Postharvest Storage

A Workshop for Producers and Processors

NORTHEAST SARE
Sustainable Agriculture Research & Education

www.sare.org
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

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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?
- Do you have any specific storage practices you'd like to share?

Importance of Food Storage

- Product quality preservation
- Food safety
- Harvesting & season flexibility
- Food security
- Sunk costs in product
- Market expansion & 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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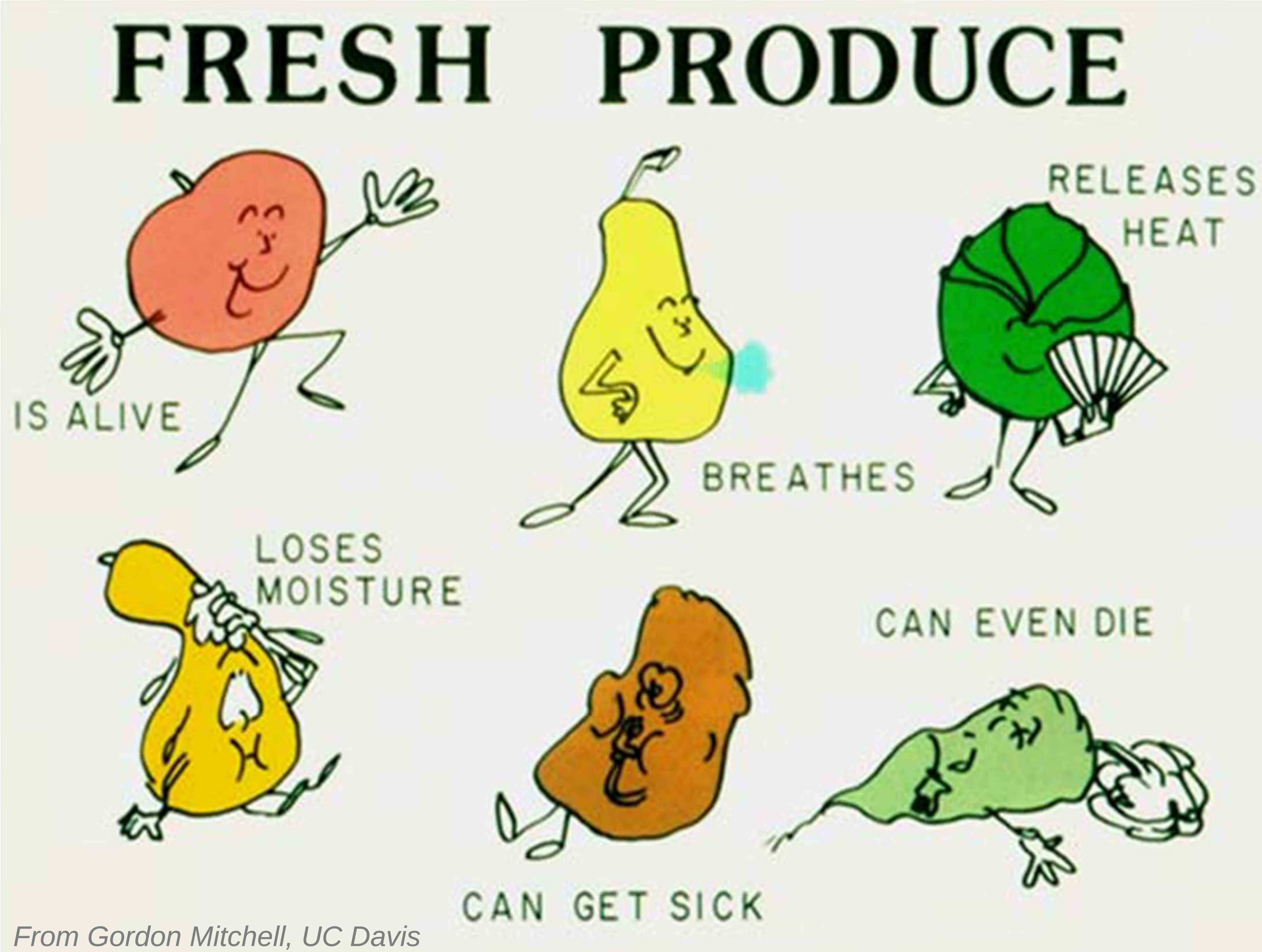

From Gordon Mitchell, UC Davis

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: Sweet Corn, Winter Squash

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

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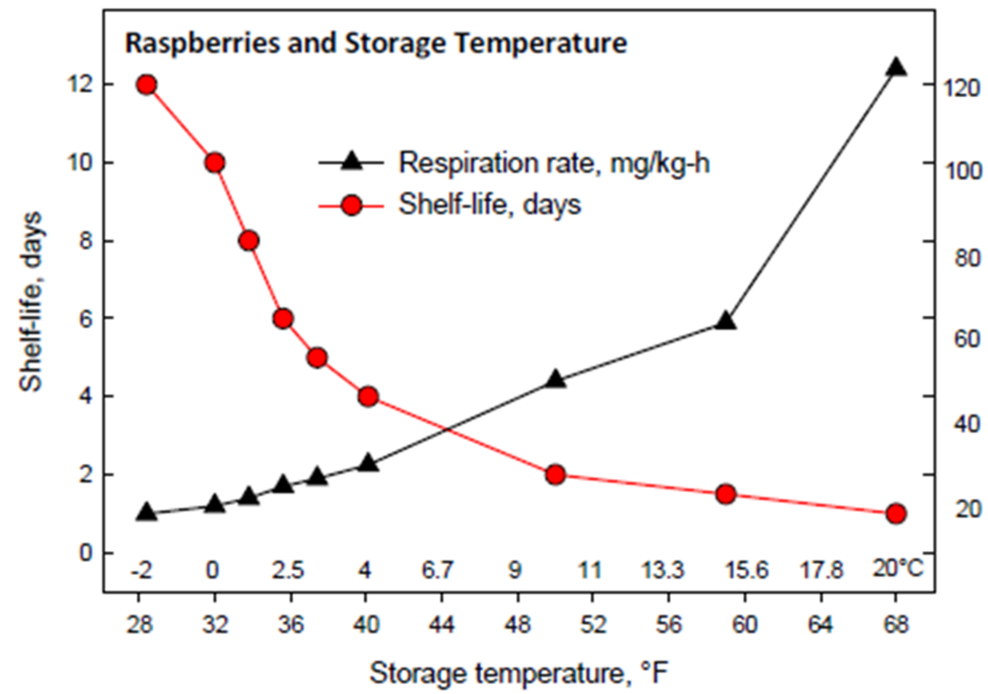
Temperature

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



Cantwell, UC Davis

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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)

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Ethylene Scrubber

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

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

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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	36-40	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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Recap - What do we mean by "Conditions"?

- Temperature
- Humidity
- Ethylene / Ventilation

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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

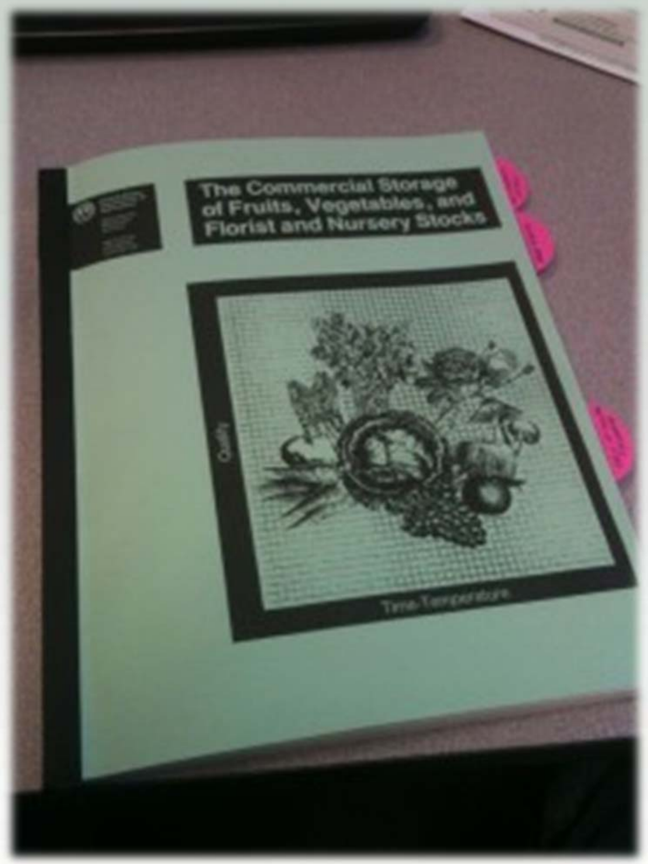
Rhizopus Soft Rot on Sweet Potatoes

Potato Affected by Fusarium Dry Rot

Potato Affected by Soft Rot

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

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Breakout

- Pick a crop
  - Potato
  - Beet
  - Carrot
  - Onion
  - Cabbage
  - Winter Squash
  - Garlic
  - Sweet Potato
- Read through Handbook 66 chapter on your crop.
- Report out to the group on your findings.

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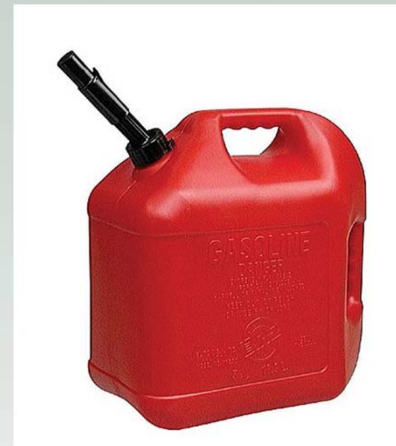
Energy in Food Storage

- 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



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.

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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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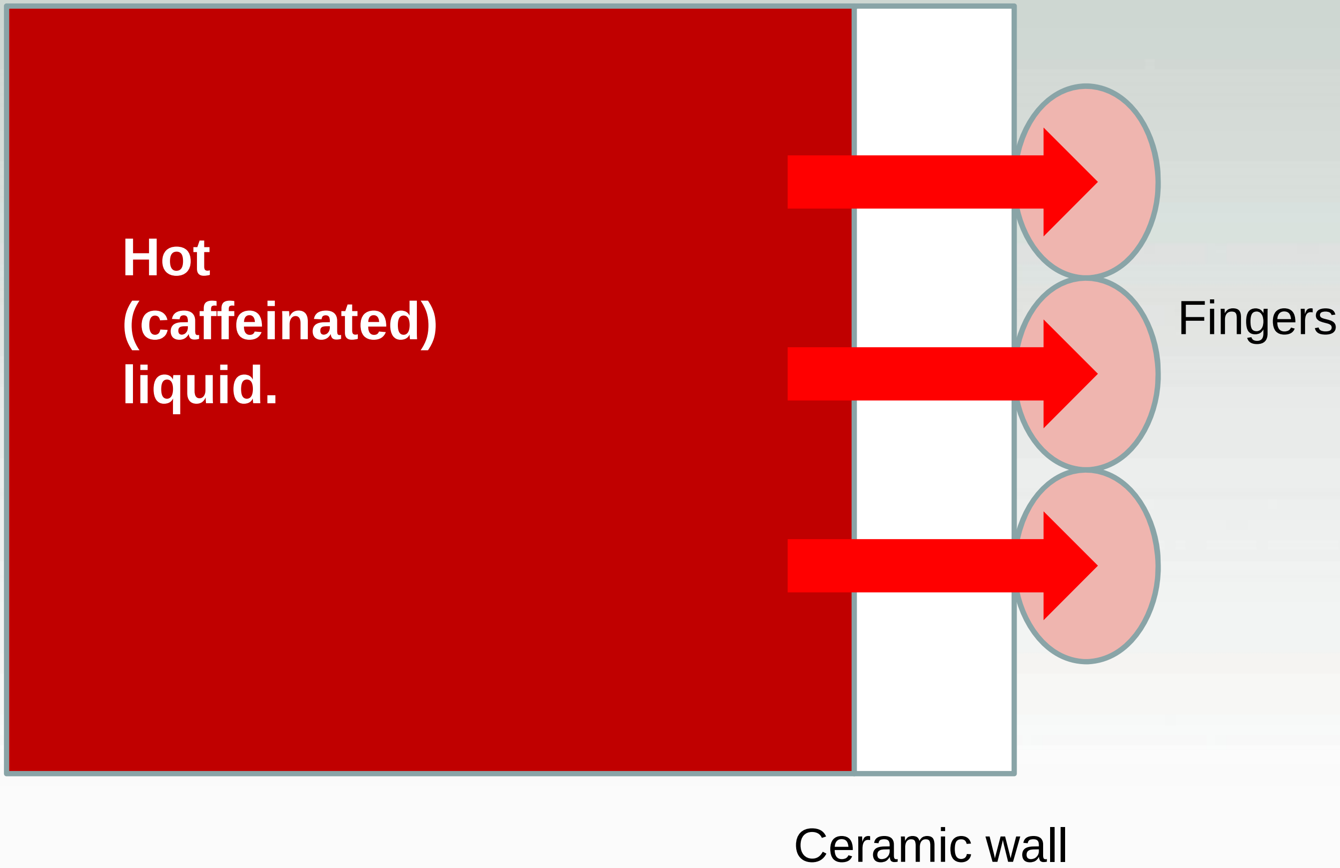
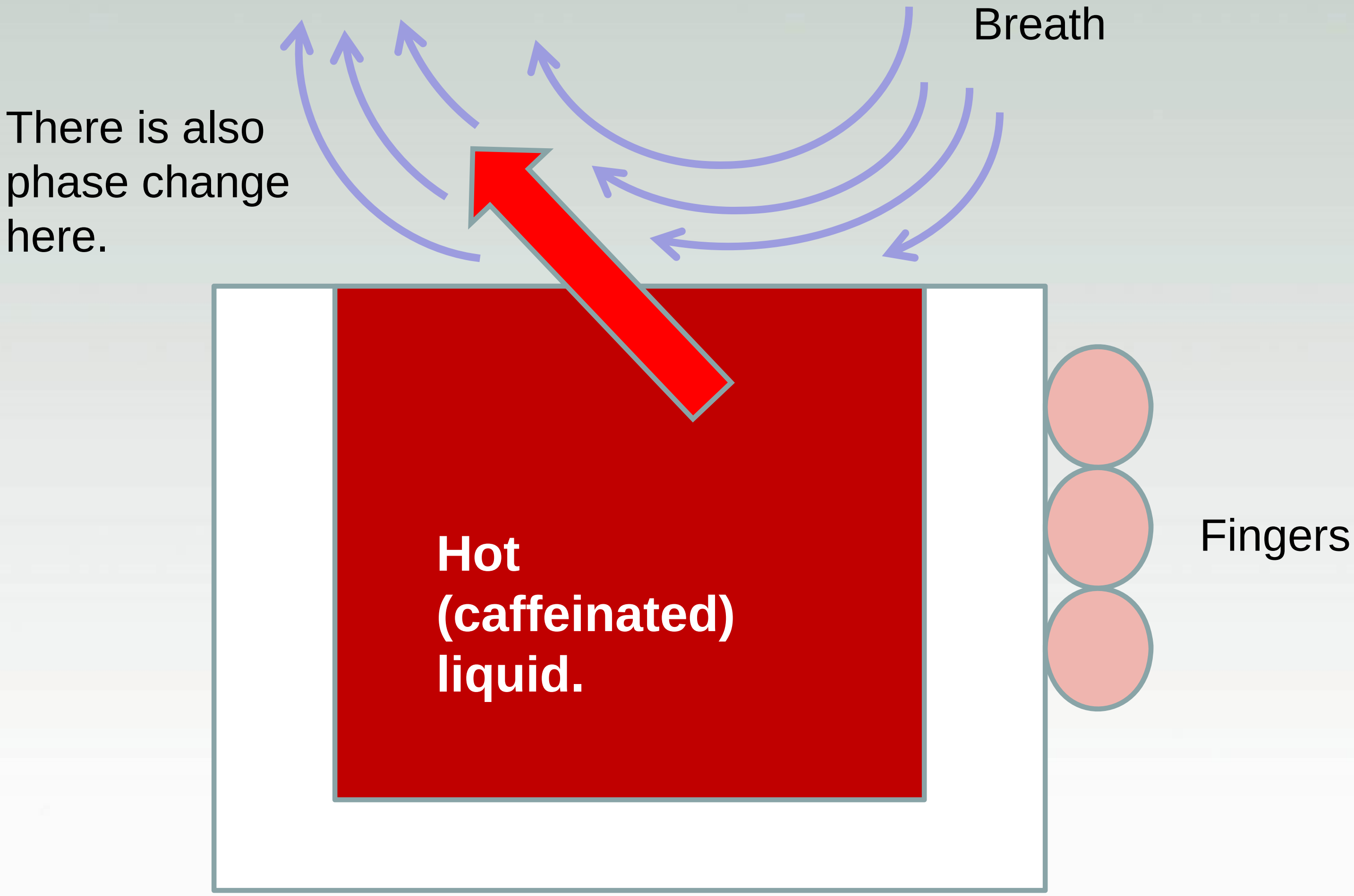
Conduction



