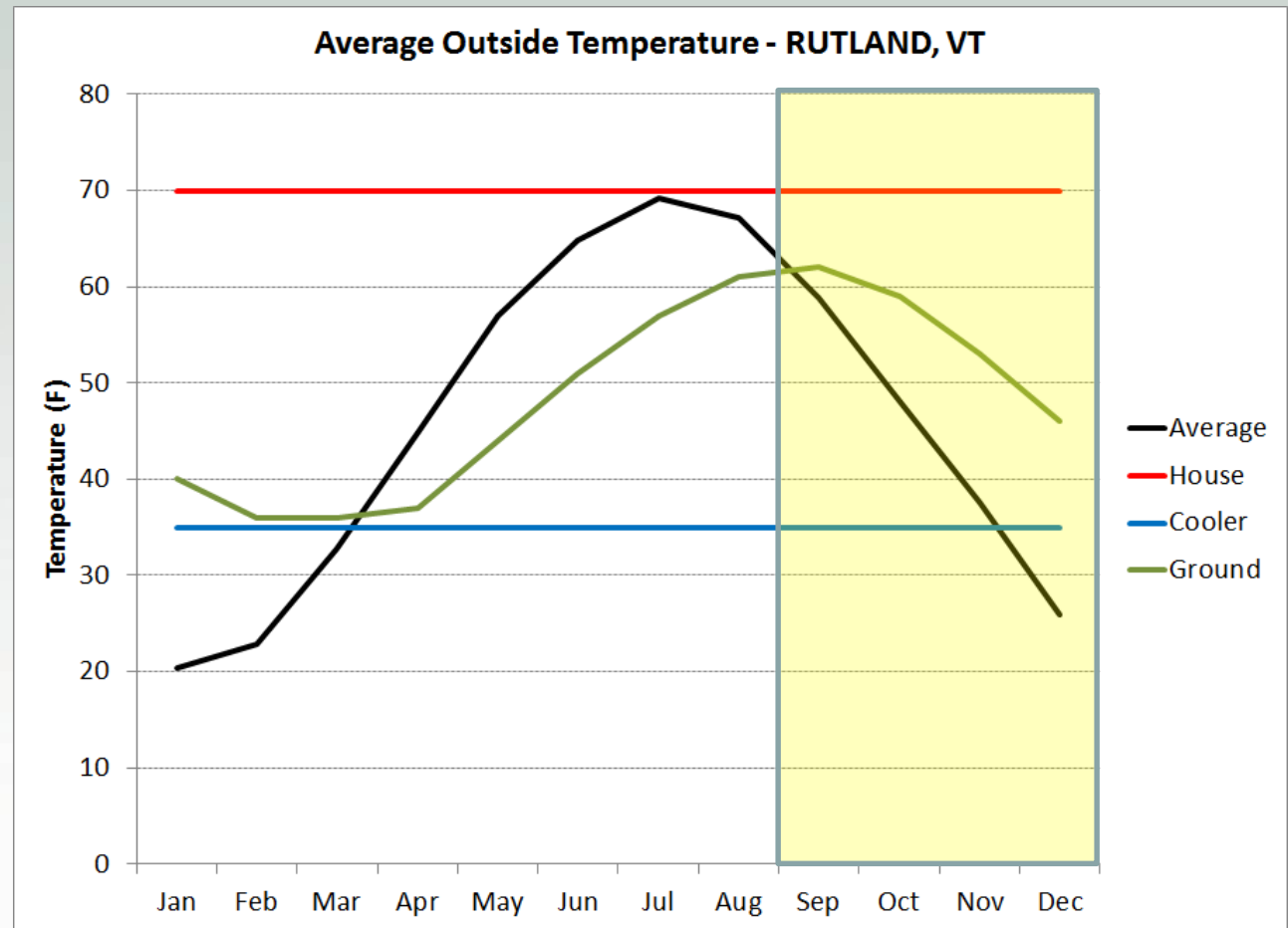
	With 2 inch wall insulation R8	With 4 inch wall insulation R16	With 6 inch wall Insulation R24	
Peak Loss / Evaporator Sizing	4,960	2,580	1,787	BTU/hr
Peak Loss / Compressor Sizing	0.7	0.3	0.2	HP
Electricity Use (6 months)	1,041	564	405	kWhr/yr
Operating Costs (6 months)	156	85	61	\$/yr

Breakout

- Why is slab insulation so significant?

Why Slab Insulation Has Such an Impact.

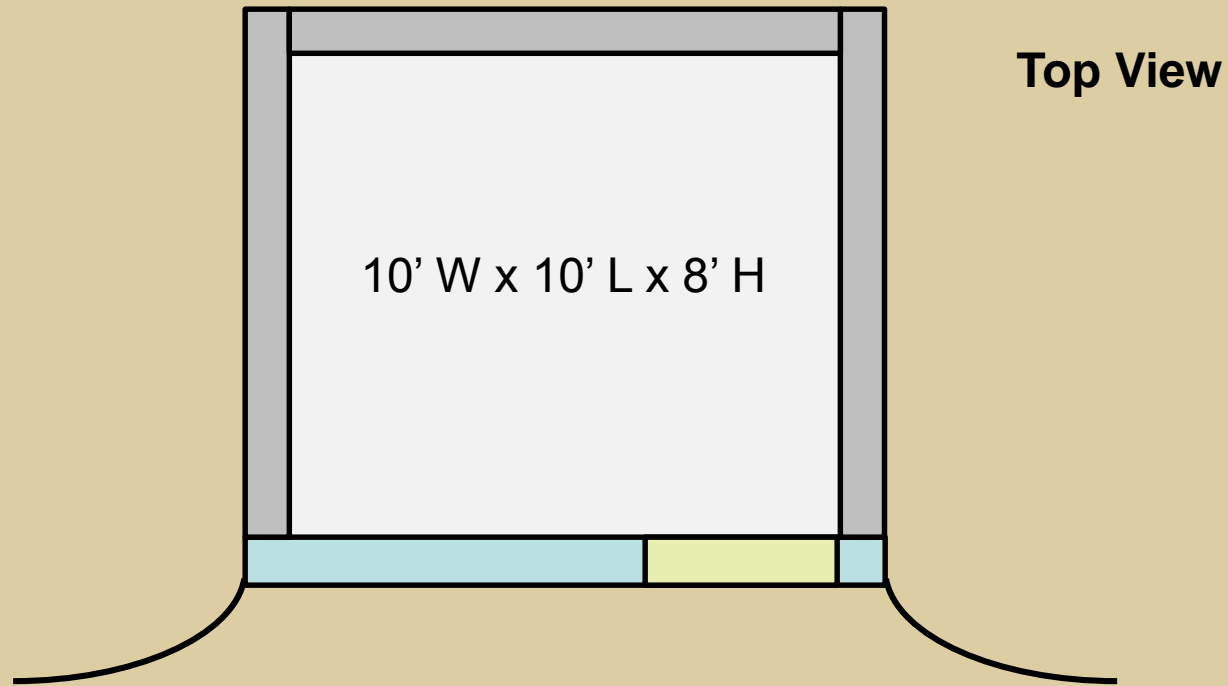
- Ground temperature lags air temperature seasonally.
- It is highest right when most growers are seeking long-term storage.
- And stays higher than desired storage temperature.
- Always a load.



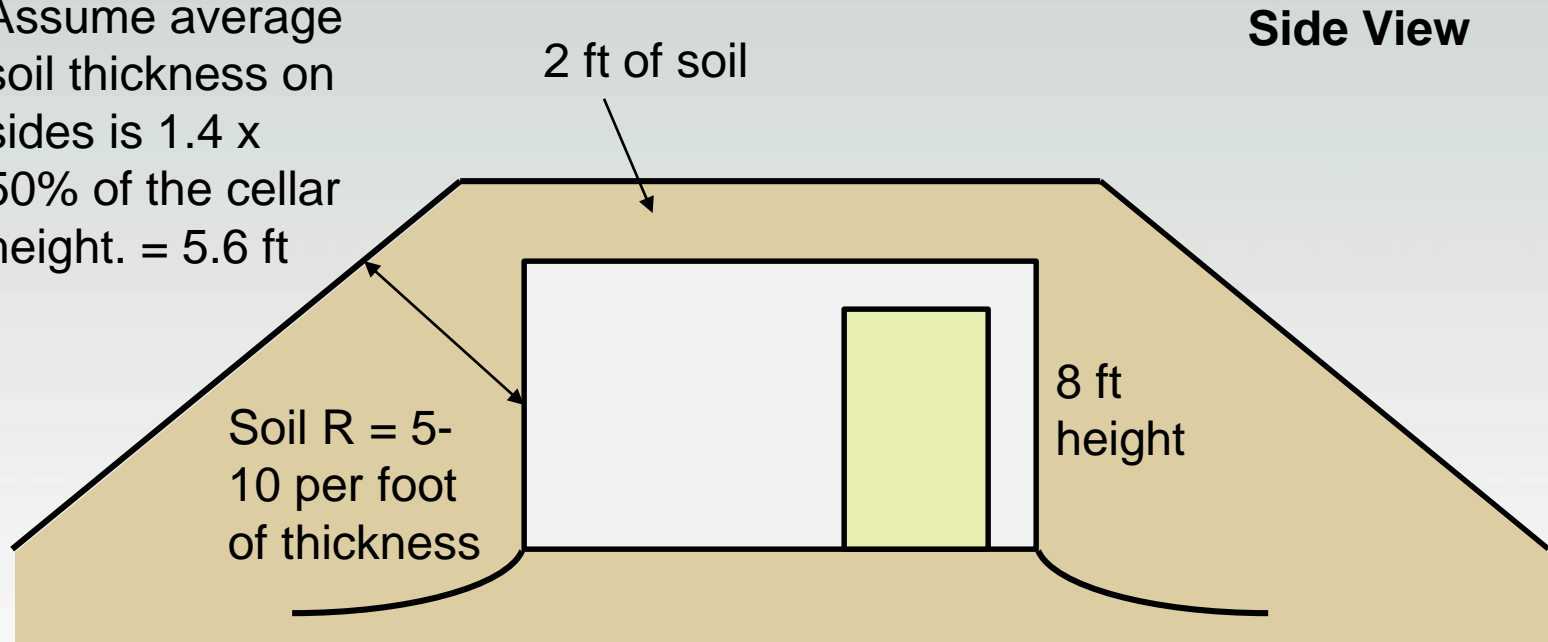


Elliston root cellar, photo credited to http://donjarri.blogspot.com/2009_07_01_archive.html

Root Cellar



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)
- $\Delta T =$
27 C
49 F

Heat from Product

- Total Volume: $8 \times 10 \times 10 = 800 \text{ ft}^3$
- Product Volume: $67\% \text{ of } 800 = 530 \text{ ft}^3$
- Product Mass: $42 \text{ lb/ft}^3 \times 530 \text{ ft}^3 = 22,512 \text{ lbs}$
 $10,186 \text{ kg}$
- **Respiration Rate:**
 $110 \text{ BTU/ton/hr} \times 22,512 \text{ lbs} / 2000 \text{ lbs/ton}$
 $= \mathbf{1,238 \text{ BTU/hr}}$
 $\mathbf{363 \text{ Watts}}$

Heat from Ground

- Ground Temperature: 7 C / 45 F
 - Inside Temperature: 2 C / 36 F
- $\Delta T = 5 \text{ C} / 9 \text{ F}$**
- Heat Gain Coefficient: 0.3 BTU/hr/ft²/F
 - Floor Area: 100 ft²
- **Heat gain from Ground: 270 BTU/hr
79 Watts**

