Part 2: A Year of Operation, Data & Growing in a Solar Greenhouse

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Wayward Springs

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Outline

Part 1:

1. About me, my farm and my research project
2. What are passive solar greenhouses?
3. Fully passive systems
4. Mostly passive systems

Part 2:

1. Details of my prototype & analysis
2. A review of 2020 performance data
3. Analysis & resulting design guidelines
4. Some of the stuff we are/have grown

About my research project

Objective:

Produce data regarding design trade-offs of passive solar greenhouses features as well as demonstration of a selected design.

Motivation:

Cold northern climates prevent year-round crop production and make greenhouses too costly for tropical produce. This results in long distance shipping of fruits and vegetables from central America and prevents many types of delicate produce from being available in local markets.

FNC19-1185
High Efficiency Year-Round Tropical Greenhouse

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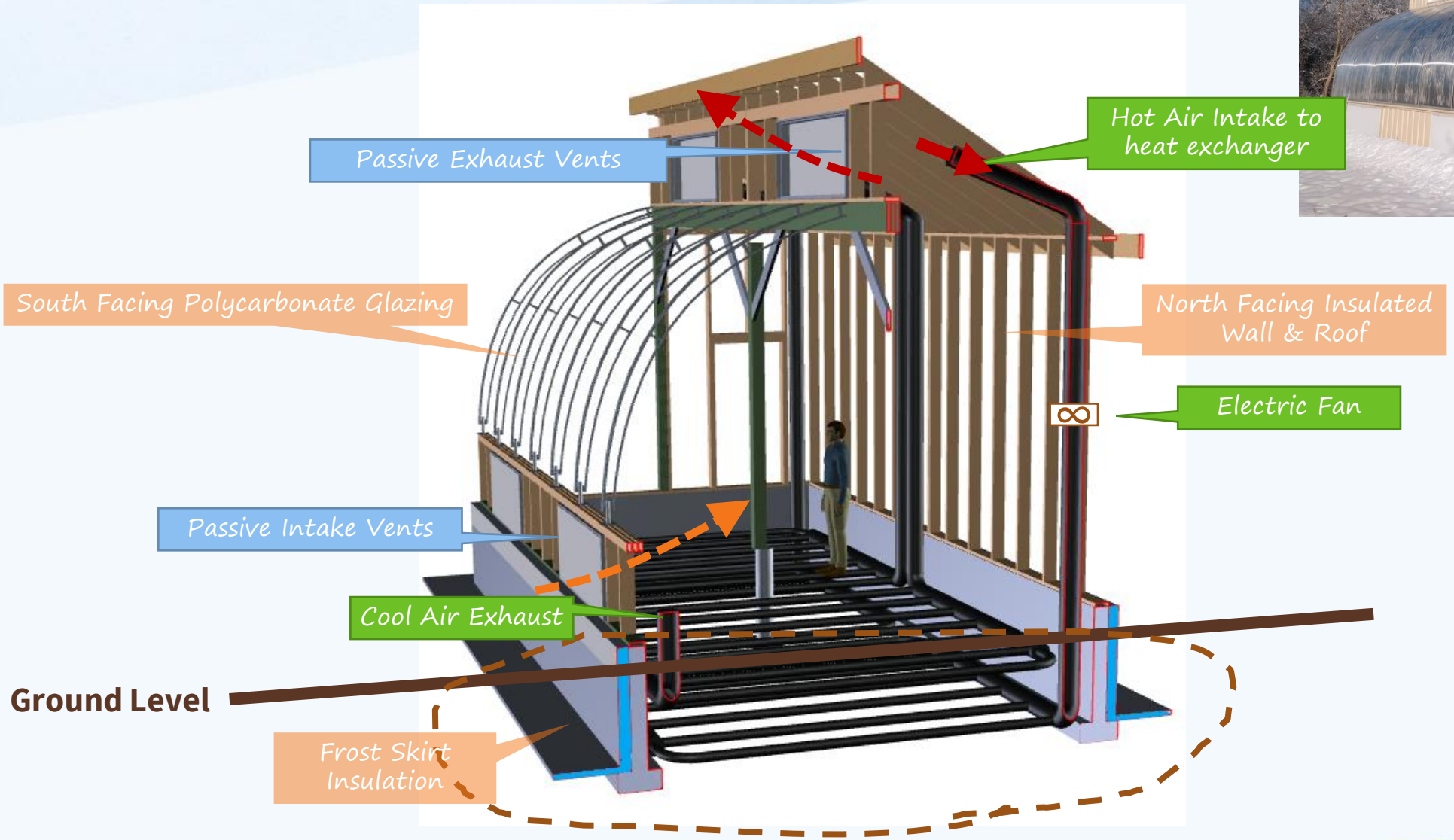
Prototype Details