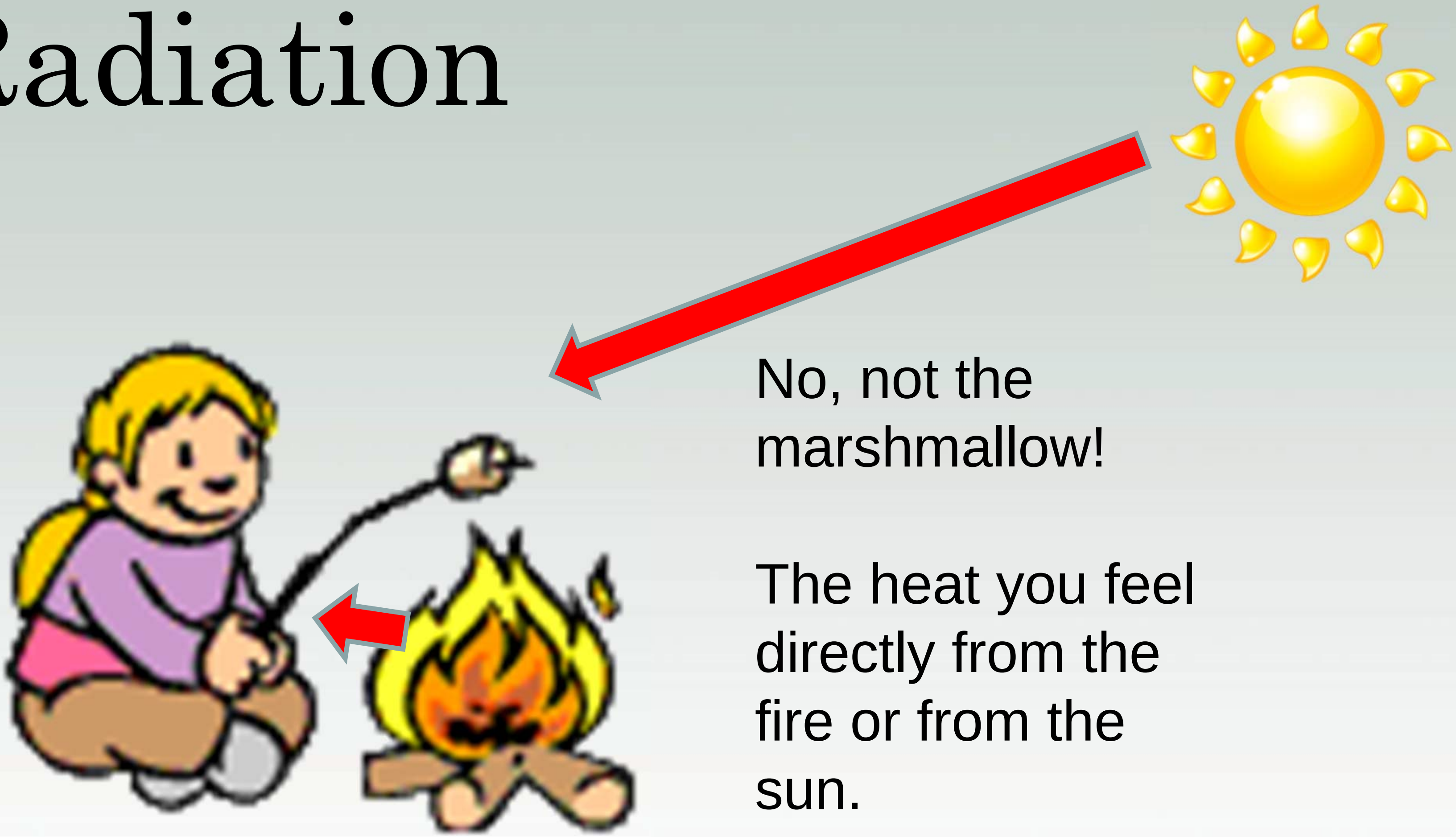
Convection



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

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

Radiation



No, not the marshmallow!

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

Paddle Check

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.

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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

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What Does R-Value Tell Us?

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

$$Q = \frac{\text{Area} \times (\text{Tout} - \text{Tin})}{\text{R-value}} \qquad \textit{BTU/hr}$$

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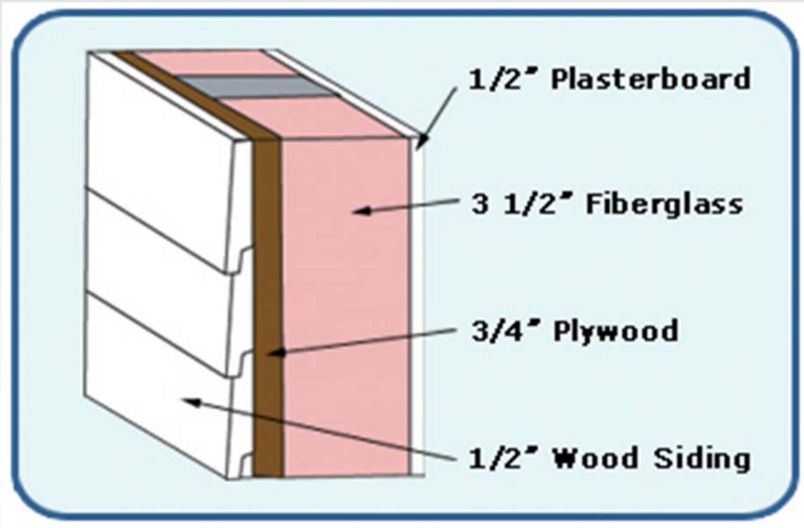
Breakout

- 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 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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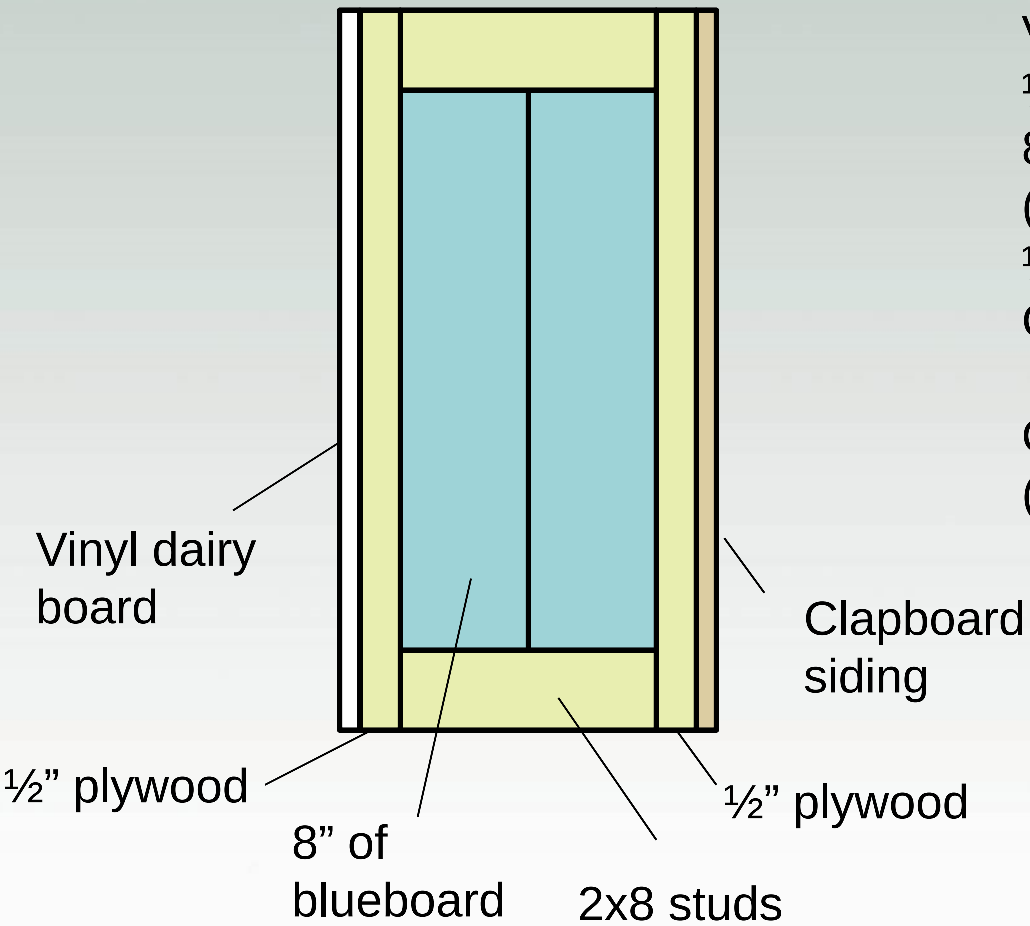


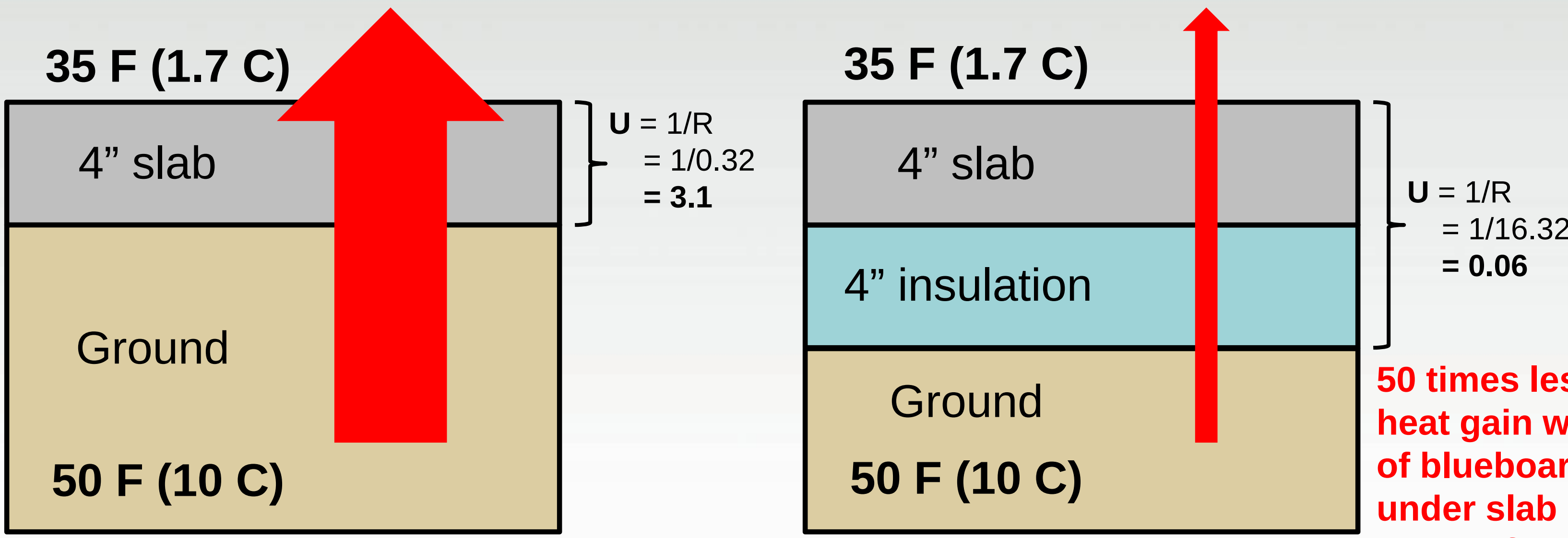
Vinyl dairy board (FRP) =	0.00
½" Plywood =	0.63
8" Blueboard (Expanded Polystyrene) =	32.00
½" Plywood =	0.63
Clapboard Siding =	0.80

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

Neglecting heat transfer through studs

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**.

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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

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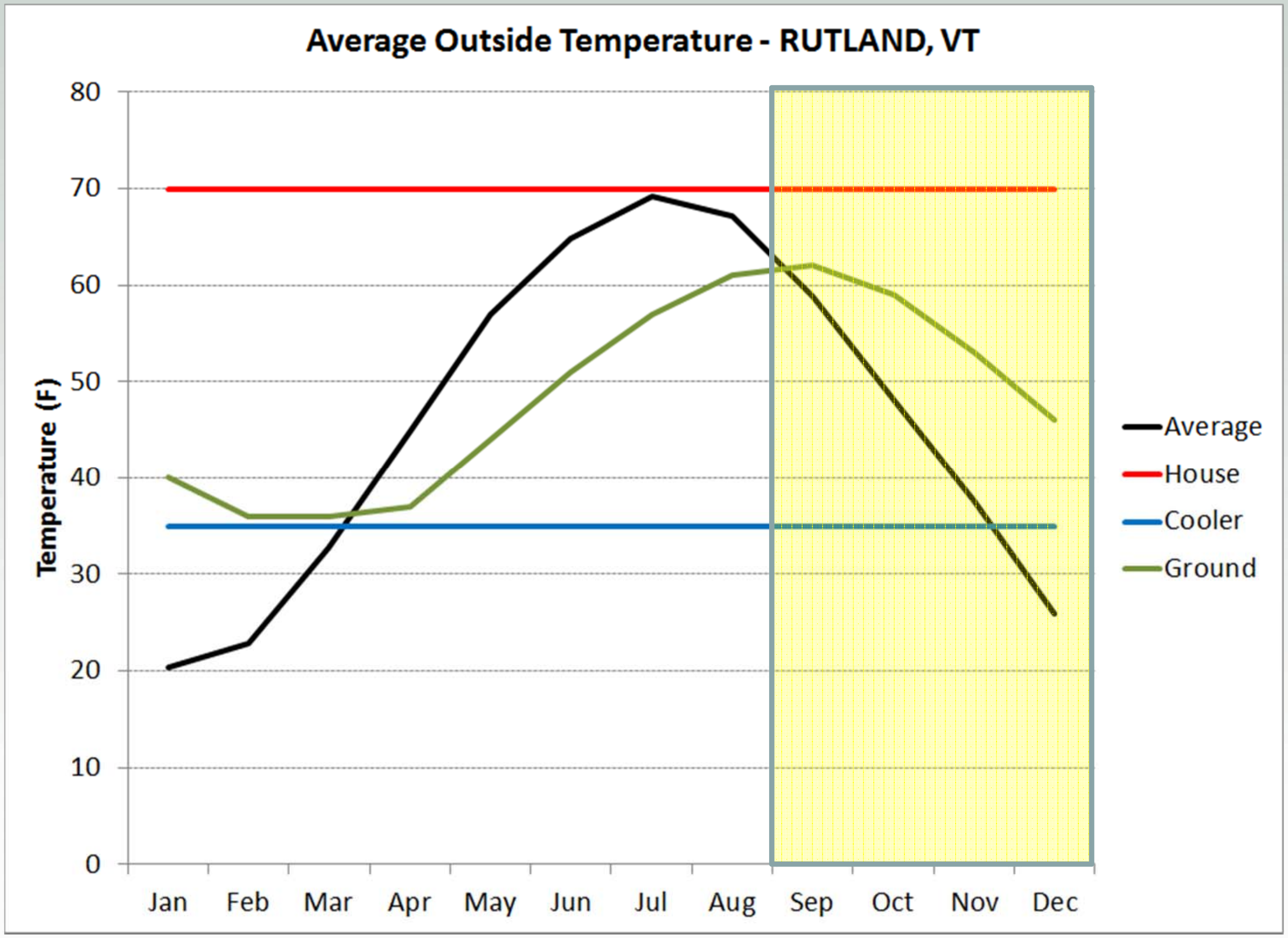
Breakout