Heat Loss Through Roof

- 2 feet deep soil
- Assume lower R value of 5 ft²-hr-F/BTU per foot
- $R = 2 \times 5 = 10$
- $A = 10 \text{ ft} \times 10 \text{ ft} = 100 \text{ ft}^2$
- $A/R = 100 / 10 = \mathbf{10 \text{ BTU/hr-F}}$
- **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
- $R = 5.6 \times 5 = 28$
- $A = 8 \text{ ft} \times (10 + 10 + 10 \text{ ft}) = 240 \text{ ft}^2$
- $A/R = 240 / 28 = 8.6 \text{ BTU/hr-F}$
- **420 BTU/hr or 123 Watt**

Heat Loss Through Front Wall

- Assume 6" Blueboard Wall
- R value of 4 ft²-hr-F/BTU per inch
- $R = 6" \times 4 = 24$
- $A = 8 \text{ ft} \times 10 \text{ ft} = 80 \text{ ft}^2$
- $A/R = 80 / 24 = \mathbf{3.3 \text{ BTU/hr-F}}$
- **163 BTU/hr or 48 Watt**

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)

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 Transfer

- 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



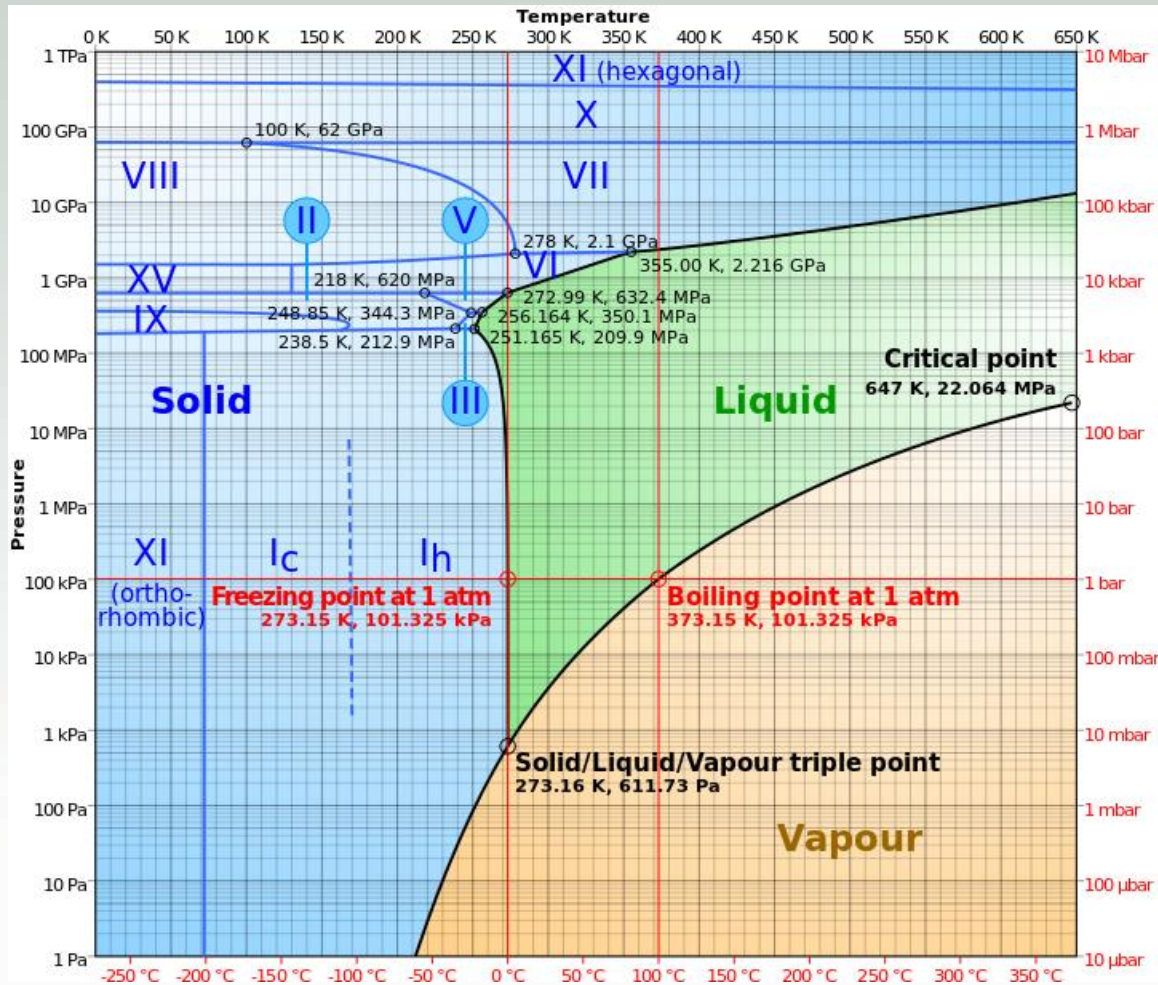
Humidifying and Drying

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

Water's Phase Change

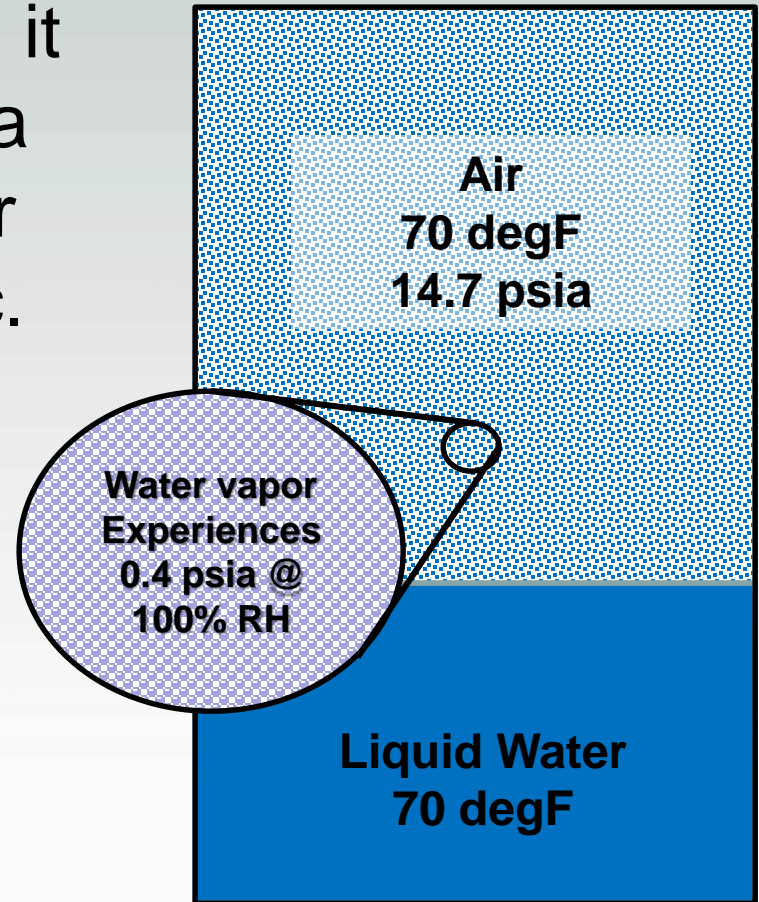
- What we think we know...
 - Water freezes at 32 F and 0 C
 - Water boils at 212 F and 100 C
- It is true....but...
- Only at standard atmospheric pressure!
- How is there water vapor in air?

Sorry... it's a bit more complicated



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.

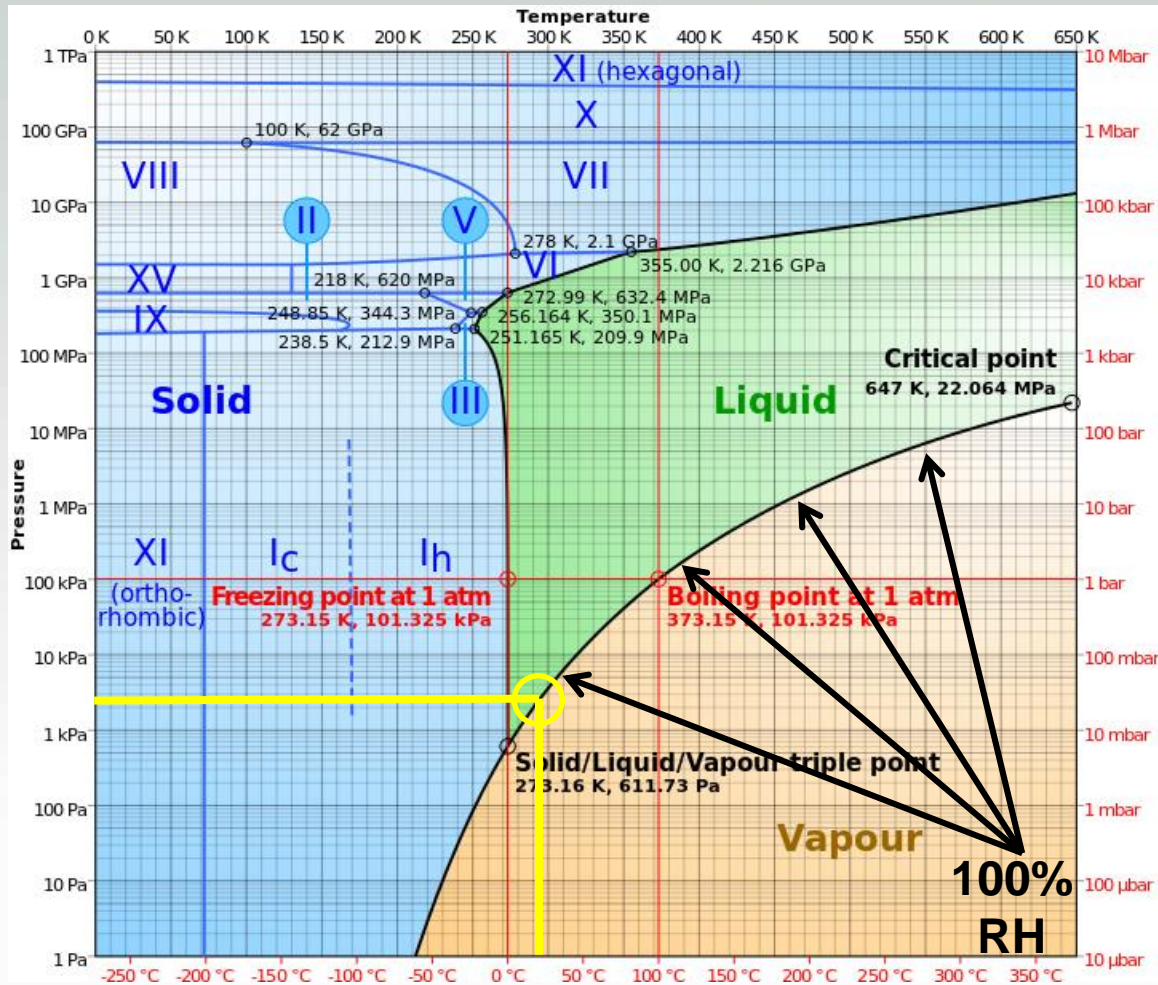








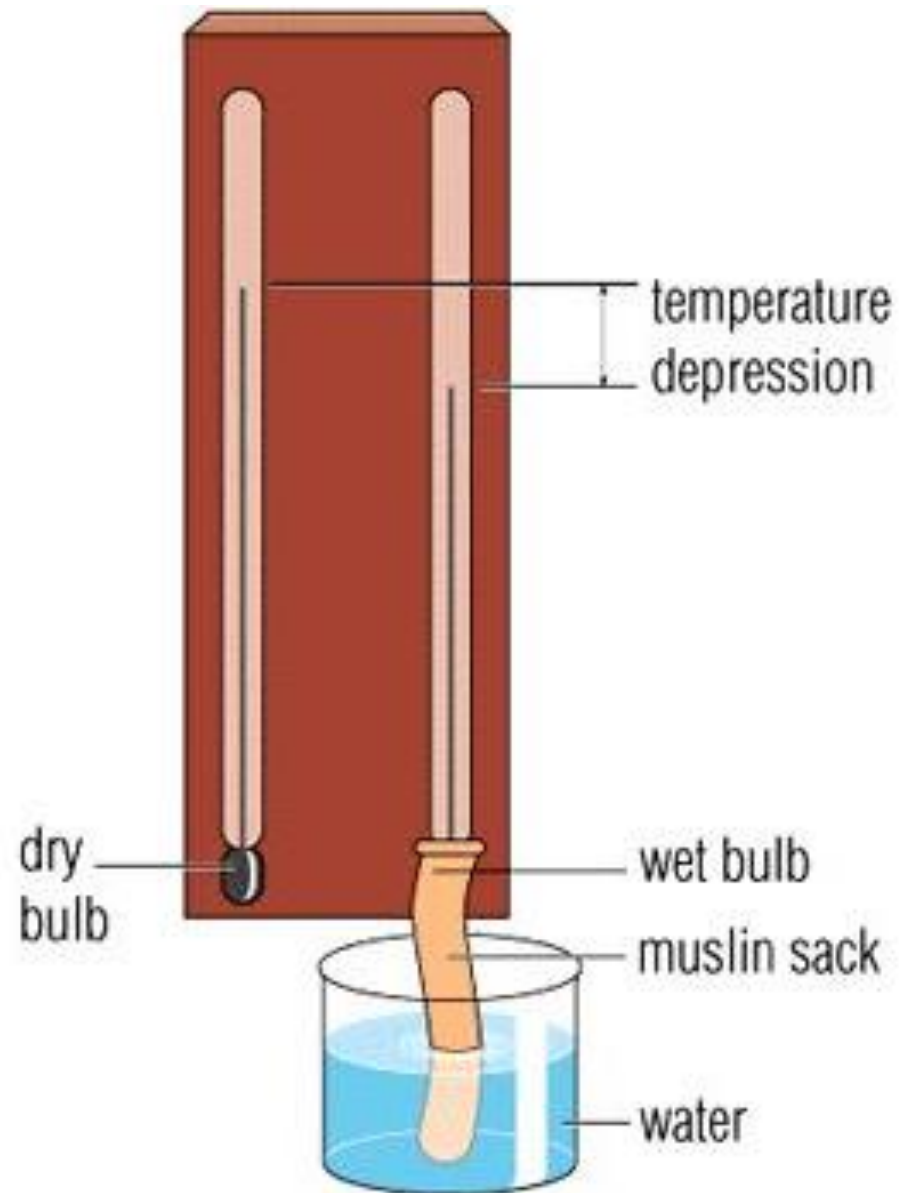
Water and Air Mixtures



Relative Humidity

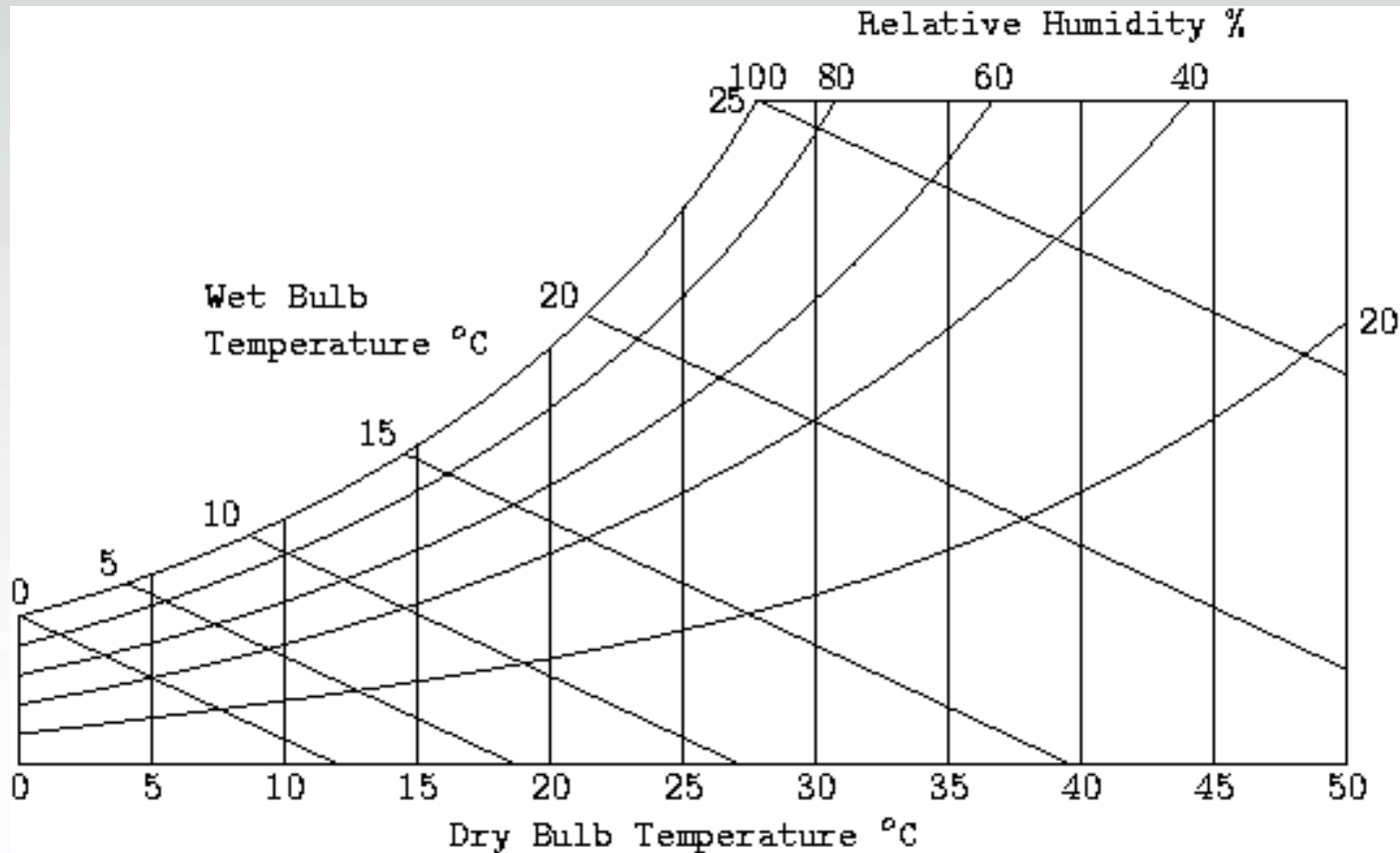
- The degree to which air is “saturated” with water vapor at a certain temperature and barometric pressure.
- Since barometric pressure is relatively constant, RH is really a function of temperature.
 - For *most* agricultural applications
 - Pressure’s influence is the basis of vacuum cooling, however...

- 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.

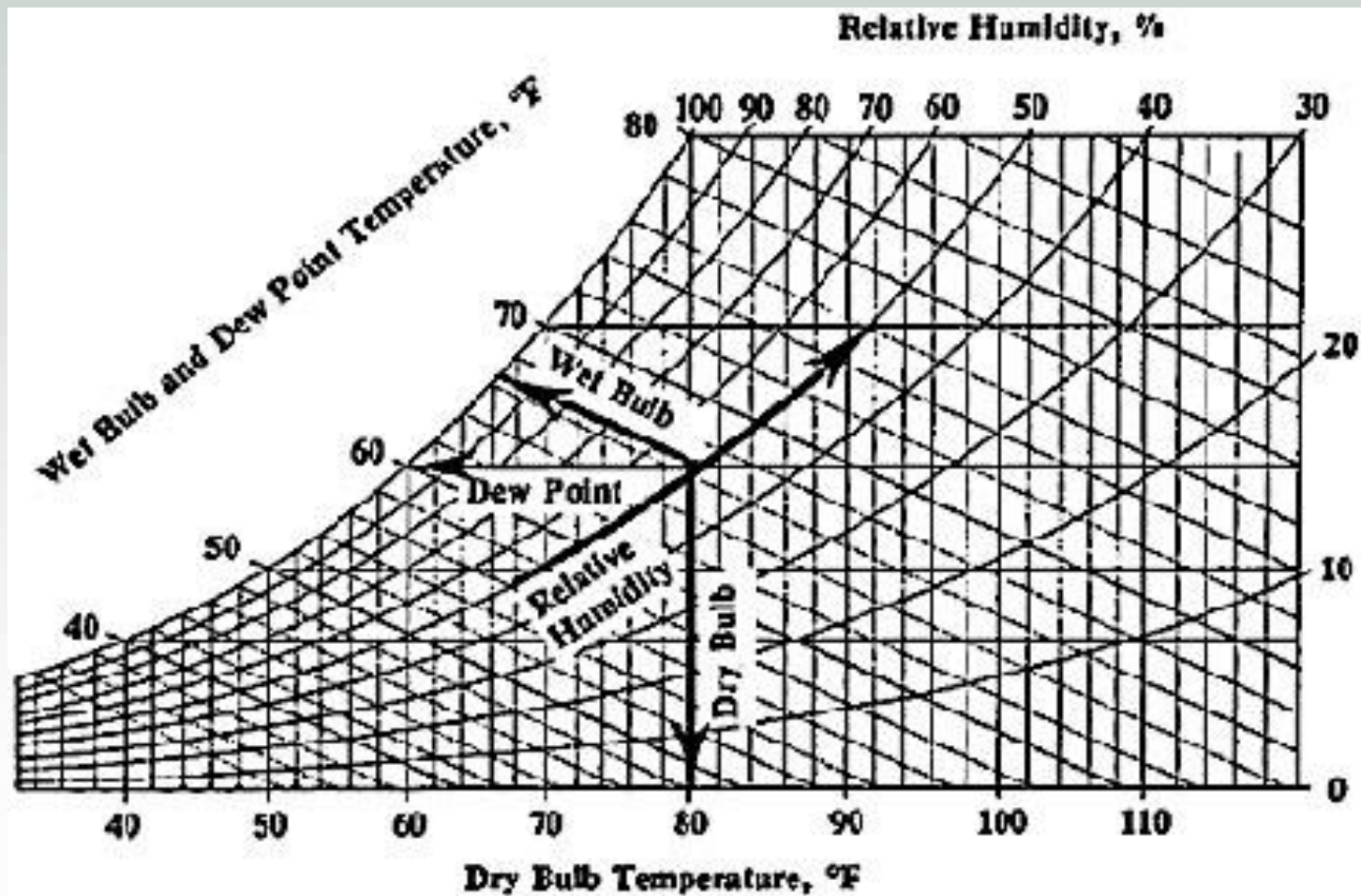


Psychrometric Charts

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

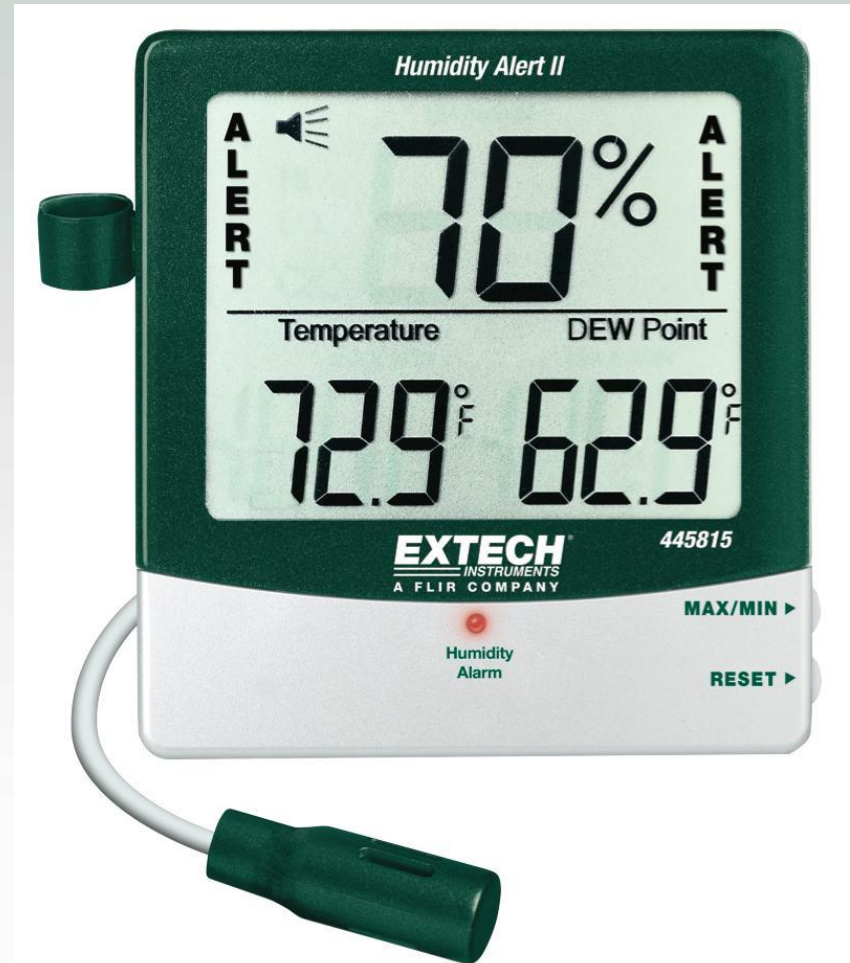


Psychrometric Charts



Humidity Sensors

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



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.