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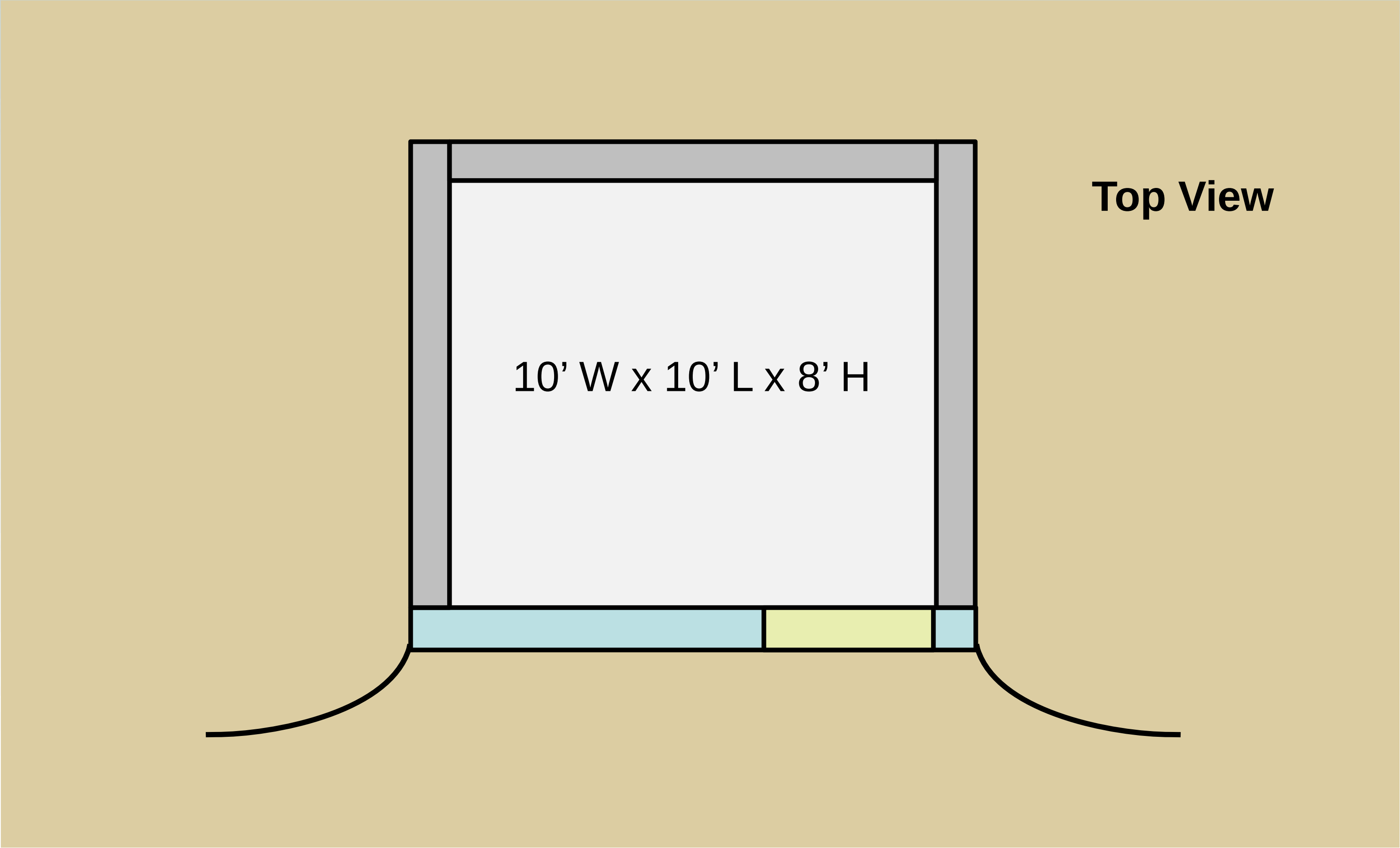
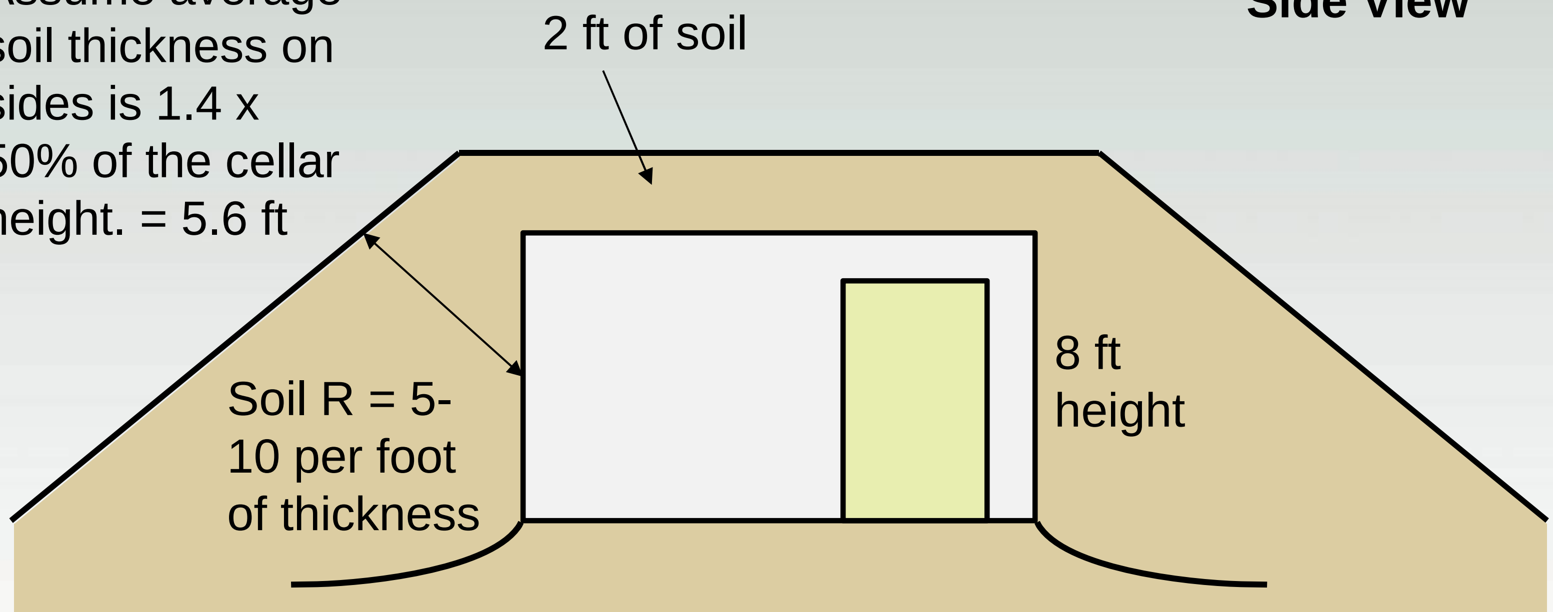
Elliston root cellar, photo credited to http://donjarrl.blogspot.com/2009_07_01_archive.html

Root Cellar



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

Side View



Root Cellar

- Outside Temperature: -25 C / -13 F
- Inside Temperature: 2 C / 36 F

ΔT = 27 C 49 F

- Some other assumptions:
  - 2/3 of volume is taken up by crop (22,500 lbs)
  - Crop is potatoes (110 BTU/ton/hr)
  - Neglecting the door
  - Assuming a tight construction (no air exchange)

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Heat gains and losses…

- 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 Watts)**

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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.

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Same song; different verse…

- Heat Gains
  - Product +185 BTU/hr
  - Floor +270 BTU/hr
- Heat Loss
  - Roof -490 BTU/hr
  - Soil Berm -407 BTU/hr
  - Front Wall/Door -161 BTU/hr
- **Heat Addition Needed 619 BTU/hr (181 Watts)**

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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

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What is happening here?

Humidifying and Drying

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

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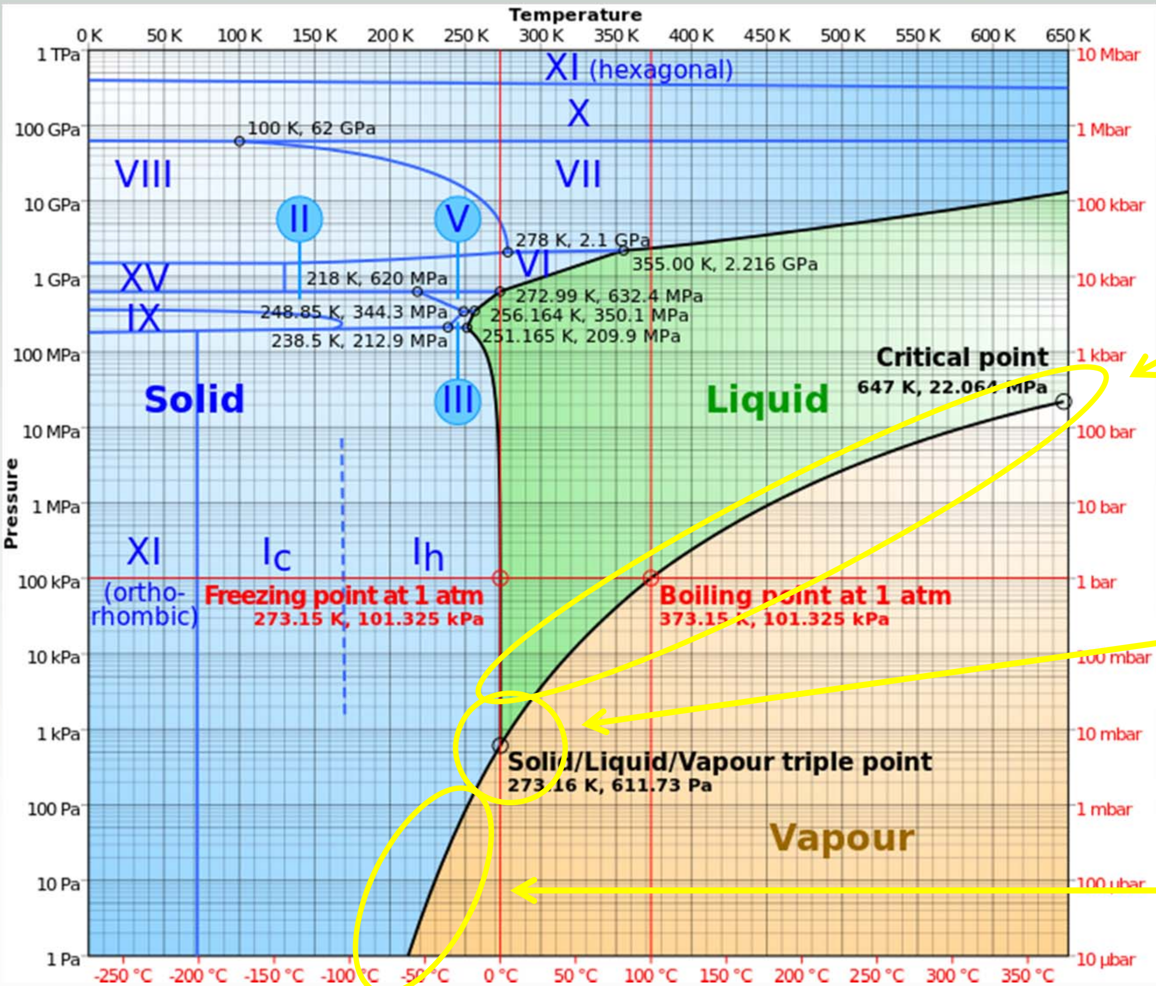
Water's Phase Change

- What do we know about the freezing and boiling point of water?
- 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



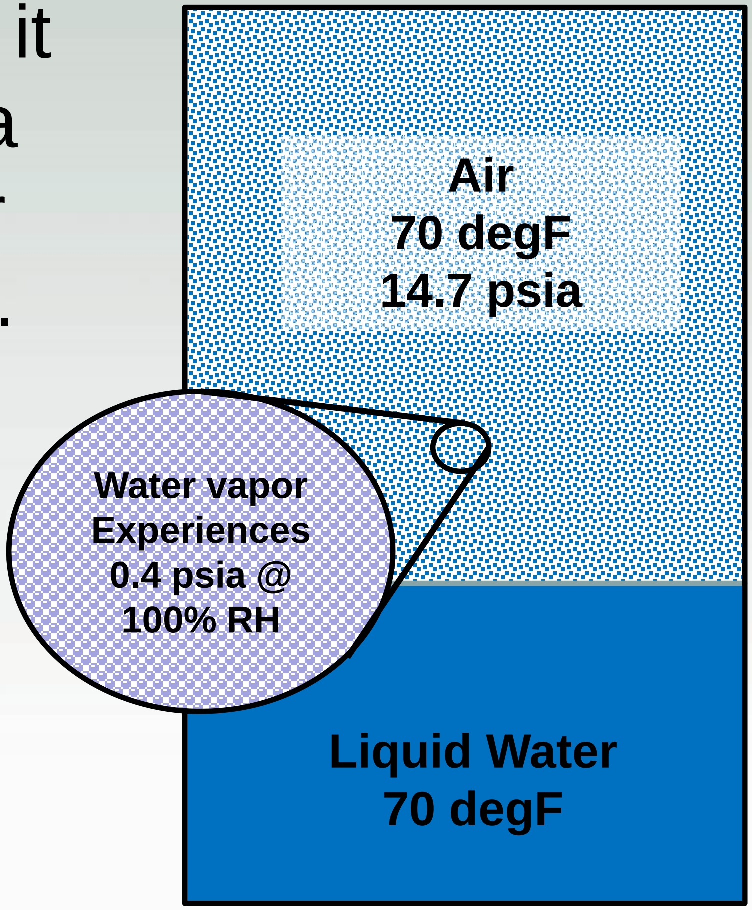
This ain't bad either.

This. Right here.
Is one of the most beautiful things in the universe.

And, what the heck is going on here?

Water and Air Mixtures

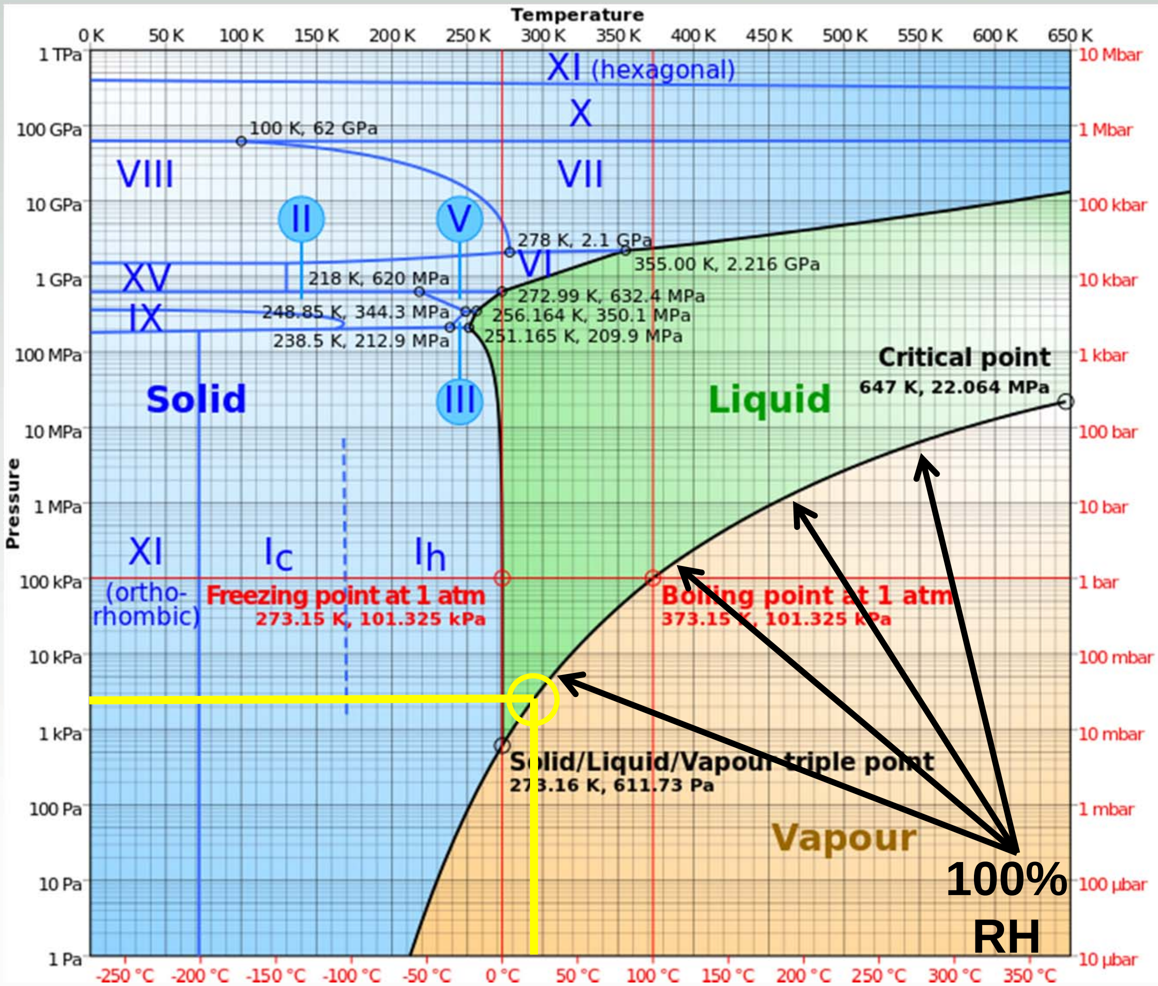
- When water vapor is in air, it behaves as though it is at a "**partial pressure**" or lower pressure than atmospheric.
- Meaning, it is vapor even though it isn't at 212 F.
- This allows for "**humidity**" below 212 F.
  - And most of the weather systems we deal with.



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…

Water and Air Mixtures



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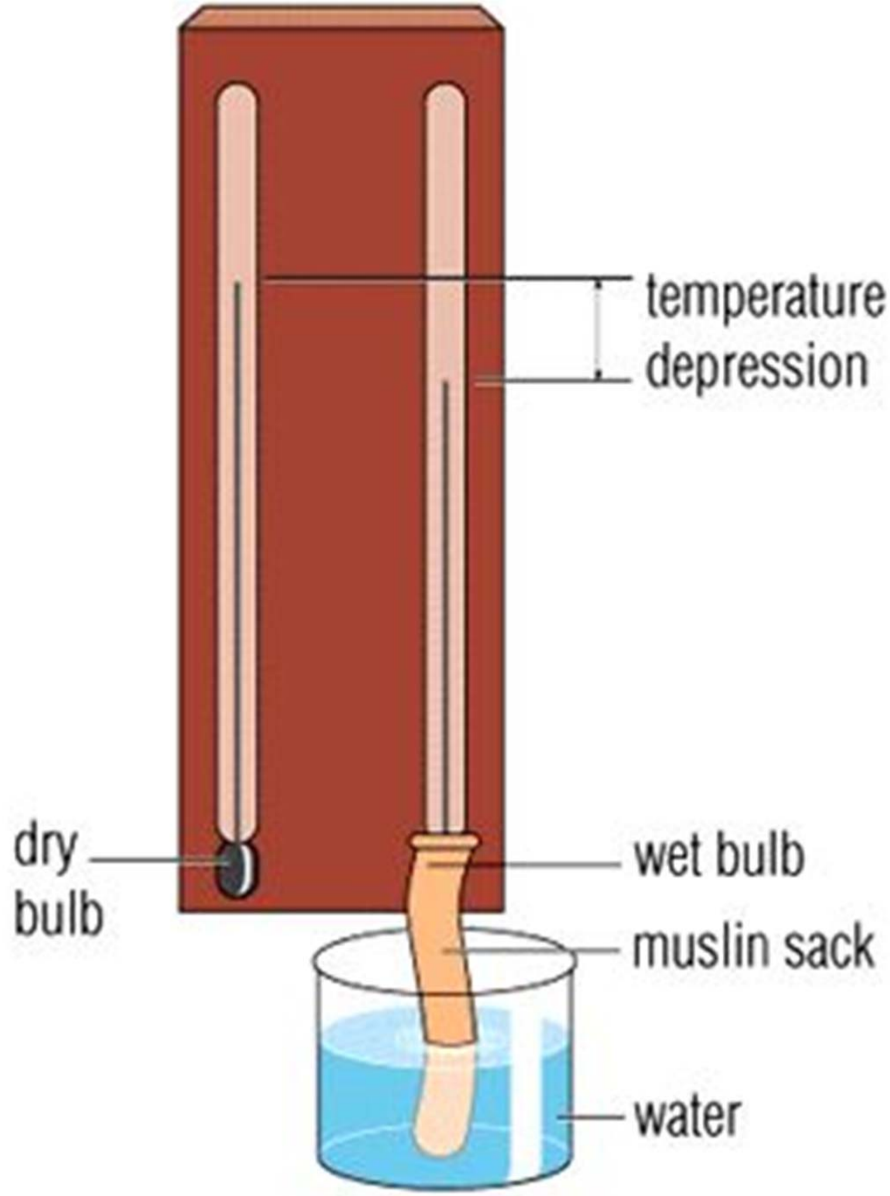
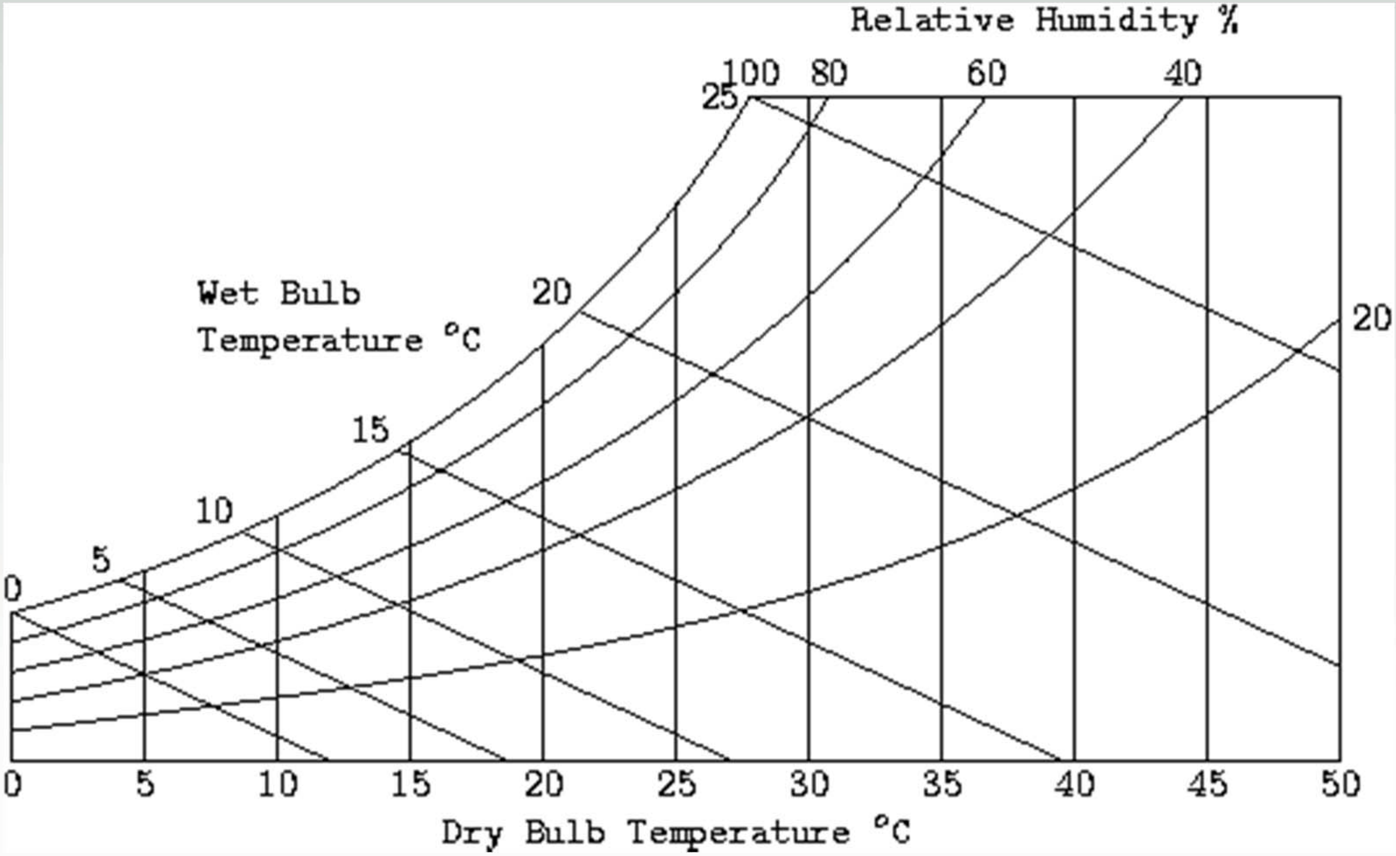
- We don’t actually measure Relative Humidity (RH)
- We measure
  - Dry Bulb Temperature, and
  - Wet Bulb Temperature
- RH is a calculation based on these two temperatures.



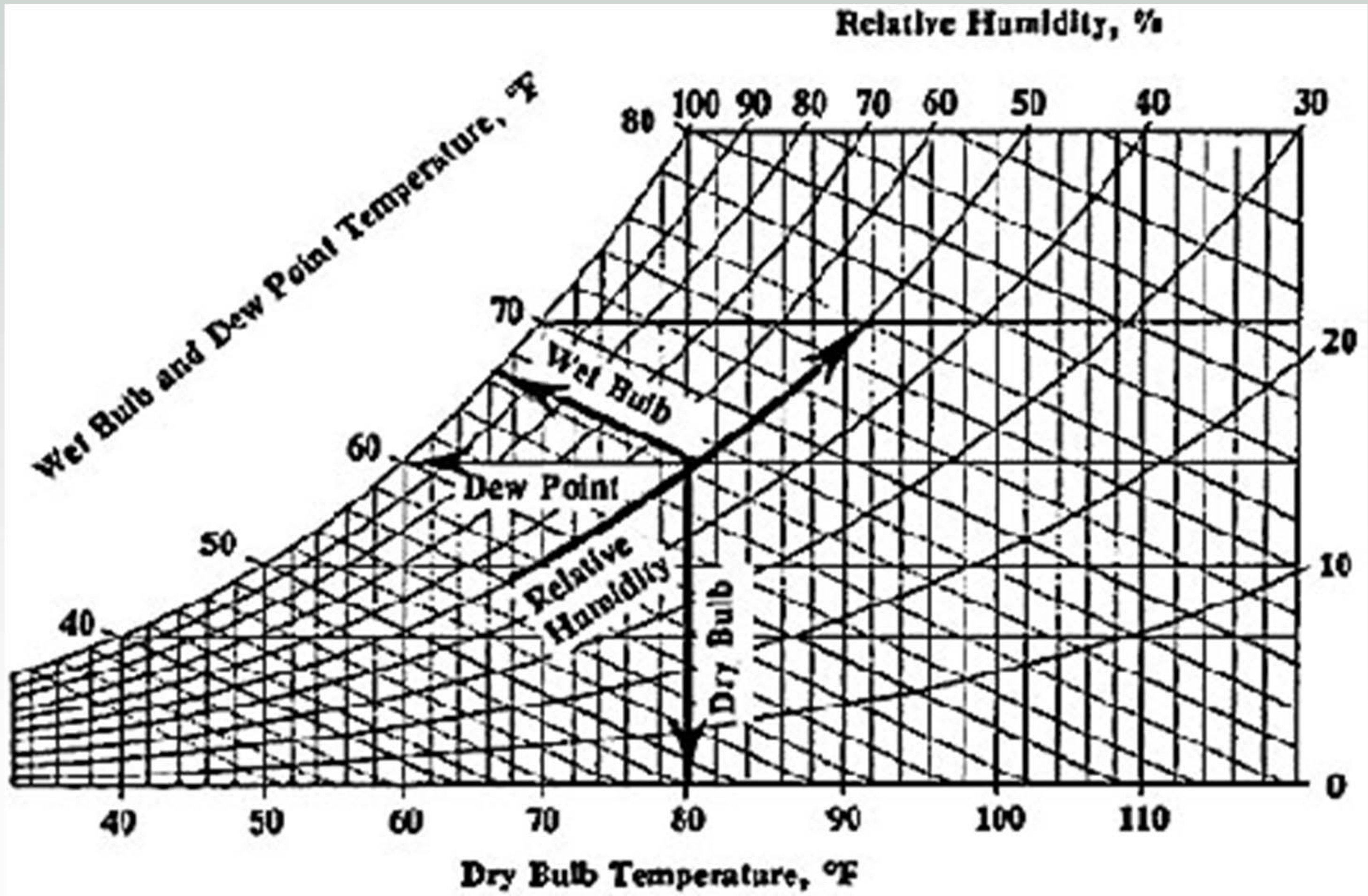
Psychrometric Charts

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



The problem with relative humidity is that it is relative.

Psychrometric Charts



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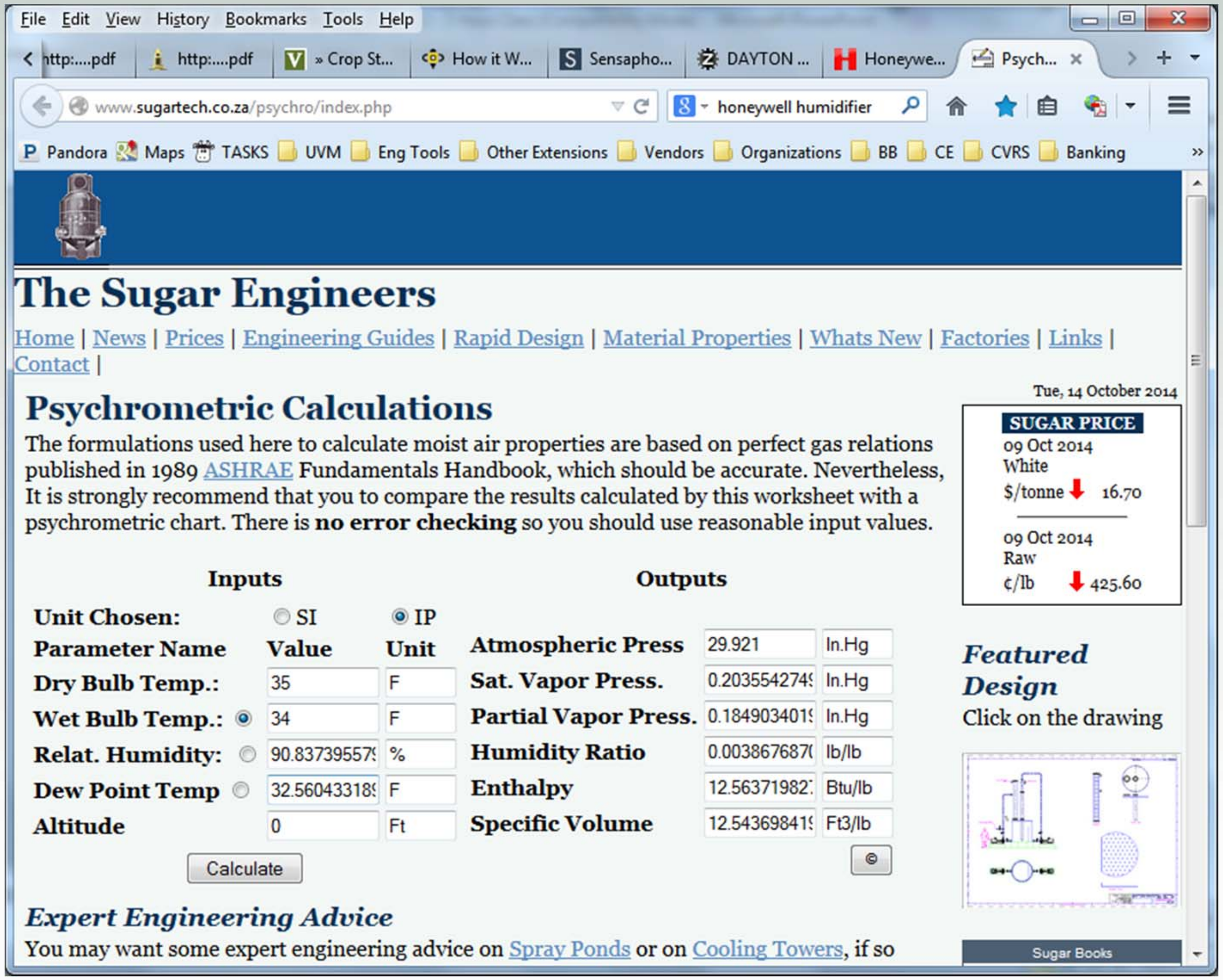
Psychrometric Calculator