PSYCHROMETRIC CHART

Low Temperature
I-P Units

SEA LEVEL

BAROMETRIC PRESSURE: 29.921 in. HG

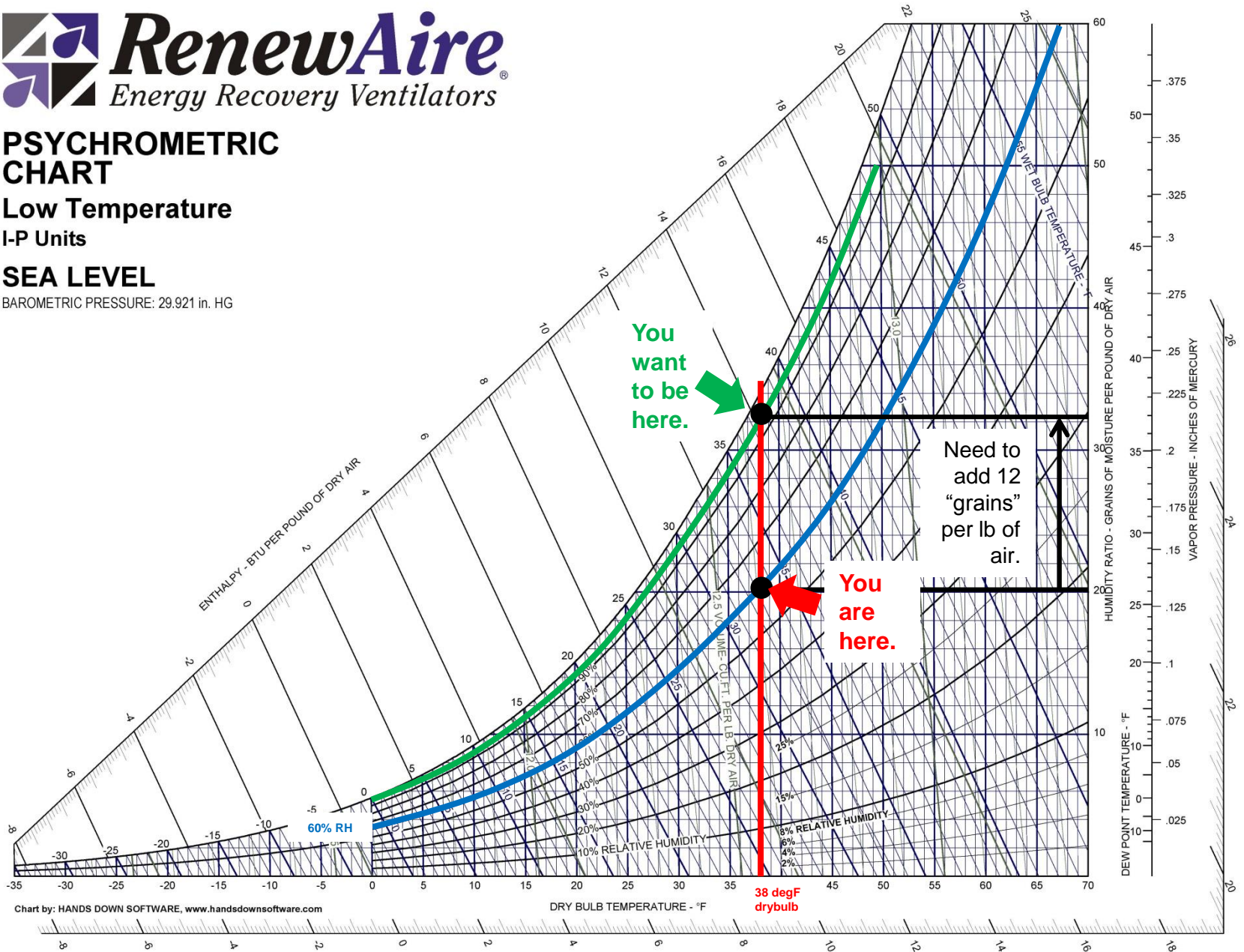


Chart by: HANDS DOWN SOFTWARE, www.handsdownsoftware.com

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 $3/100^{\text{th}}$ gallon = **3.3 fluid ounces**

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

Dry Bulb

Wet Bulb

Break

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Structure and Materials

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



Alternatives

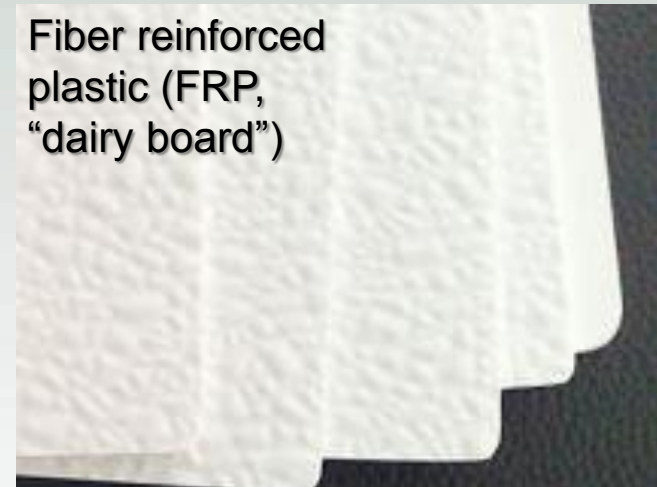
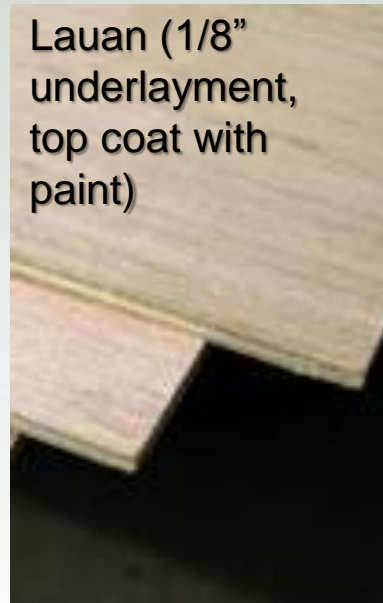
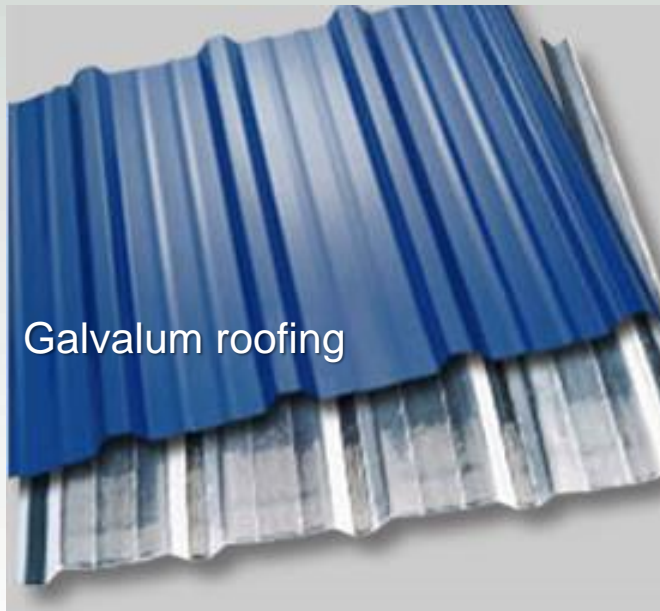
- Overseas shipping container
- Refrigerated tractor-trailer



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

Structure and Materials

“Smooth and cleanable”



Structure and Materials

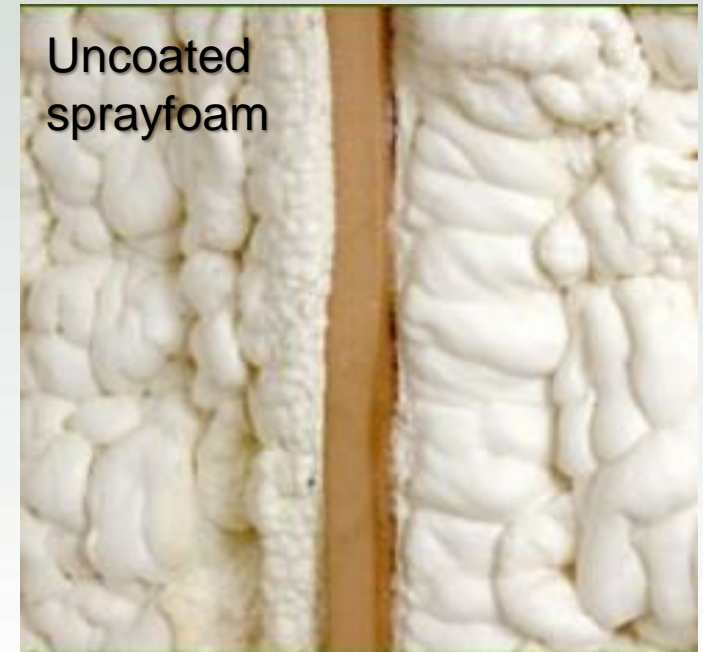
Practices to avoid



Direct soil contact



Uncoated plywood / chipboard / sheetrock



Uncoated sprayfoam

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



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:**

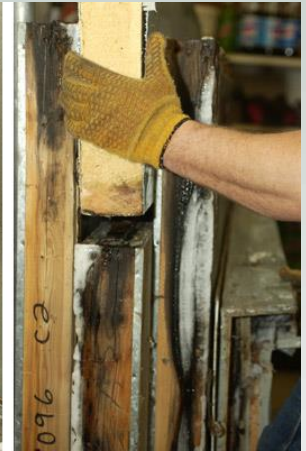
- smooth;
- impervious;
- free of cracks and crevices;
- nonporous;
- nonabsorbent;
- non-contaminating;
- nonreactive;
- corrosion resistant;
- durable and maintenance free;
- nontoxic;
- easily cleanable.