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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
$155

Vented Psychrometer

Gorman Industries
South Melville, PE, Canada
www.gormancontrols.com
$2500

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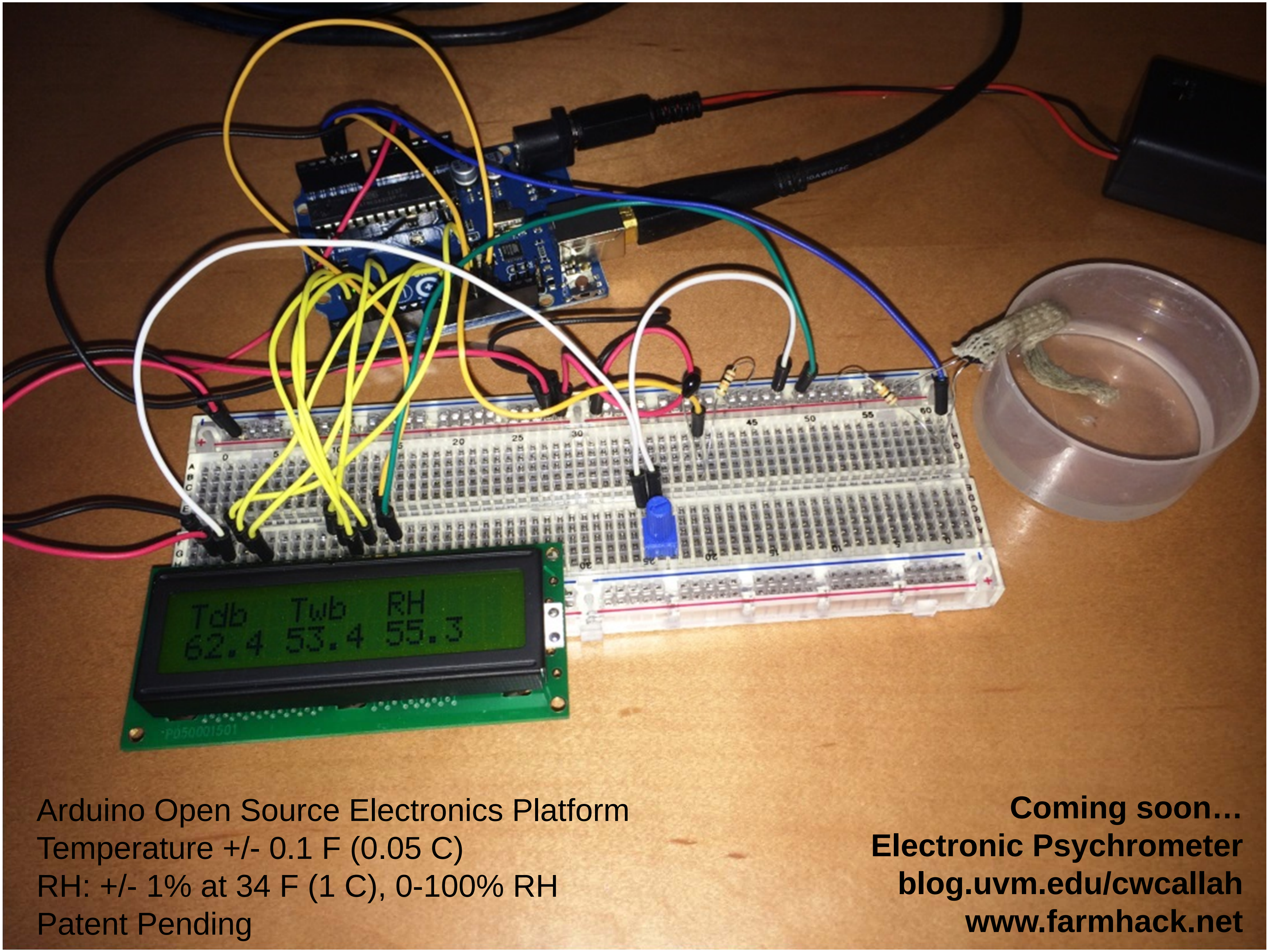
Tdb Twb RH
62.4 53.4 55.3
Arduino Open Source Electronics Platform
Temperature +/- 0.1 F (0.05 C)
RH: +/- 1% at 34 F (1 C), 0-100% RH
Patent Pending
Coming soon…
Electronic Psychrometer
blog.uvm.edu/cwcallah
www.farmhack.net

Breakout

- Measuring RH with a sling psychrometer.

QA Supplies
Bacharach Heavy Duty Sling
Psychrometer - $155
www.qasupplies.com

Ben Meadows
Weksler Sling
Psychrometer - $68
www.benmeadows.com

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HYSIDE
Paddle Check

Workshop Outline

- Importance of Food Storage
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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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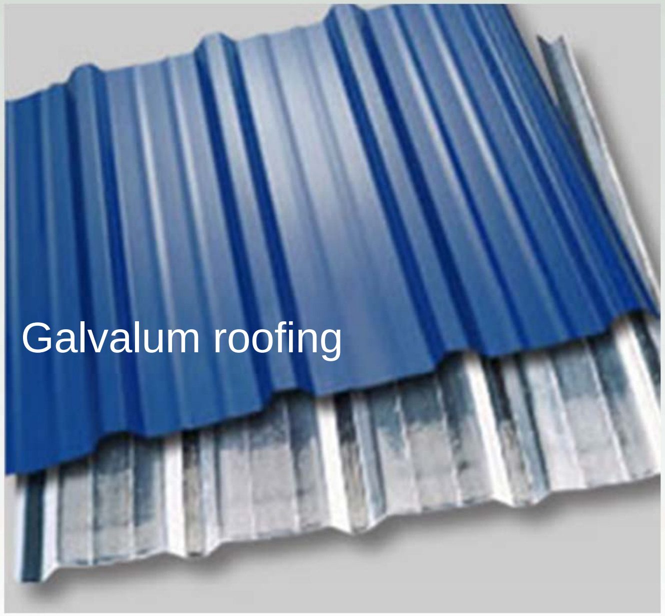
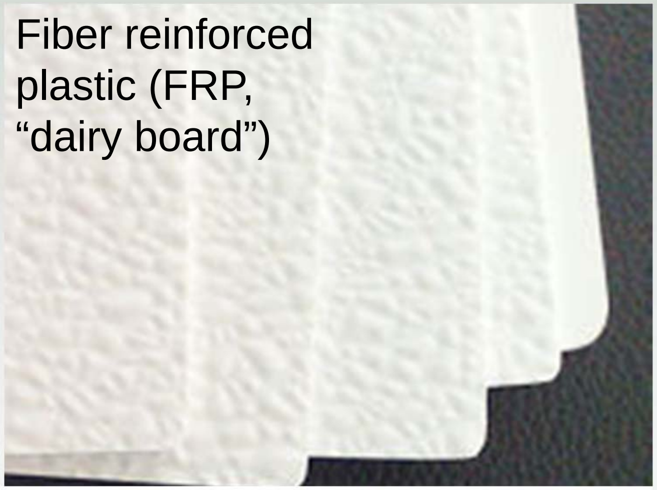
Structure and Materials

“Smooth and cleanable”





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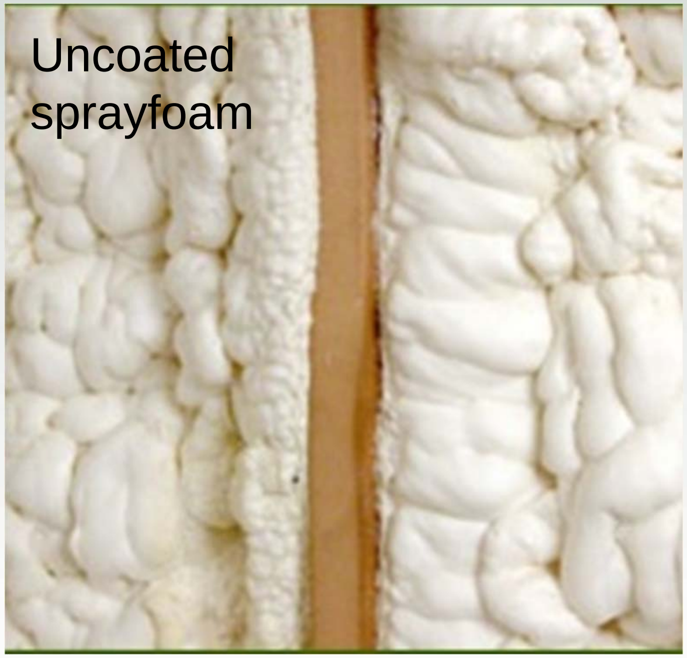
Structure and Materials

Practices to avoid

Direct soil contact

Uncoated plywood / chipboard / sheetrock



Uncoated sprayfoam

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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)

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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.

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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

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Avoid Bare Wood & Liquid Water

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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

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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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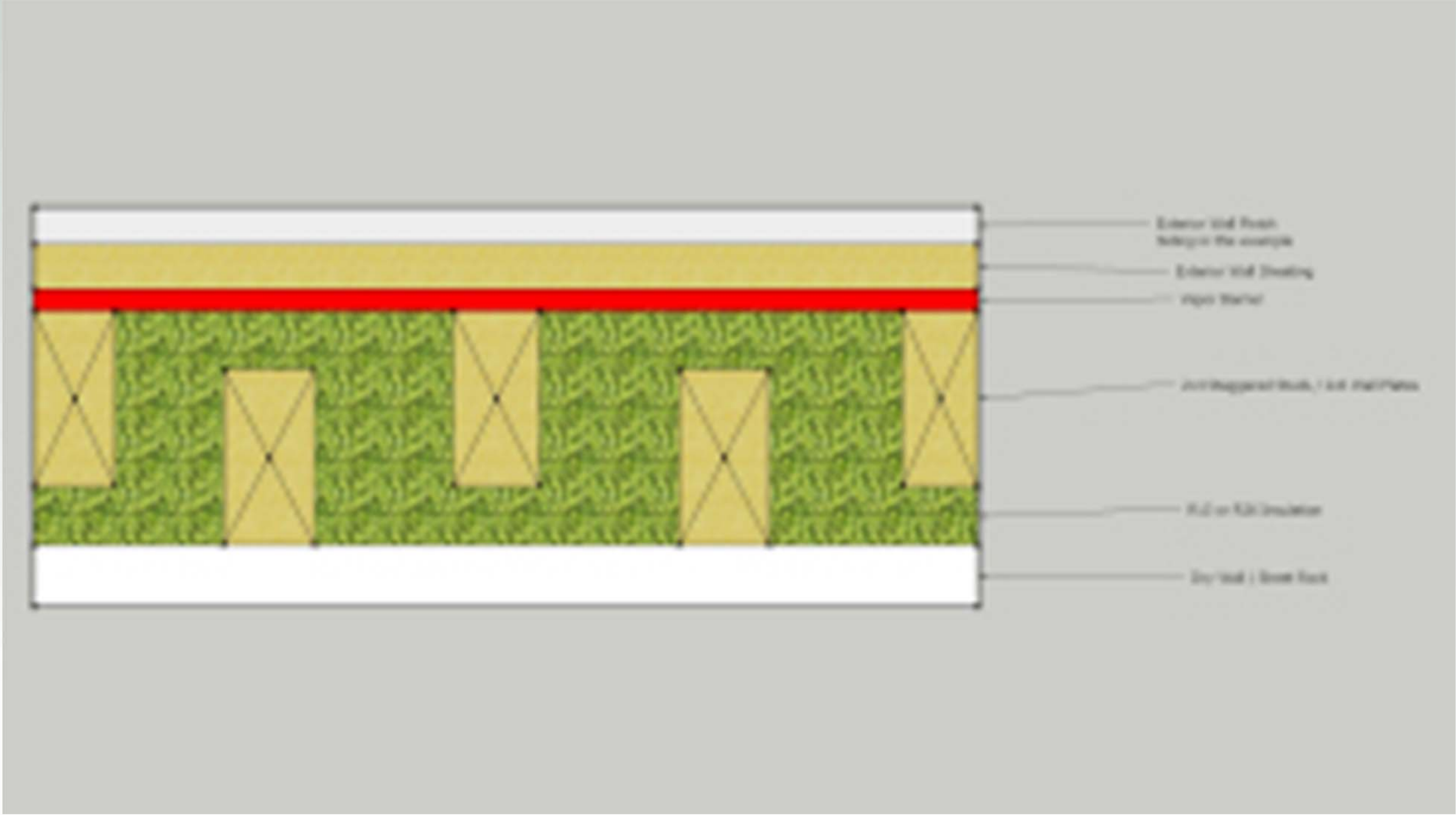
Homemade Panels

- 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



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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

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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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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!

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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
- Caulking / Silicone at Wall Seams

Sliding cooler door with plastic curtains at Jericho Settlers Farm

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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? Condenser heat?

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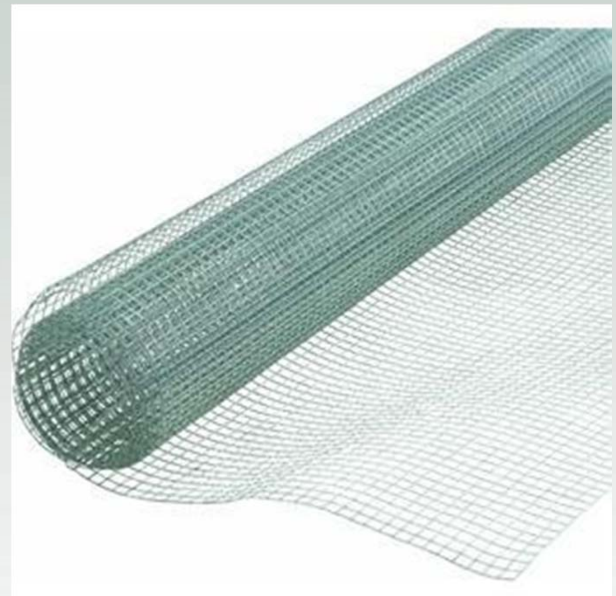
http://extension.umass.edu/vegetable/projects/umass-carrot-storage-trials

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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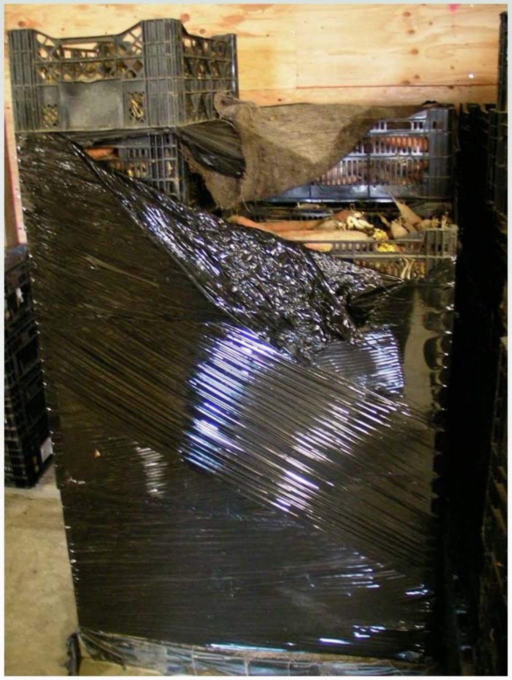
Good Agricultural Practices

- 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.