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

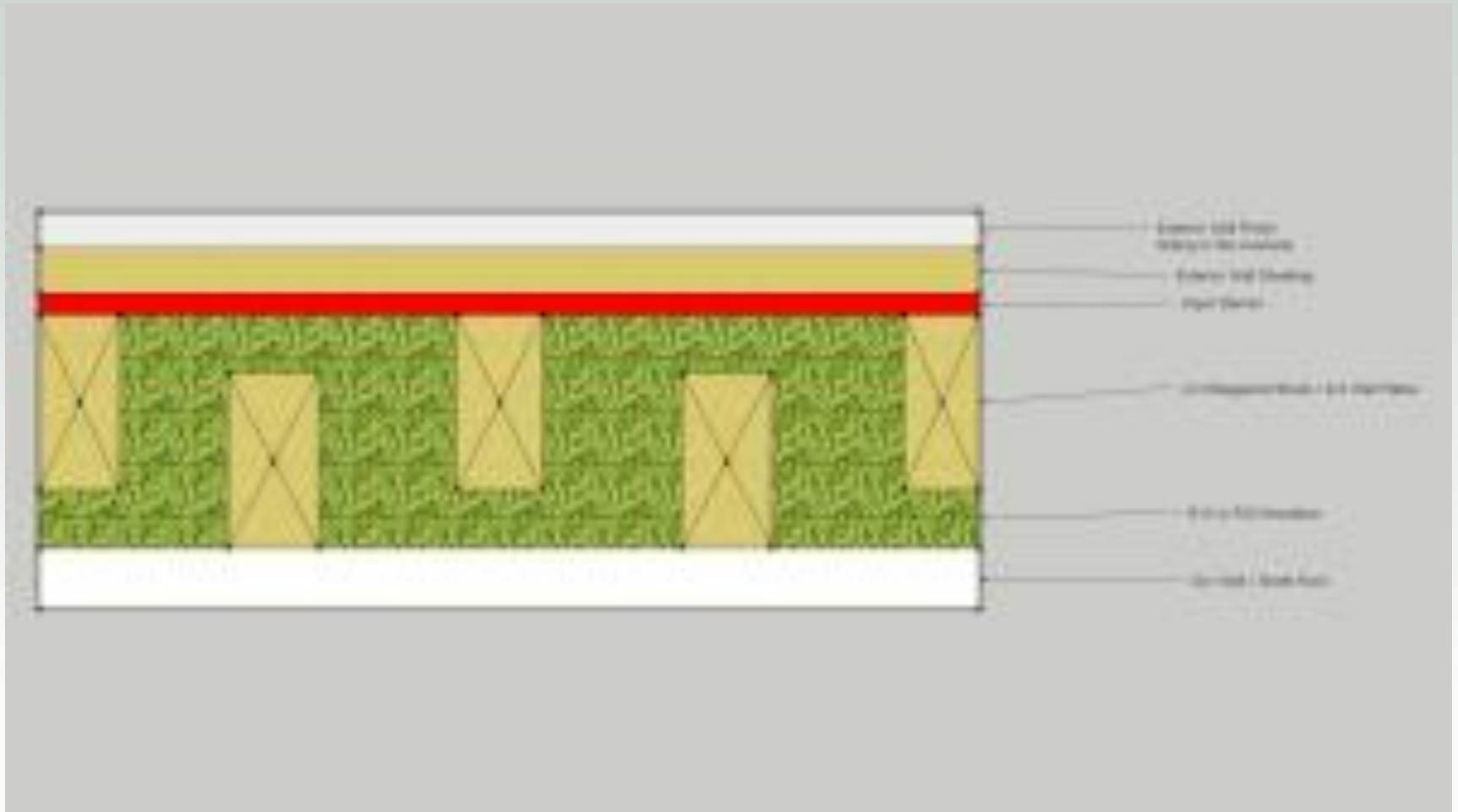


Homemade Panels

- 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.



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*



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”)

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).



Containers

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



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?

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



Berlanda
Harvest #3
11/30/11

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



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



VERMONT'S
ORGANIC
BIG HAWK
BRAND

NET WT. 25 LBS. (11.35kg)
WESTMINSTER ORGANICS
PA 501 55
CERTIFIED BY IOP

VERMONT'S
ORGANIC
BIG HAWK
BRAND

VERMONT'S
ORGANIC
BIG HAWK
BRAND

1 3/4 BU.

1 3/4 BU.

1 3/4

ROMAINE

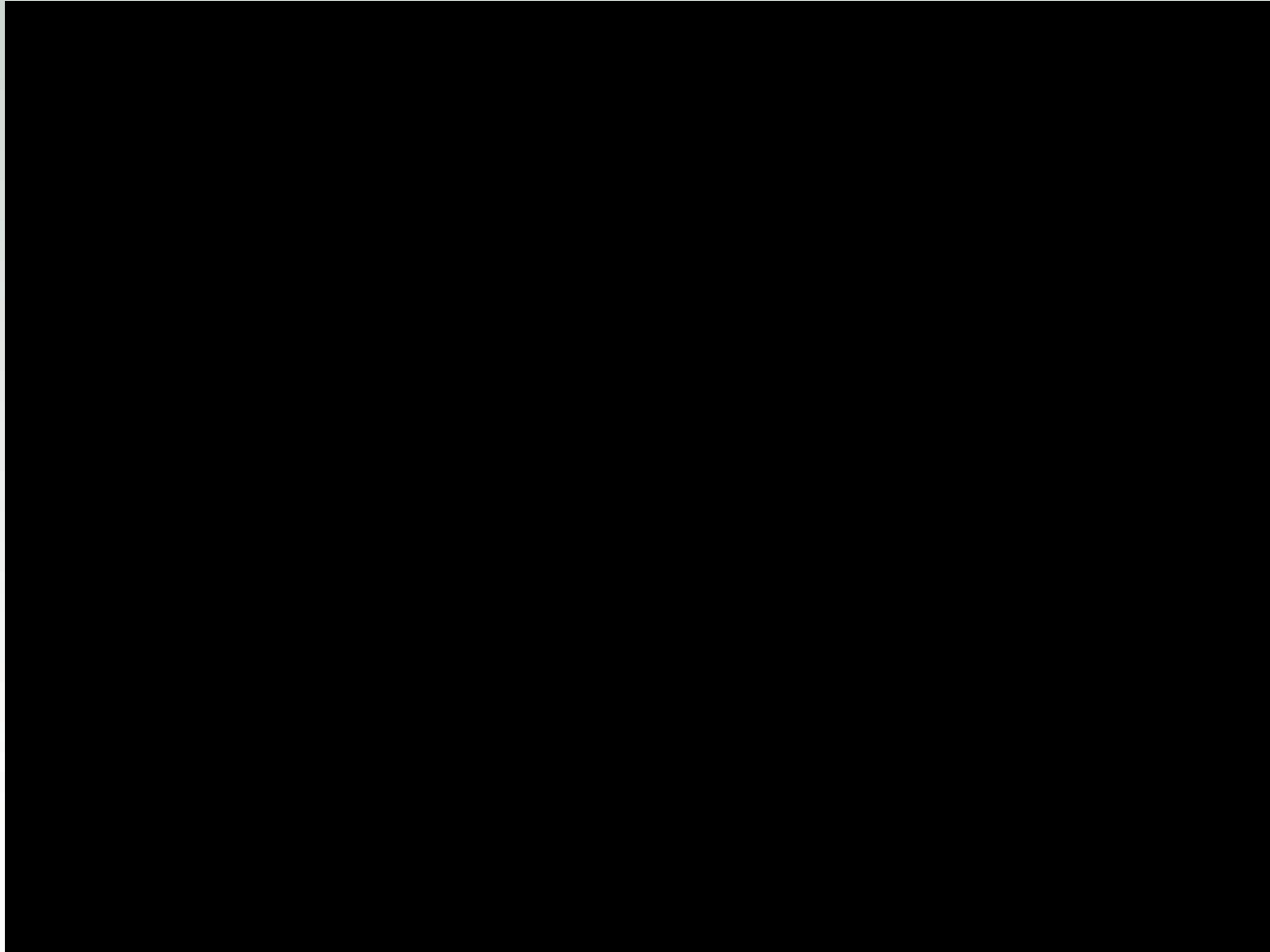
Breakout

- What have you built or what do you have planned?
- What construction details are you considering?

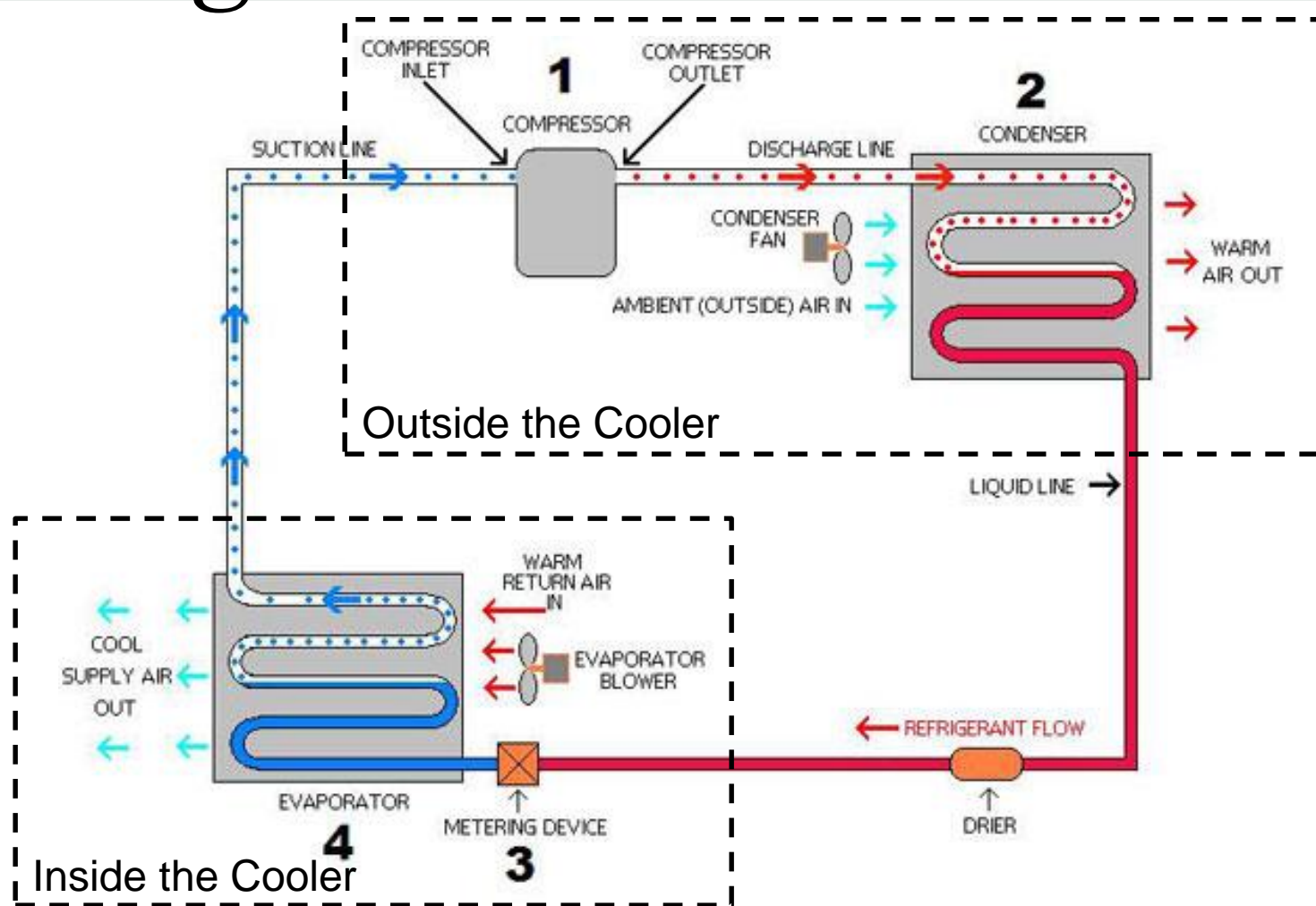
Intro to Refrigeration

- 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

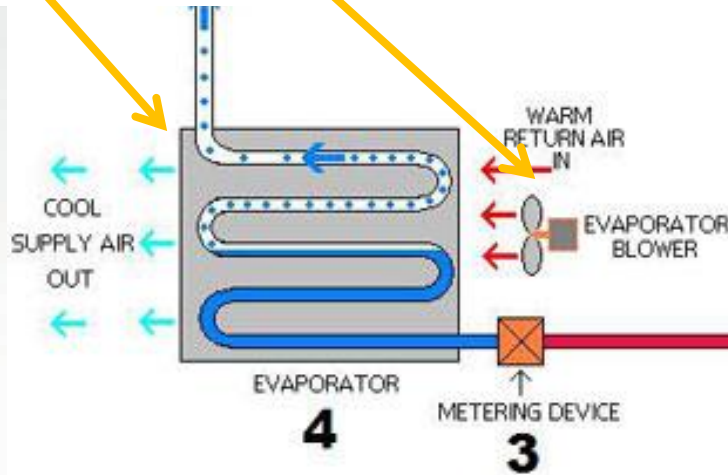
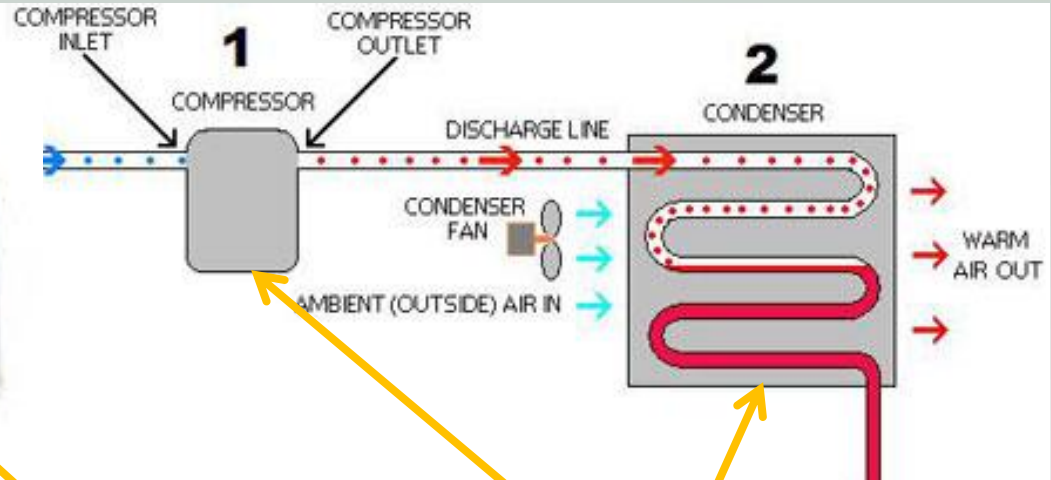


Refrigeration



Refrigeration

Evaporator Unit



Compressor / Condenser Unit

Evaporator Options

Standard



Low Velocity
(High Humidity)



Plates



Temperature distribution in a 20 ft x 50 ft x 8 ft room

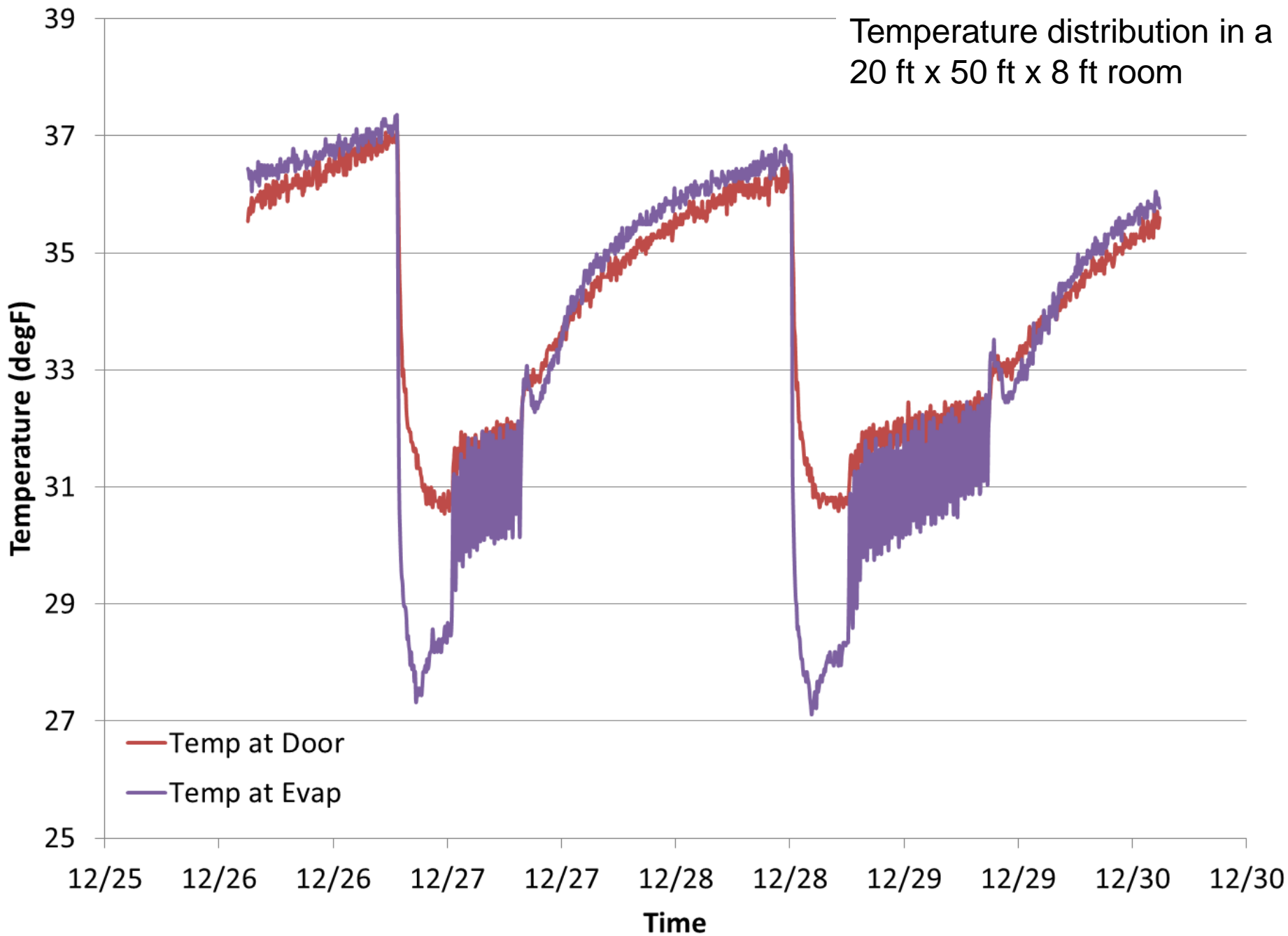


Table 3. Minimum Relative Humidity Levels¹ Developed at Various Storage and Evaporator Discharge Temperatures

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

Increasing evaporator size
and/or refrigerant
temperature

¹Calculated from Psychrometric Tables.

²Actual 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 °F

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

CoolBot vs. Conventional

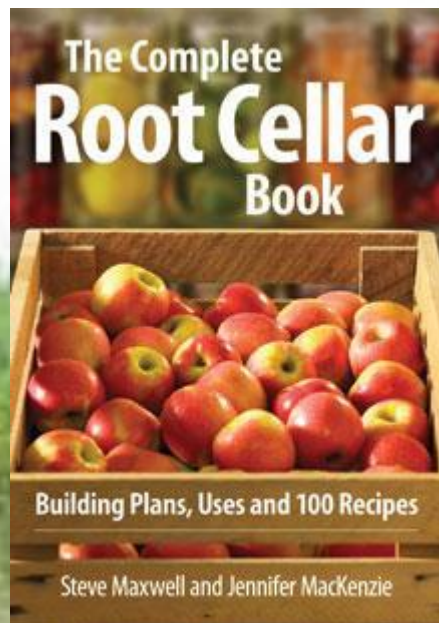
- 2009 NYSERDA Study
 - <http://storeitcold.com/coolbot%20Report%20May09.pdf>
- 8'x10' storage room - Albany, NY conditions
- Cooled to 35 F
 - with evap fan controls
 - Conventional is 74 kWhr/yr more efficient (\$10/yr)
 - without evap fan controls
 - CoolBot is 230 kWhr/yr more efficient (\$30/yr)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

Geothermal

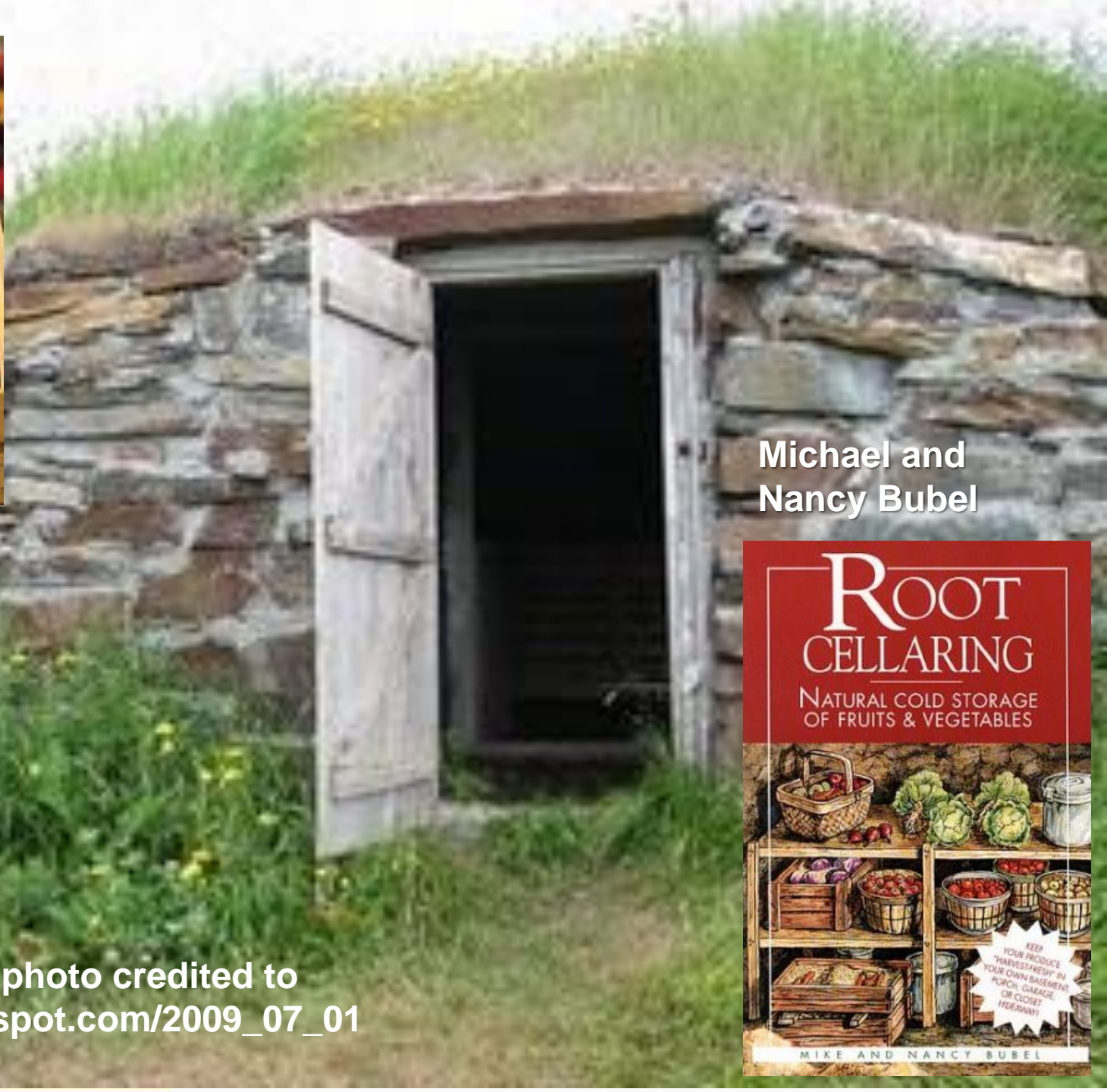
- What most people mean by “root cellar.”
- Passive thermal and humidity control using the ground as the source and sink
- Active thermal – piped air through ground.
- Soil contact should be avoided in storage.
- “Geothermal” sometime used to mean “Ground Source Heat Pump.”