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.
ROMAINE
BIG HAWK
BRAND
NET WT. 25 LBS. (11.35Kg)

Breakout

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

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HYSIDE
Paddle Check

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.

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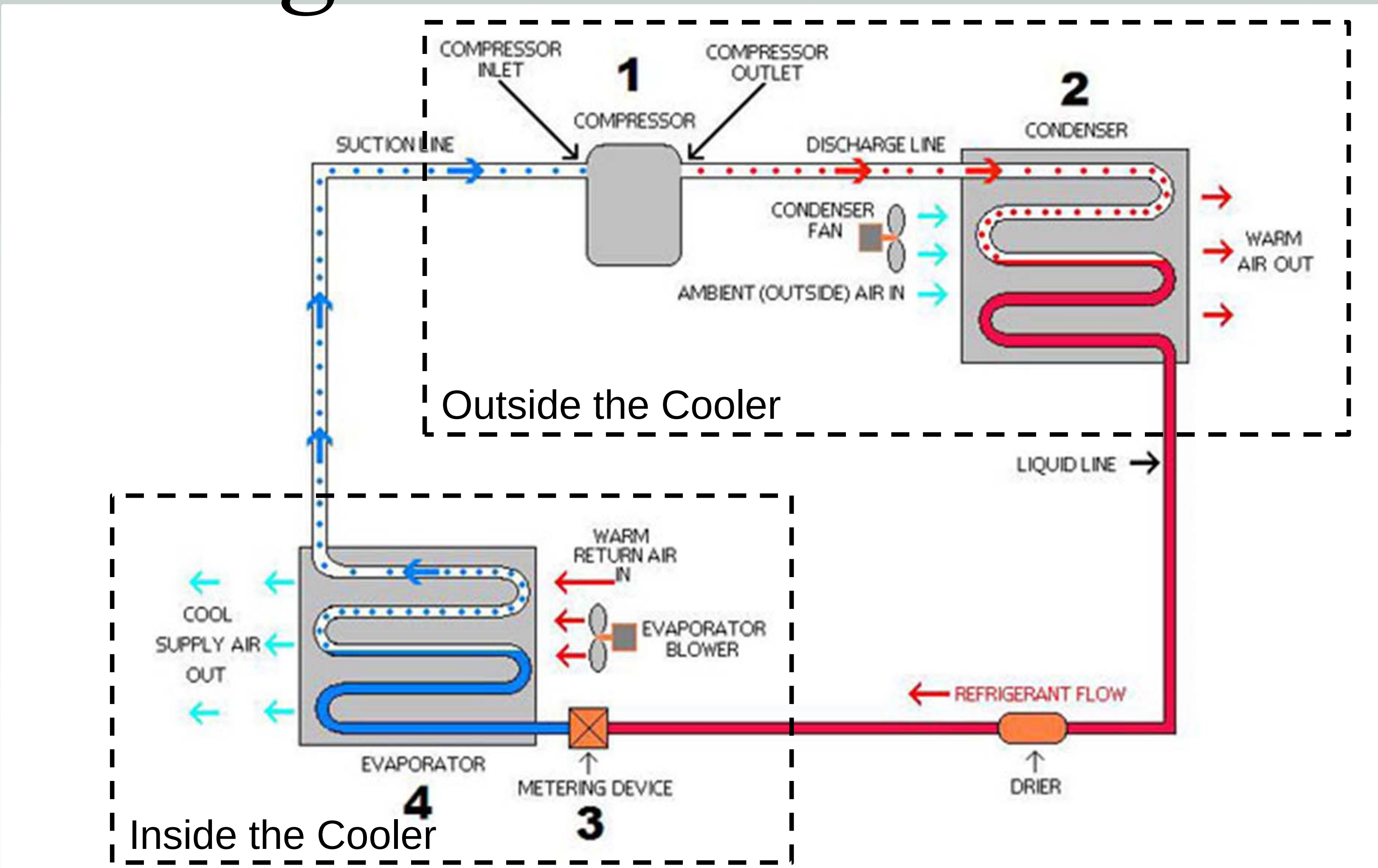
Refrigeration



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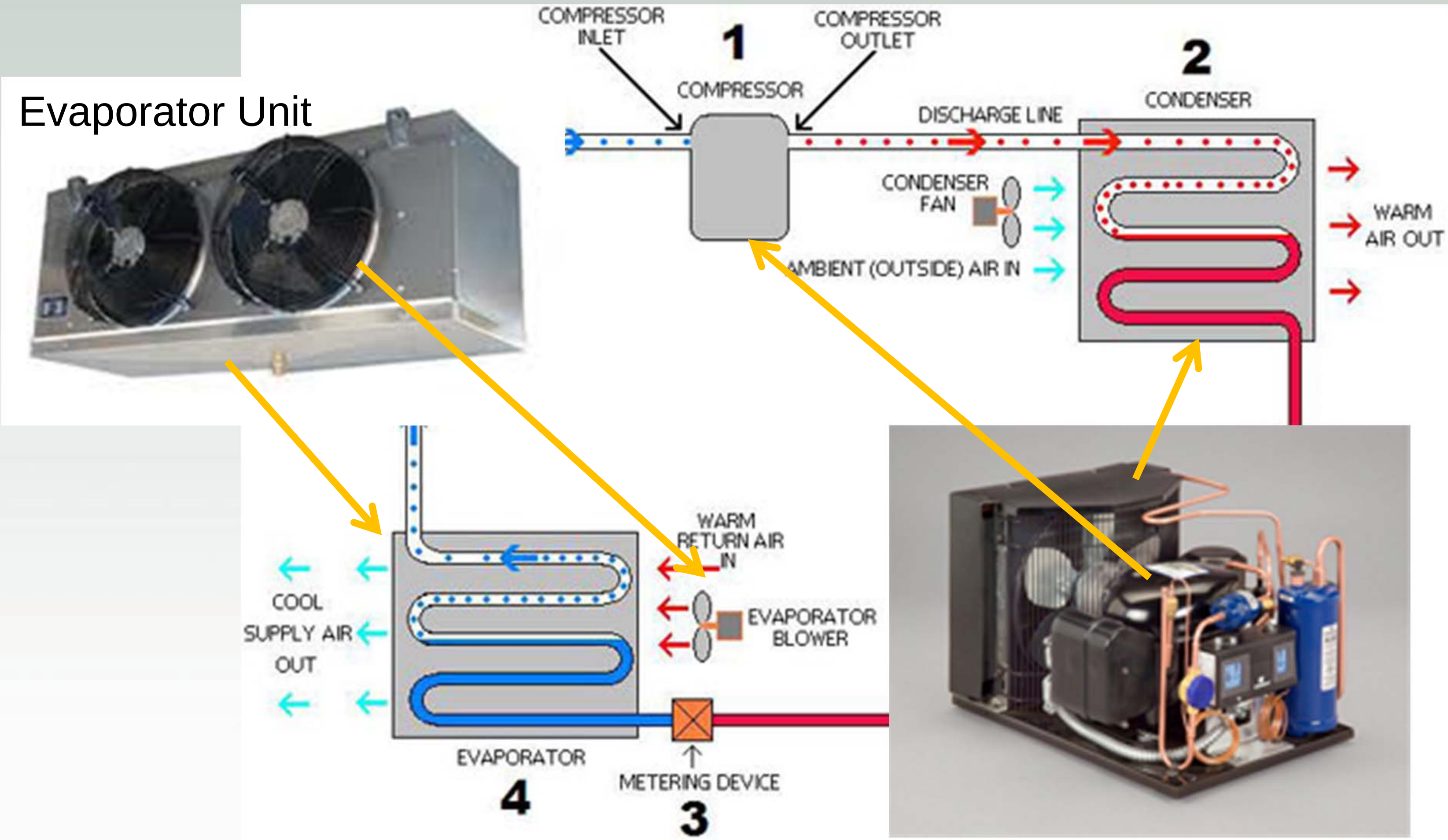
Refrigeration

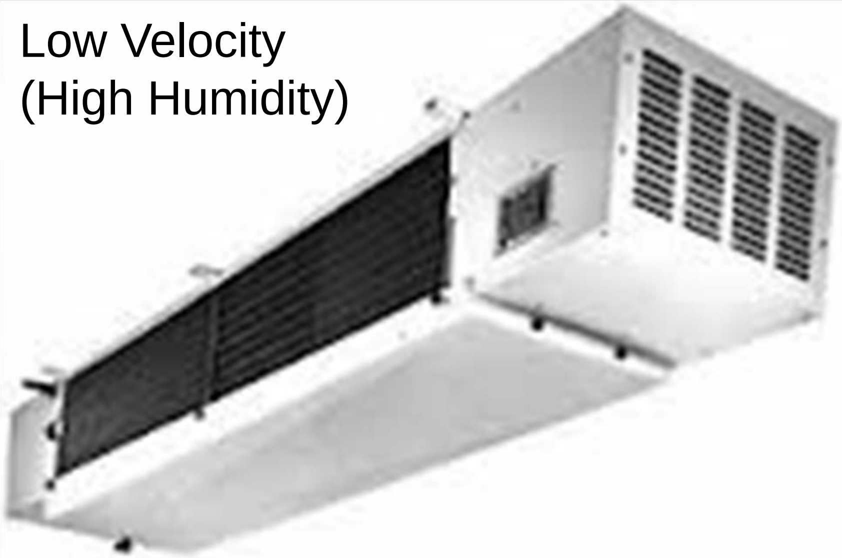


Compressor / Condenser Unit

Evaporator Options

Standard

Low Velocity
(High Humidity)



Plates

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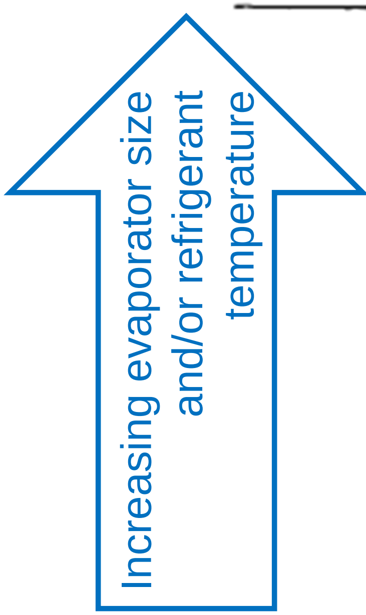
Table 3. Minimum Relative Humidity Levels[1] Developed at Various Storage and Evaporator Discharge Temperatures



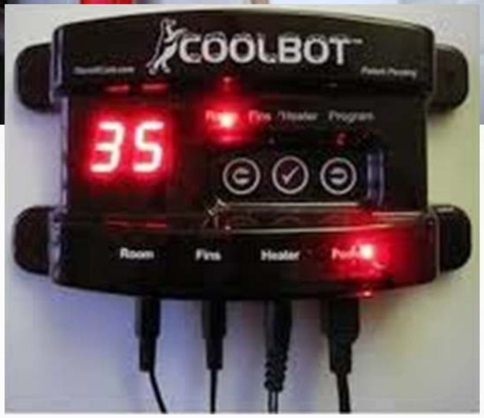
Temperature Drop[2] Across Evaporator, °F	Storeroom Temperature, °F		
	32°	35°	38°
-1°	95.8	96.1	96.1
-2°	91.2	92.3	92.4
-3°	87.1	88.7	88.8
-4°	83.0	84.7	85.3
-5°	79.4	80.9	82.0
-10°	62.7	64.1	65.3
-15°	49.3	50.5	49.4

[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.

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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)

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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

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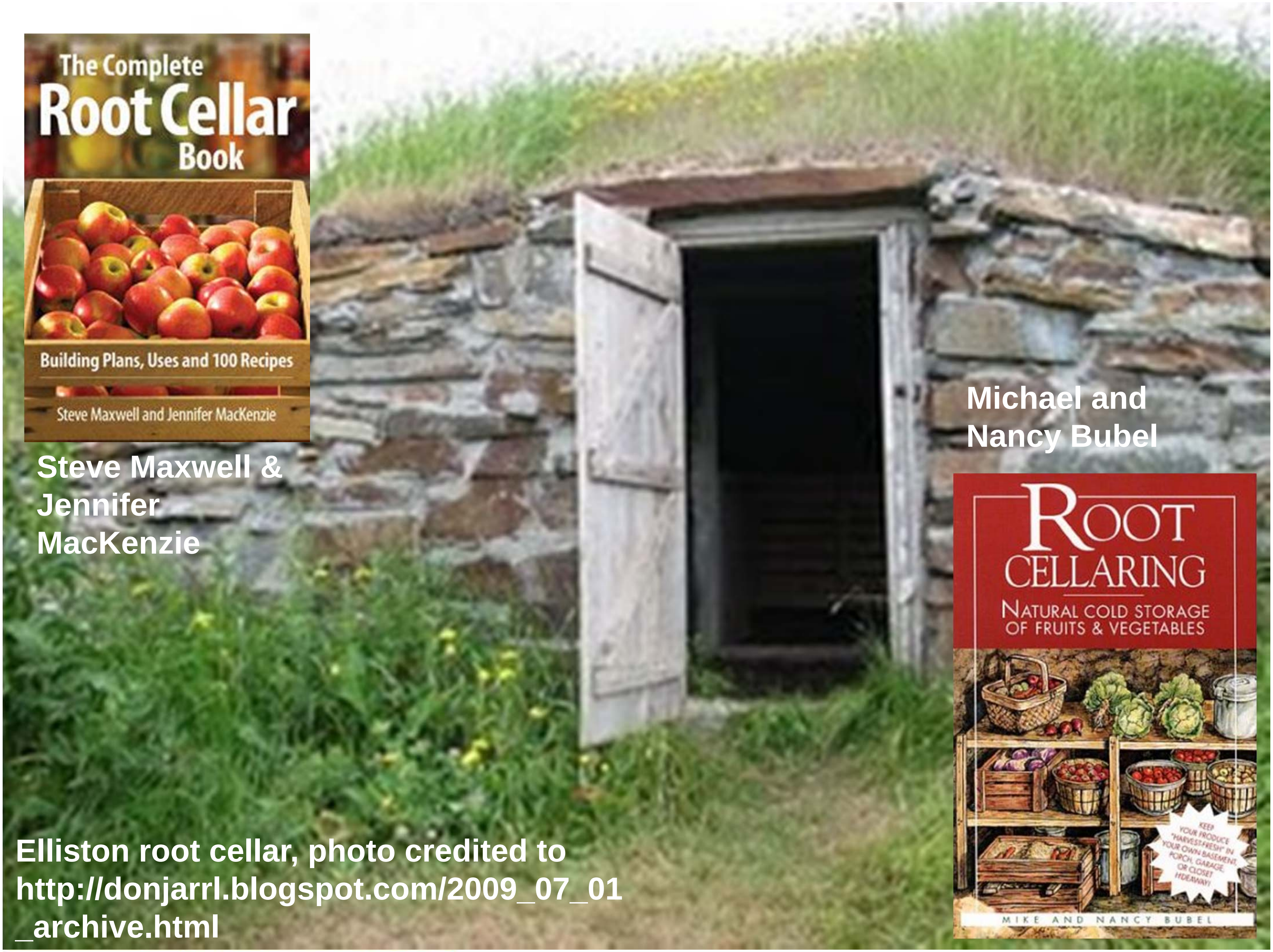