Root Cellars

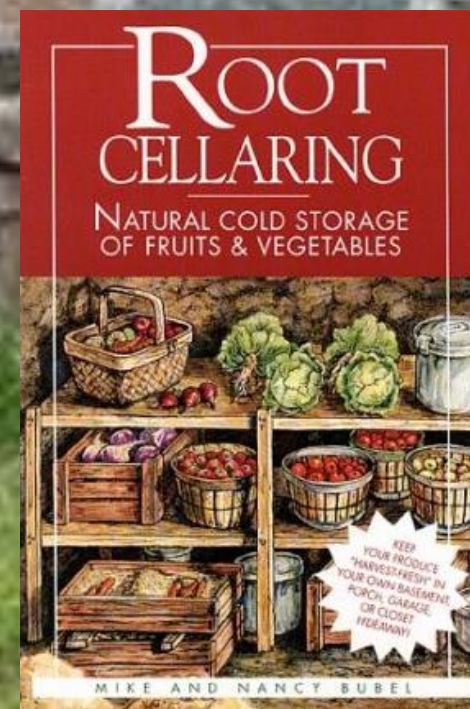
- Air Exchange
 - Helpful for shoulder months
 - Need positive shutoff to avoid passive ventilation when not wanted
 - Double thermostat design with a small fan
- Rodent Control
- Moisture and Condensation Plan



**Steve Maxwell &
Jennifer
MacKenzie**



**Michael and
Nancy Bubel**



**Elliston root cellar, photo credited to
http://donjarri.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

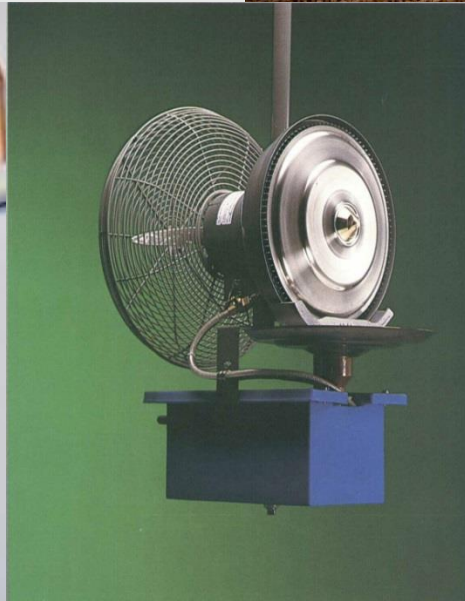


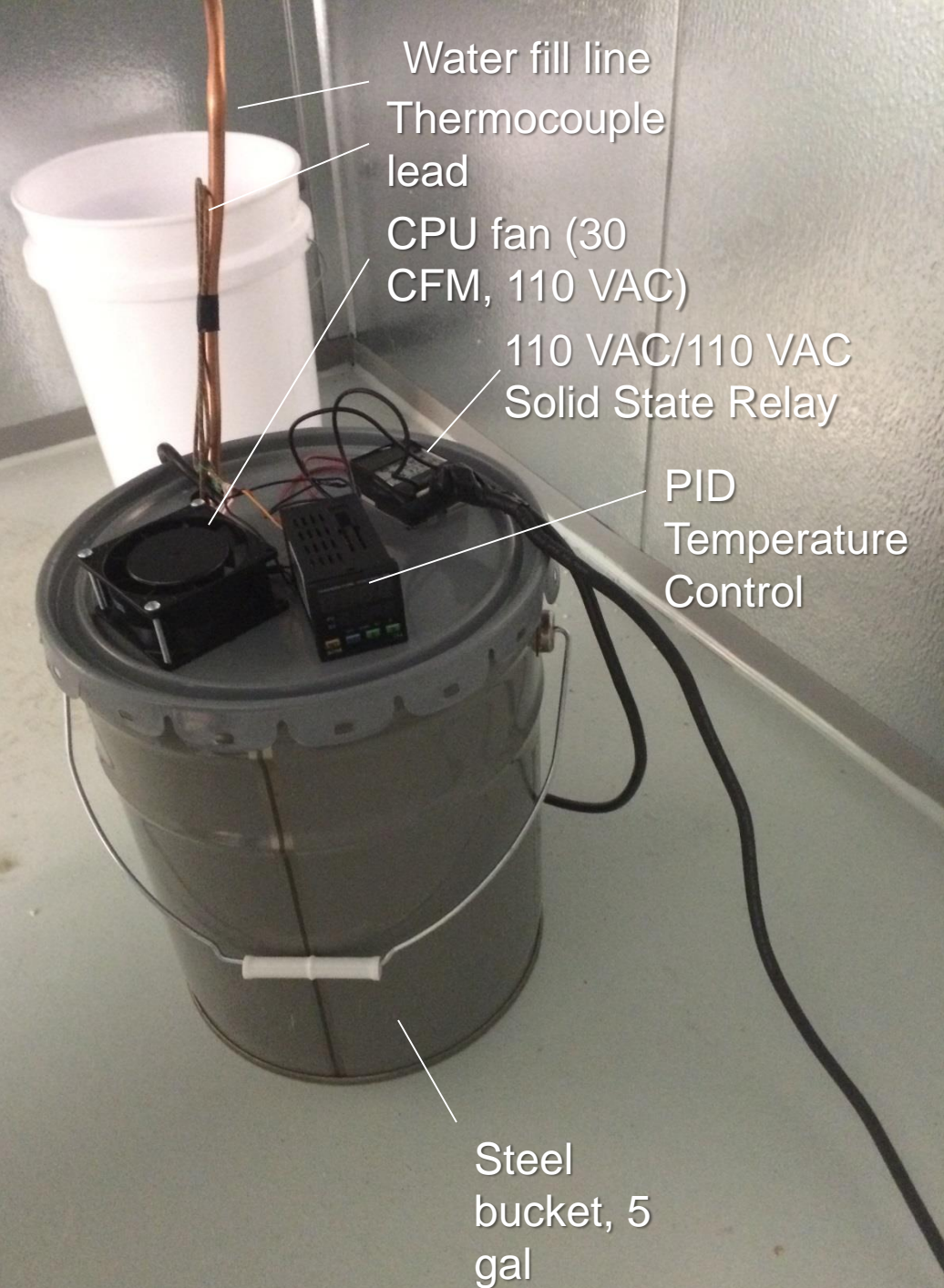
Humidification



Humidification

- Generally required for root veg storage





Water fill line

Thermocouple lead

CPU fan (30 CFM, 110 VAC)

110 VAC/110 VAC Solid State Relay

PID Temperature Control

Steel bucket, 5 gal

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.

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

- Damm – 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

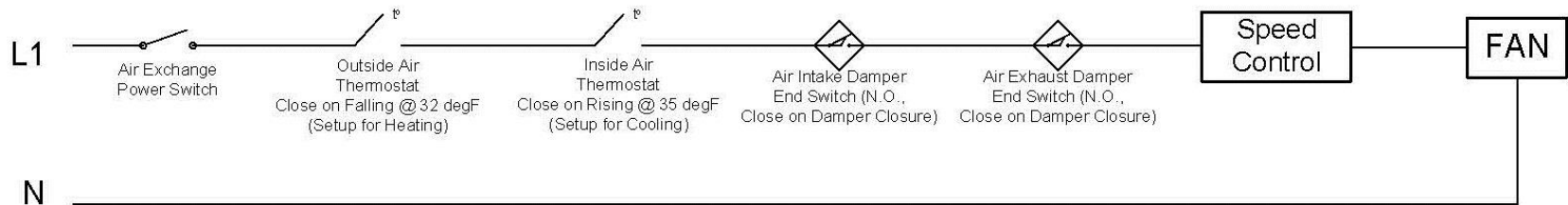
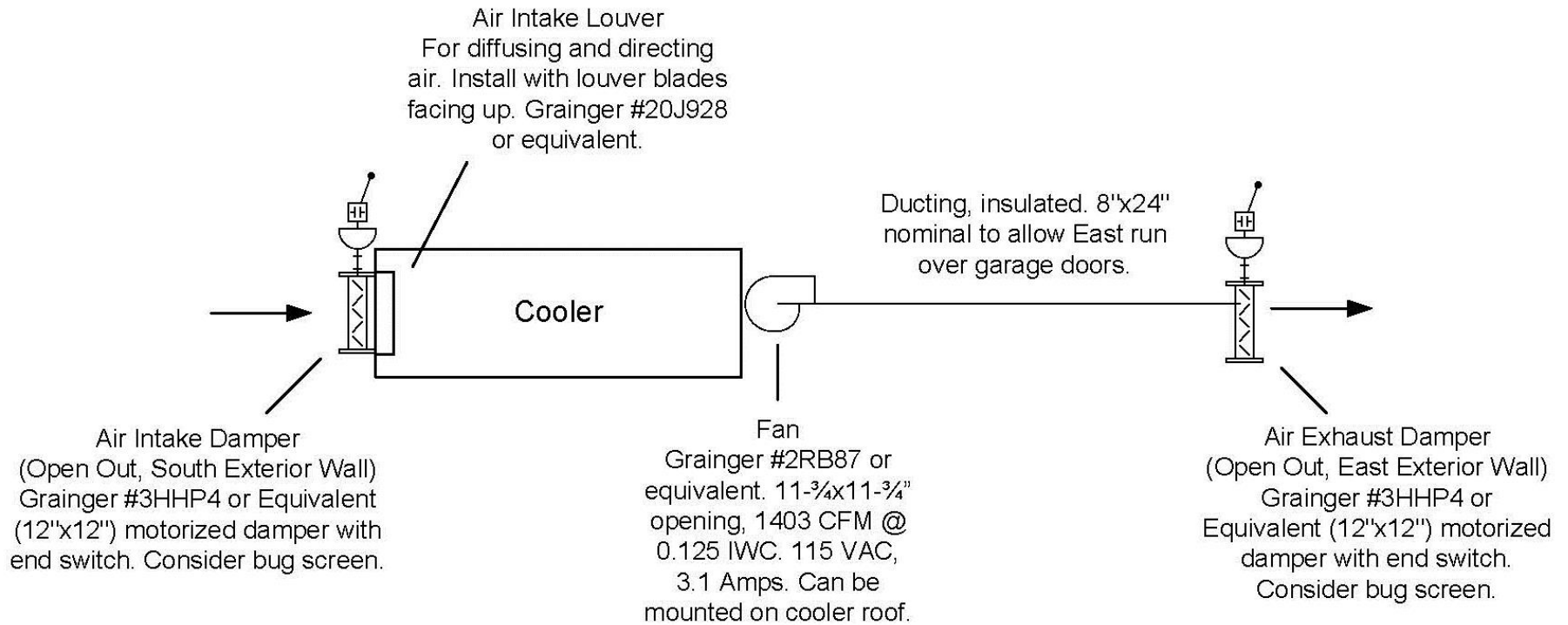
- Seeking to have a well mixed storage space.
- Avoid hot spots
- Avoid high moisture
- Strip ethylene.
- 3-5 volume changes per day is rule of thumb.
- Higher for curing or pre-cooling.

Remember that a thermostat is simply a switch



11/06/20

From Stephen Belyea



Controls - FreeAire™

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



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



Accurate



Precise



Accurate
and
Precise

Workshop Outline

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

Measure and Monitor

- “The measured variable improves.”
- Temperature **AND** 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%)

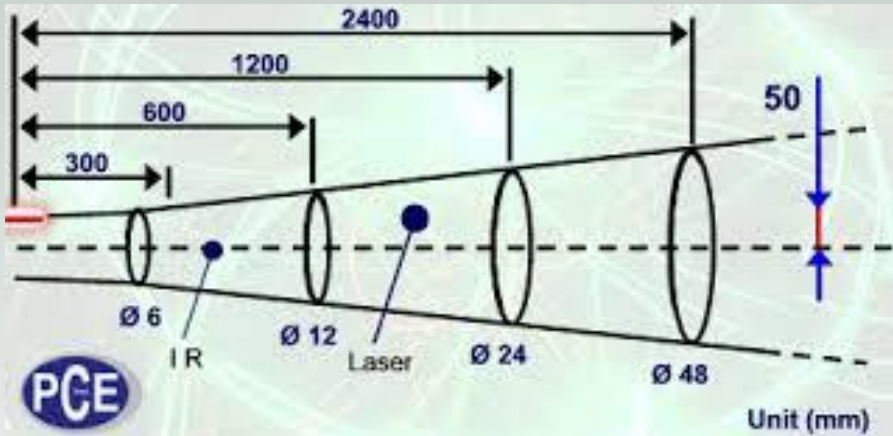


\$99 (RH +/-3%)



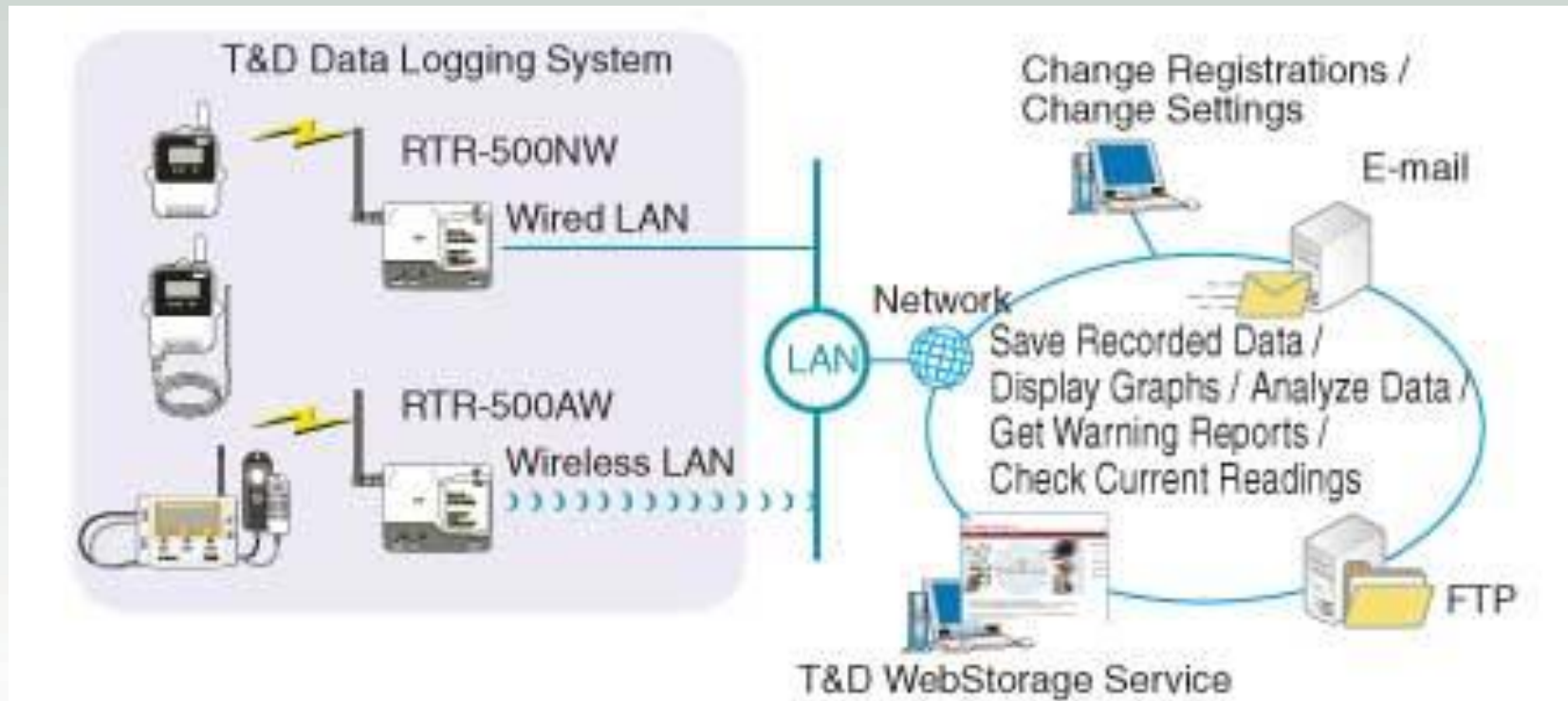
\$82 (RH +/-3%)

Infrared Thermometer



\$20-100

Remote Monitoring



Remote Monitoring

- \$400-\$2000 for a typical install.



Sensaphone

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

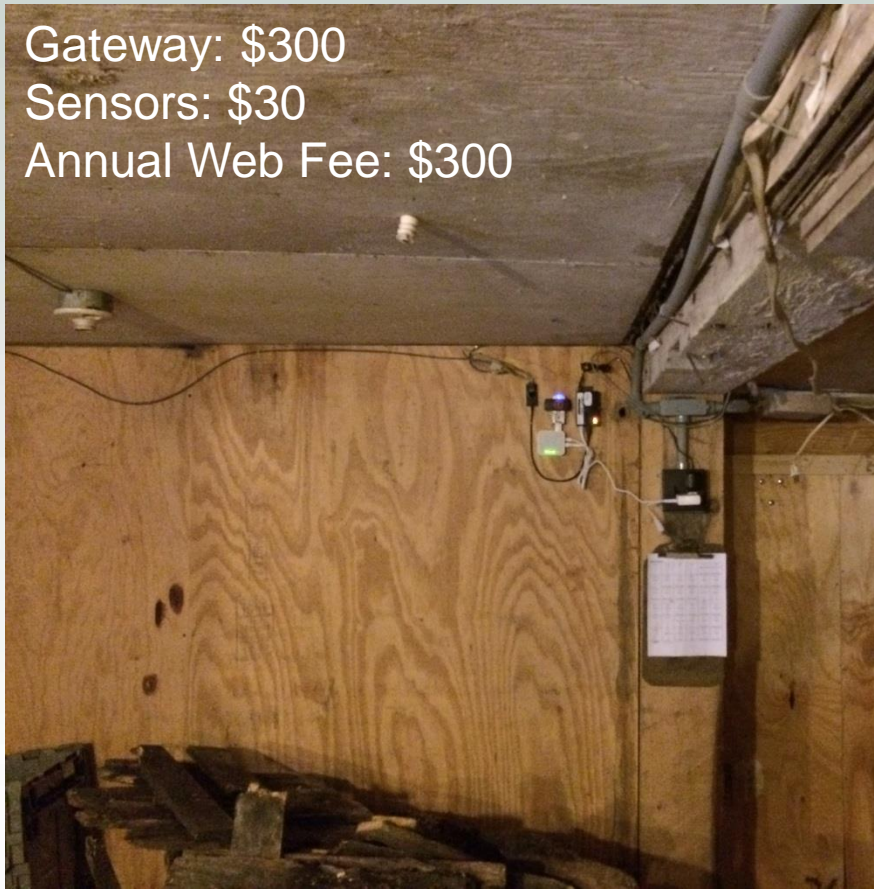


Mojyle

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.

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

Cooling Load Calculation

- Space dimensions
 - Product storage is $\frac{2}{3}$ of overall space
- Sketch the cooler
- Consider insulation thickness

Cooling Load Calculation

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

Equipment Selection

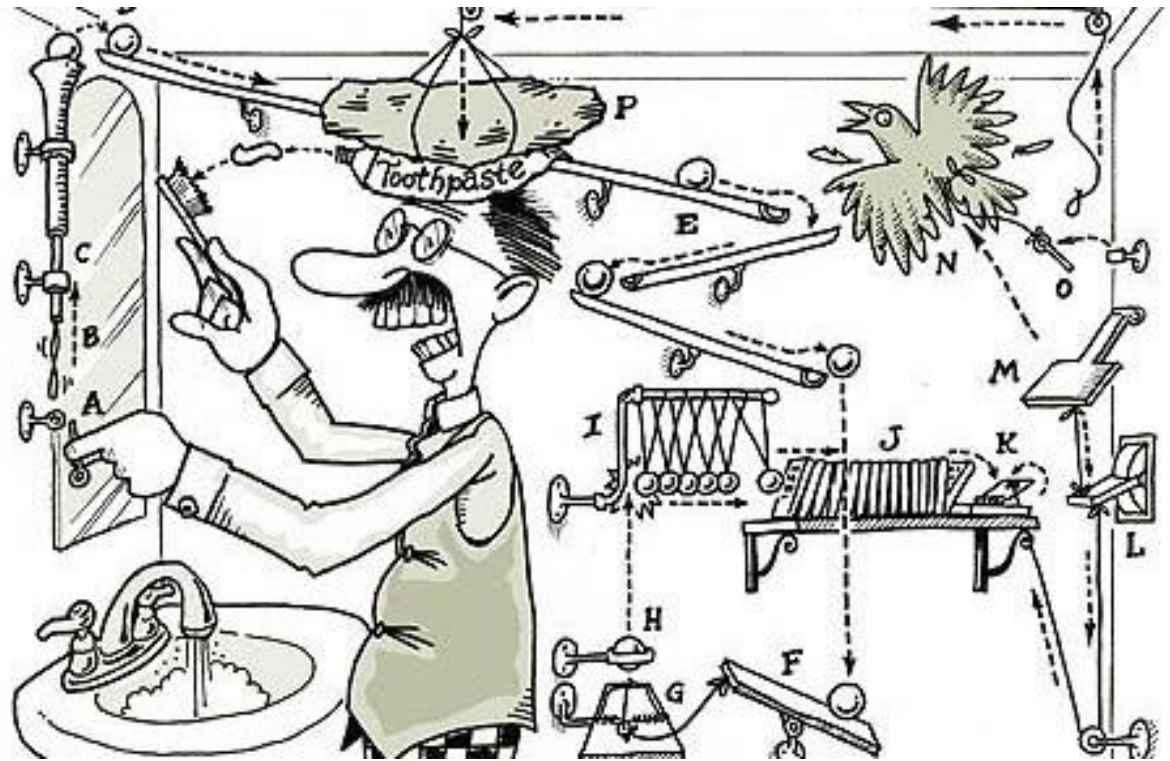
- Air Exchange
- Evaporator
- Compressor/Condenser
- CoolBot

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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1 Scale Ave, Suite 55

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Greenhouse & Tunnel Tour Video Series

Posted: January 27th, 2014 by Chris Callahan



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Blogs I Read

- Cooler Connection
- Ernesto Oroza
- RAFFL What's Growing On
- True Cost
- USDA Energy Blog
- UVM Extension Farm Viability
- UVM New Farmer Project

Calculators

- Air Ducting Loss Calculator
- Cooler Sizing Reference
- Grain Drying and Storage Calculators
- Greenhouse BTU/hr Calculator

blog.uvm.edu/cwcallah/

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The Commercial Storage of Nursery Stocks

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Commodity Summaries

Fruits and Vegetables

Annual Culinary Herbs	Cassava
Apple	Cauliflower
Apricot	Celeriac
Araz	Celery
Artichoke	Cherimoya
Asian Pear	Cherry (Sweet)
Asparagus	Chicory
Atemoya	Chinese Cabbage
Avocado	Coconut
Banana and Plantain	Cranberry
Bean	Cucumber
Beet	Currant, Gooseberry and Elderberry
Blackberry	Date
Blueberry	Dragon Fruit
Bok Choy	Durian
Breadfruit	Eggplant
Broccoli	Endive and Escarole
Brussels Sprout	Fennel

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