Steve Maxwell & Jennifer MacKenzie

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

- Generally required for root veg storage





Humidification

Trion Duct Humidifier
$285

Atomizing type
Auto-fill

6 gal per day

www.qasupplies.com

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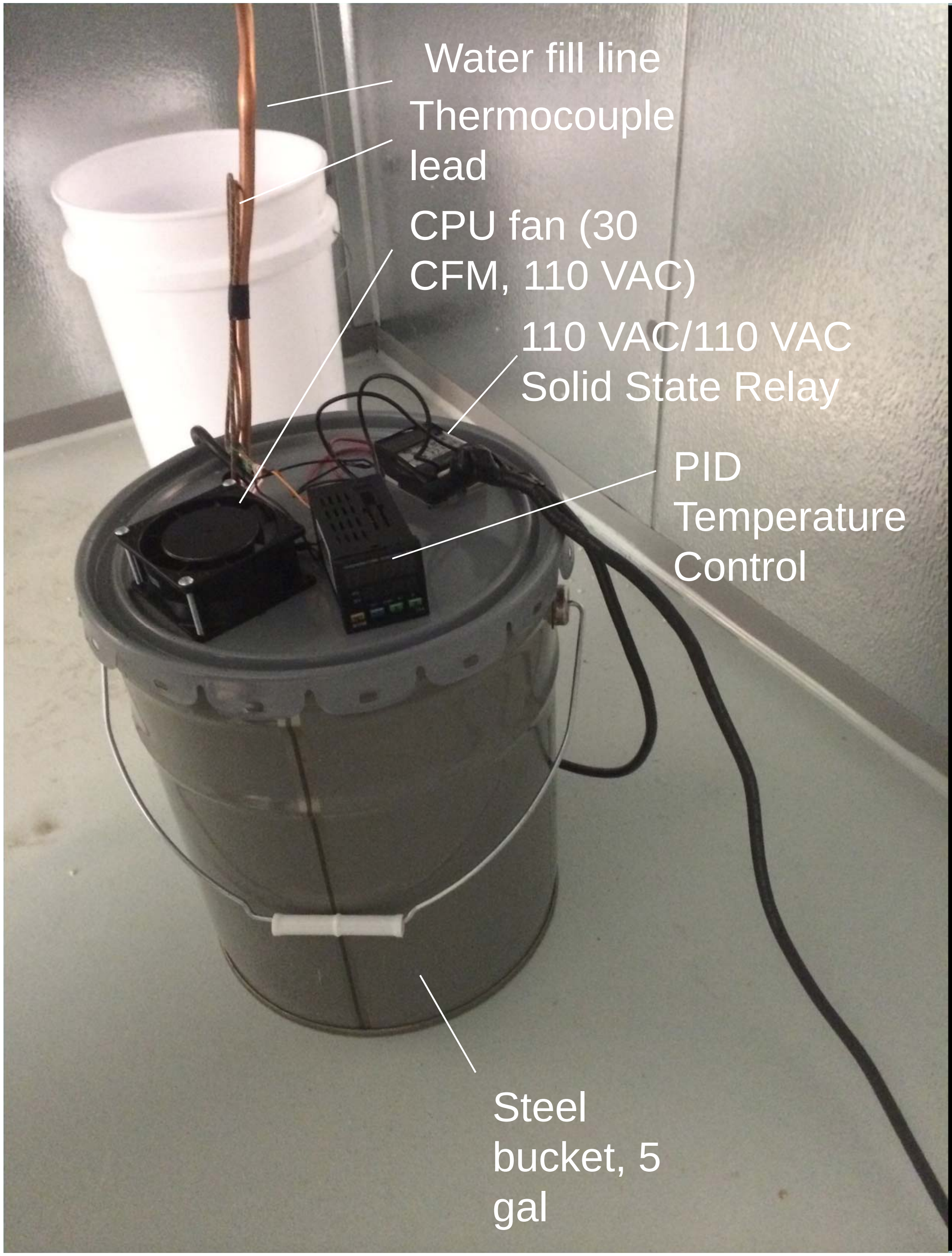

DIY Autofill Bucket Humidifier
5 gal per day at 33 F room temp
Evaporative type
Open source design
Parts ~$155

www.FarmHack.net

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


Toilet fill valve
Tank deicing heater

Humidification

Dayton – Humidifier Control 20-90%, $60

Standard room humidifier, refills are manual. $30

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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
  - Monitoring

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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.

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Controls - Humidistats

- Control a load based on measured (or calculated) RH
- Sadly, selection is lacking. Especially for cold room conditions.
- Motivated development of the new RH sensor.

Controls – Expandable Systems

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

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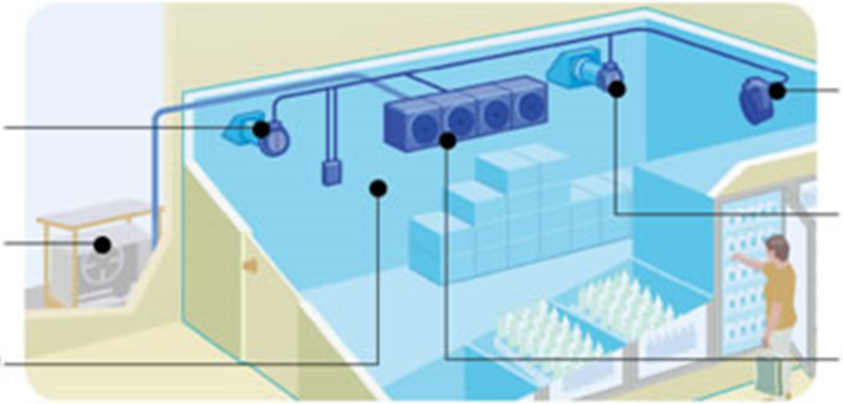
Ventilation & Airflow

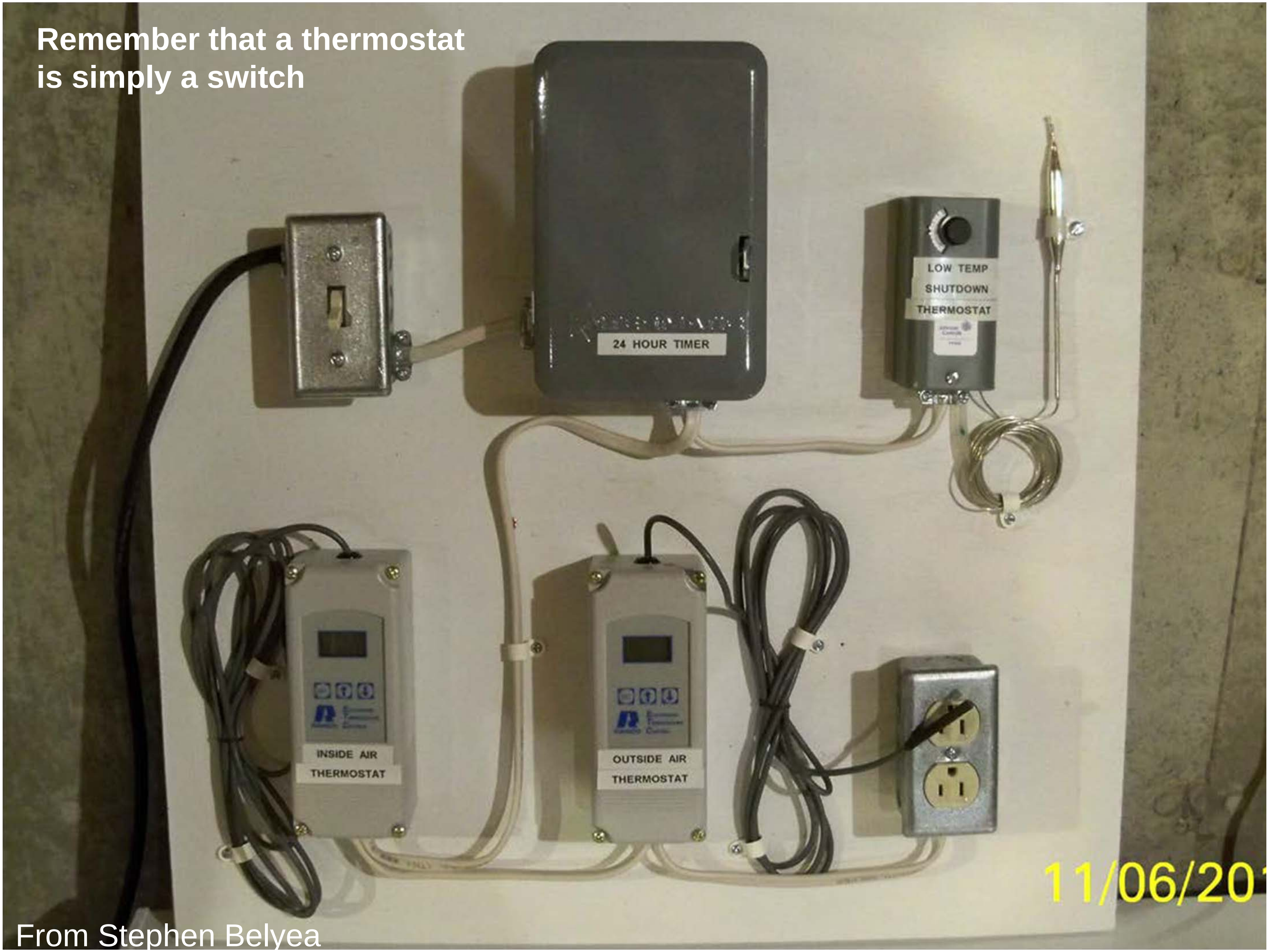
- Seeking to have a well mixed storage space.
- Avoid hot spots
- Avoid high moisture & avoid over drying
- Strip ethylene.
- 3-5 volume changes per day is rule of thumb.
- Higher for curing or pre-cooling.

Controls - FreeAire™

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



Remember that a thermostat is simply a switch



From Stephen Belyea

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

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  - Ventilation & Air Flow
  - Humidification & Drying
  - Controls
  - 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

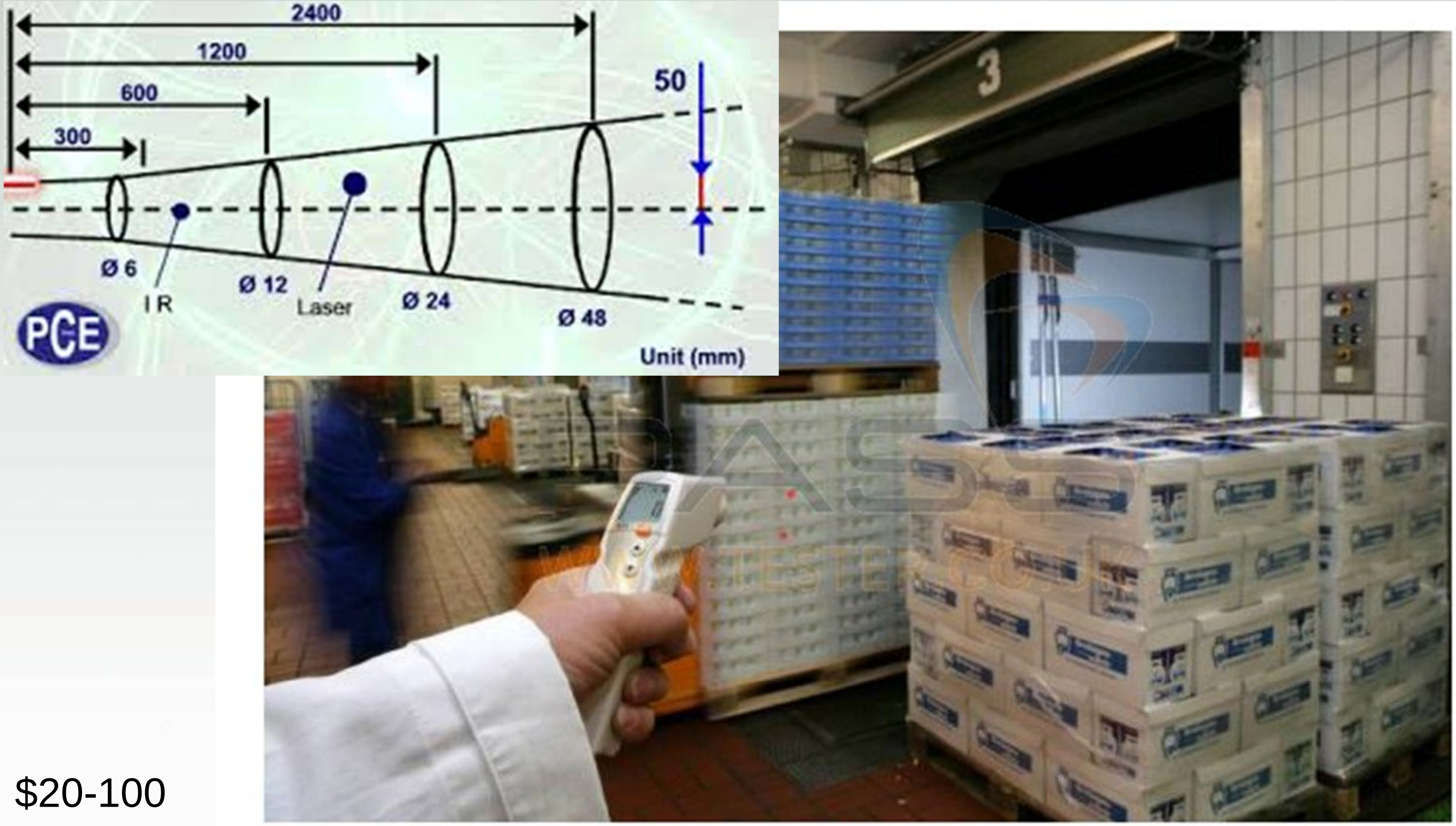
5 minute readings = 56 days storage
1 minute readings = 11 days storage
Download data to computer

$125 (RH +/-2%)

$99 (RH +/-3%)

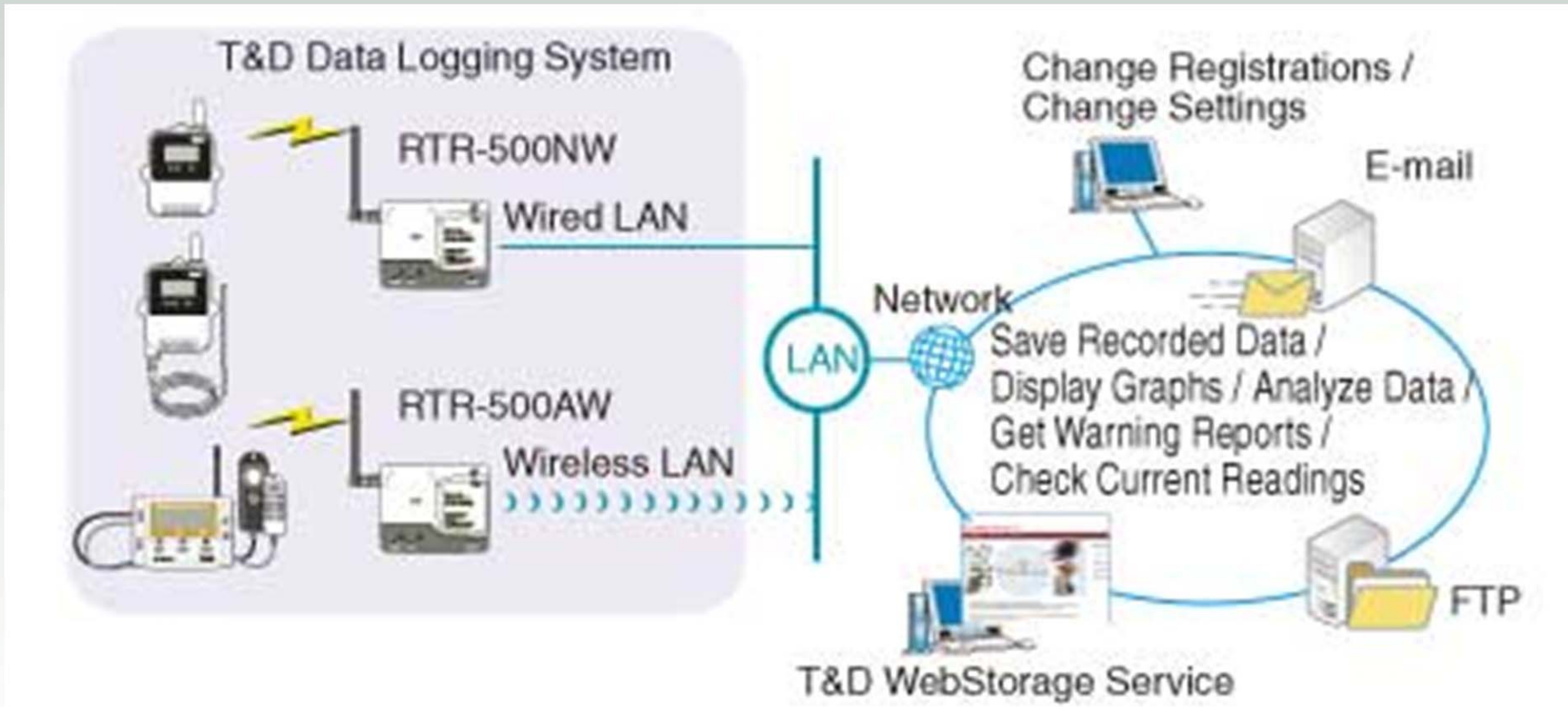
$82 (RH +/-3%)

Infrared Thermometer



$20-100

Remote Monitoring



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Remote Monitoring

- $400-$2000 for a typical install.

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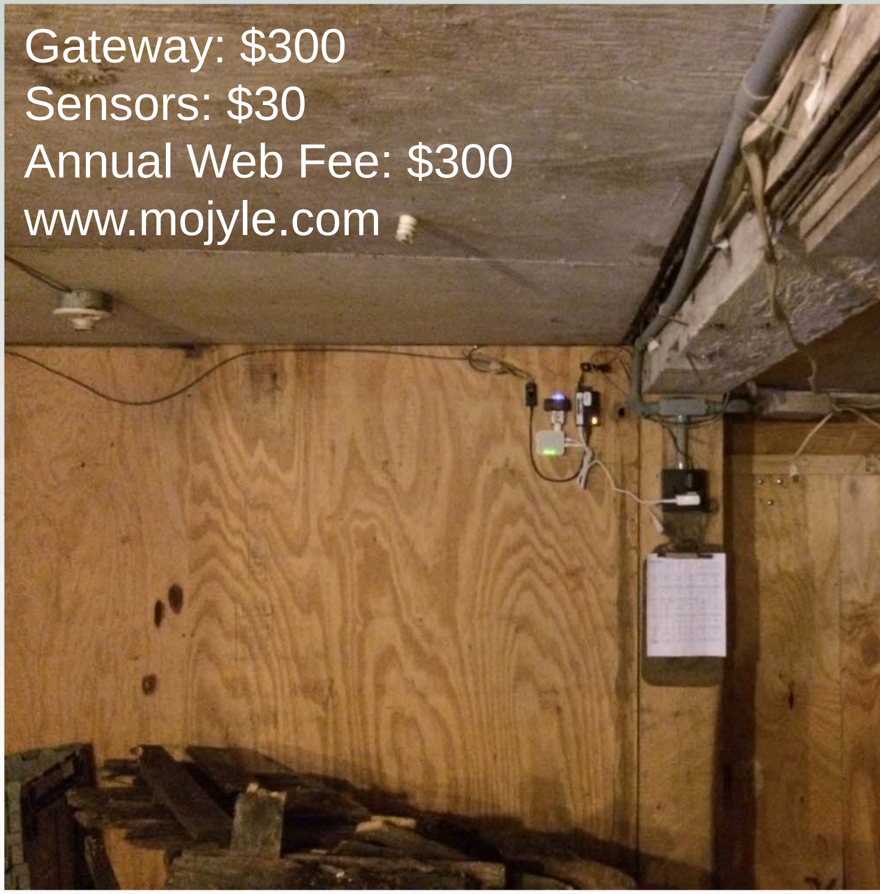
Sensaphone

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

http://www.sensaphone.com/

Mojyle

Gateway: $300
Sensors: $30
Annual Web Fee: $300
www.mojyle.com

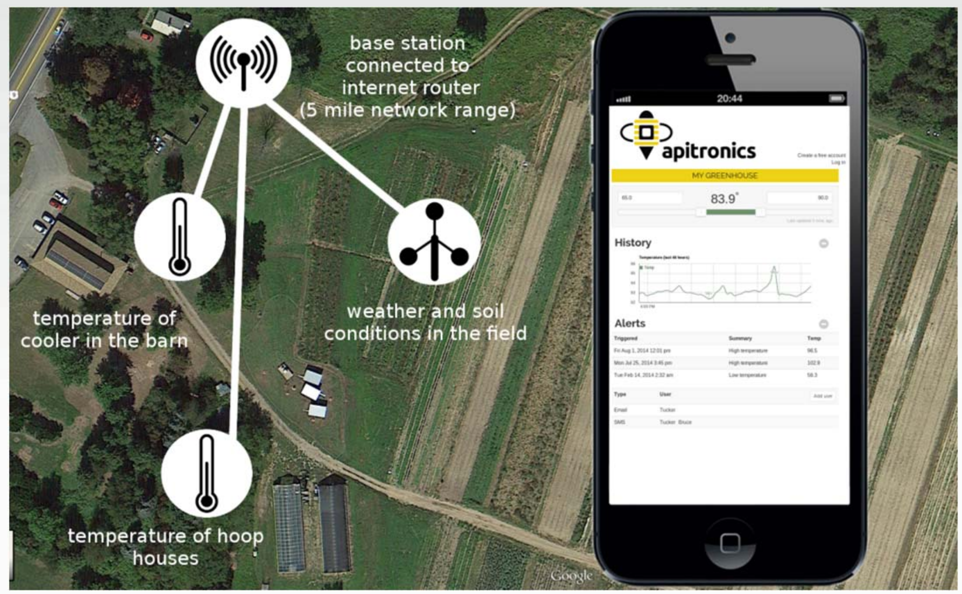


Apitronics

Base (Hive): $111
Sensors (Bees): $205-240

All wireless

www.apitronics.com



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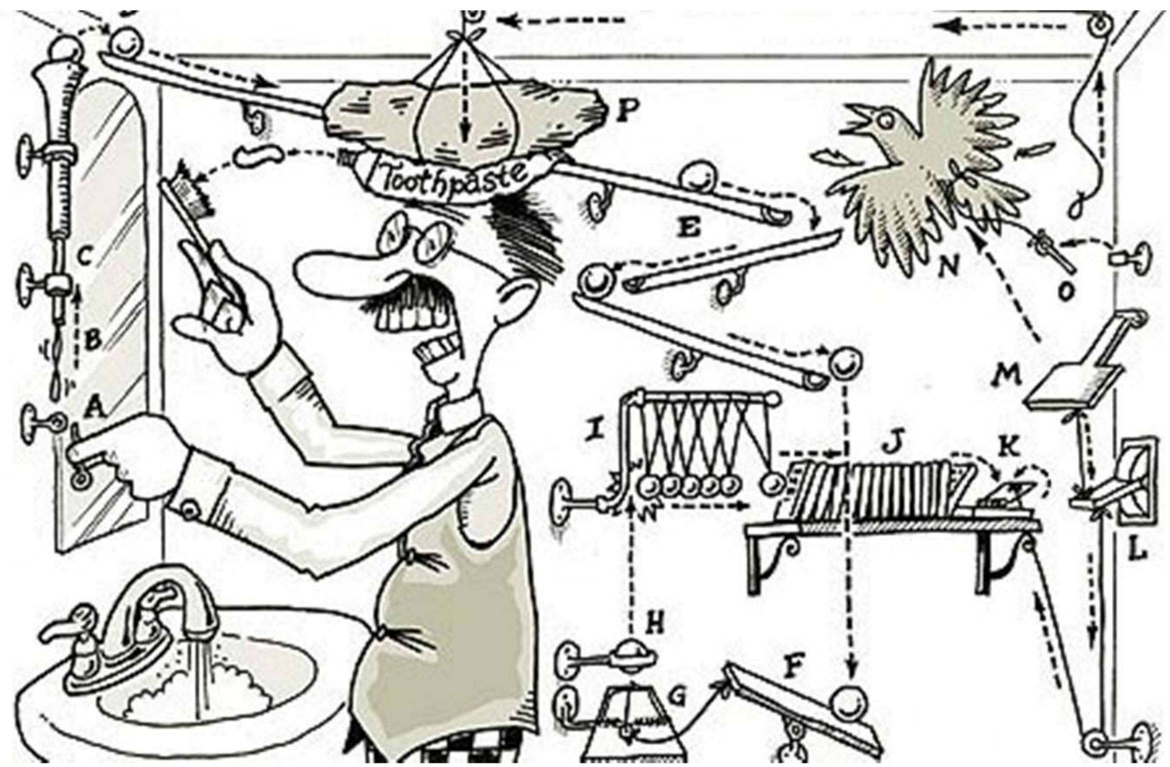
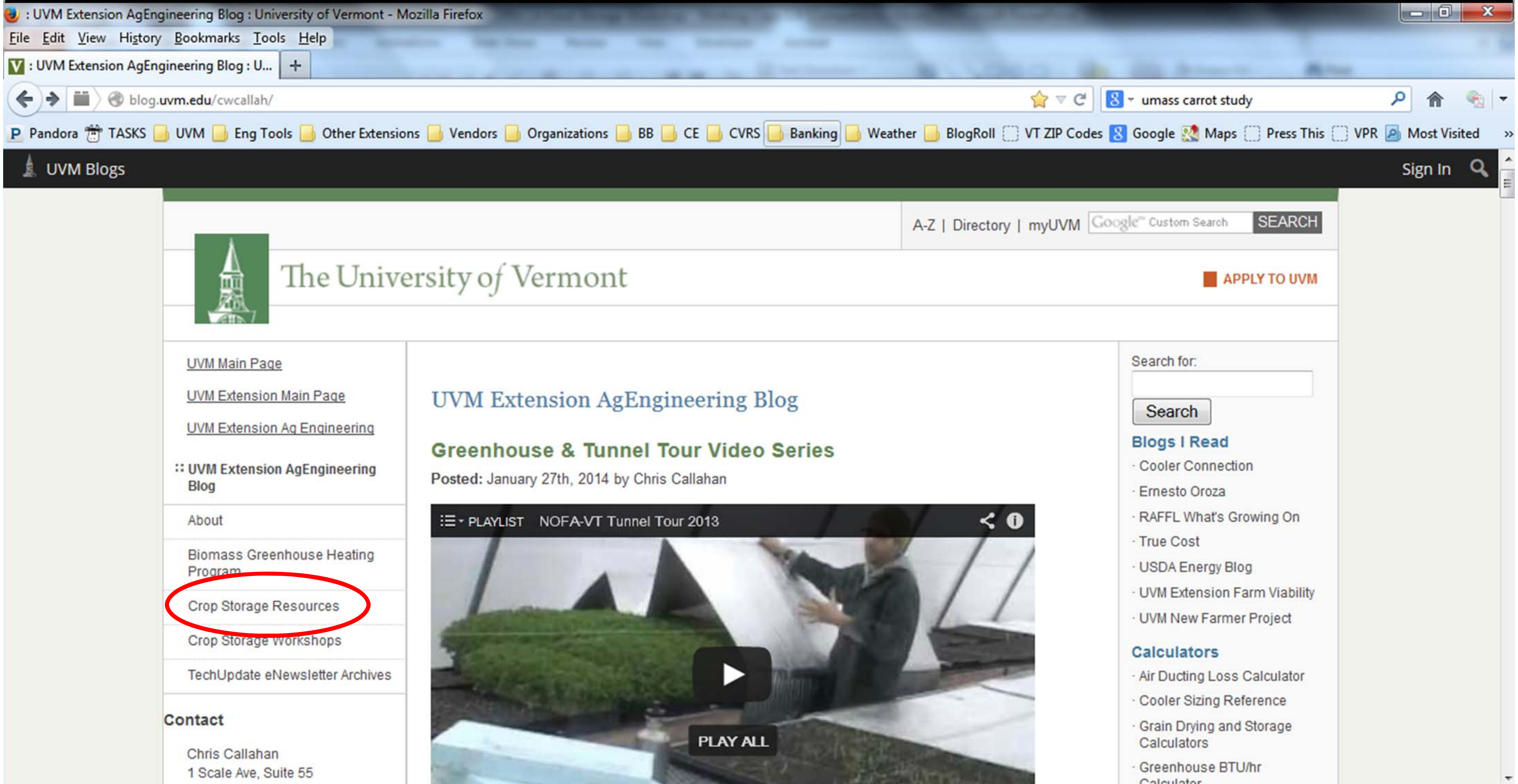
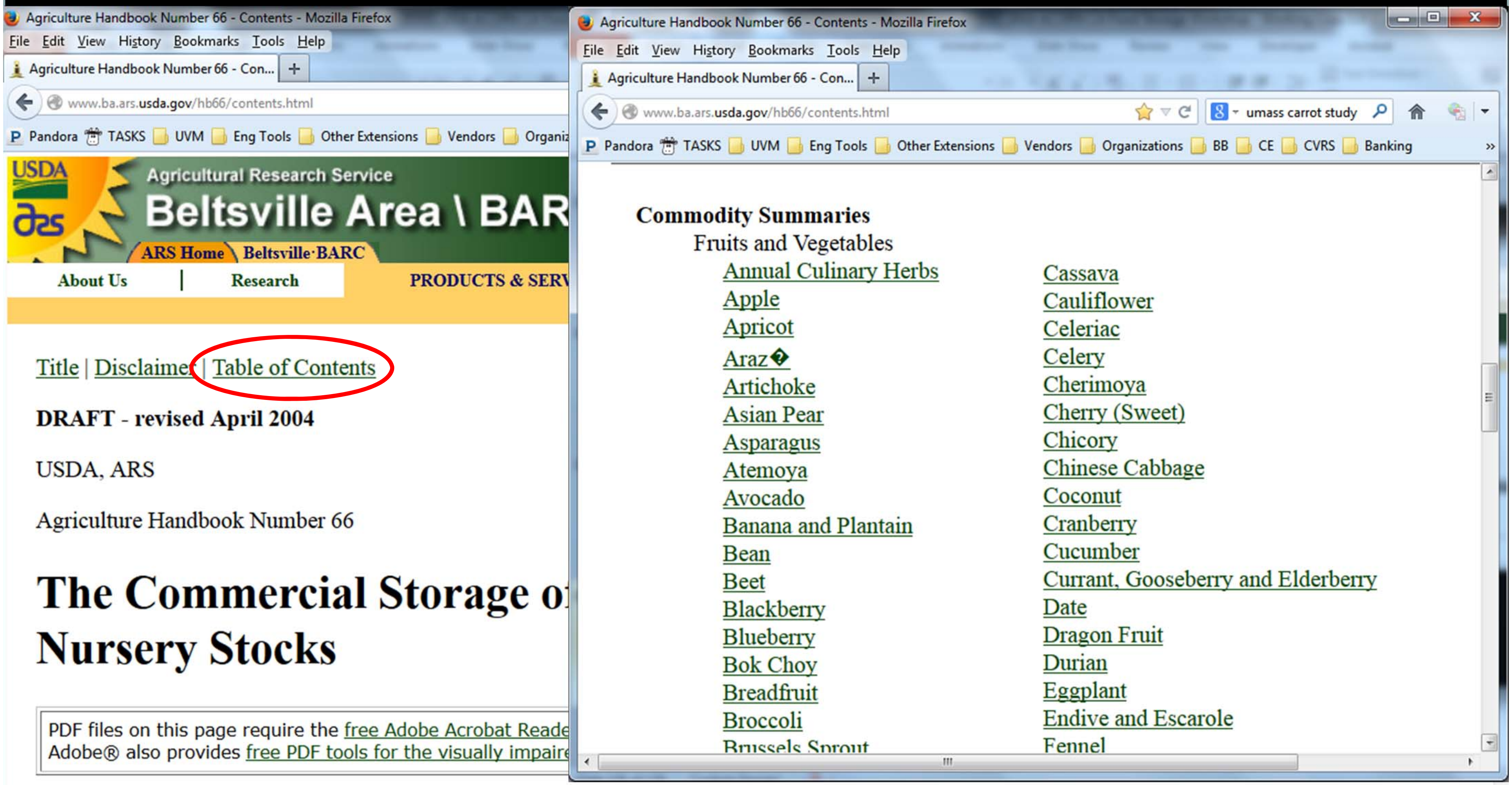
“The **perfect** is the **enemy** of the **good**.”

- Voltaire





blog.uvm.edu/cwcallah/



www.ba.ars.usda.gov/hb66/

postharvest.ucdavis.edu