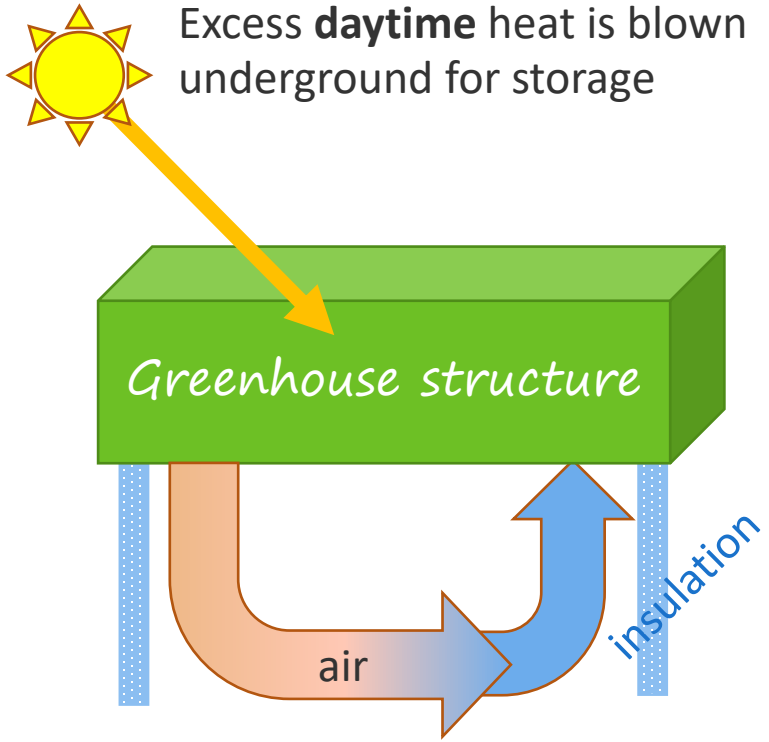
My Prototype Structure



Climate Battery

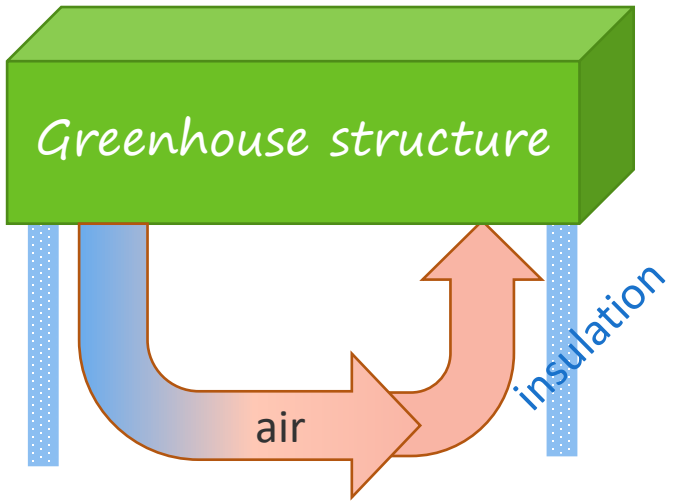
Climate/Earth Battery Function

1. Excess **daytime** heat is blown underground for storage

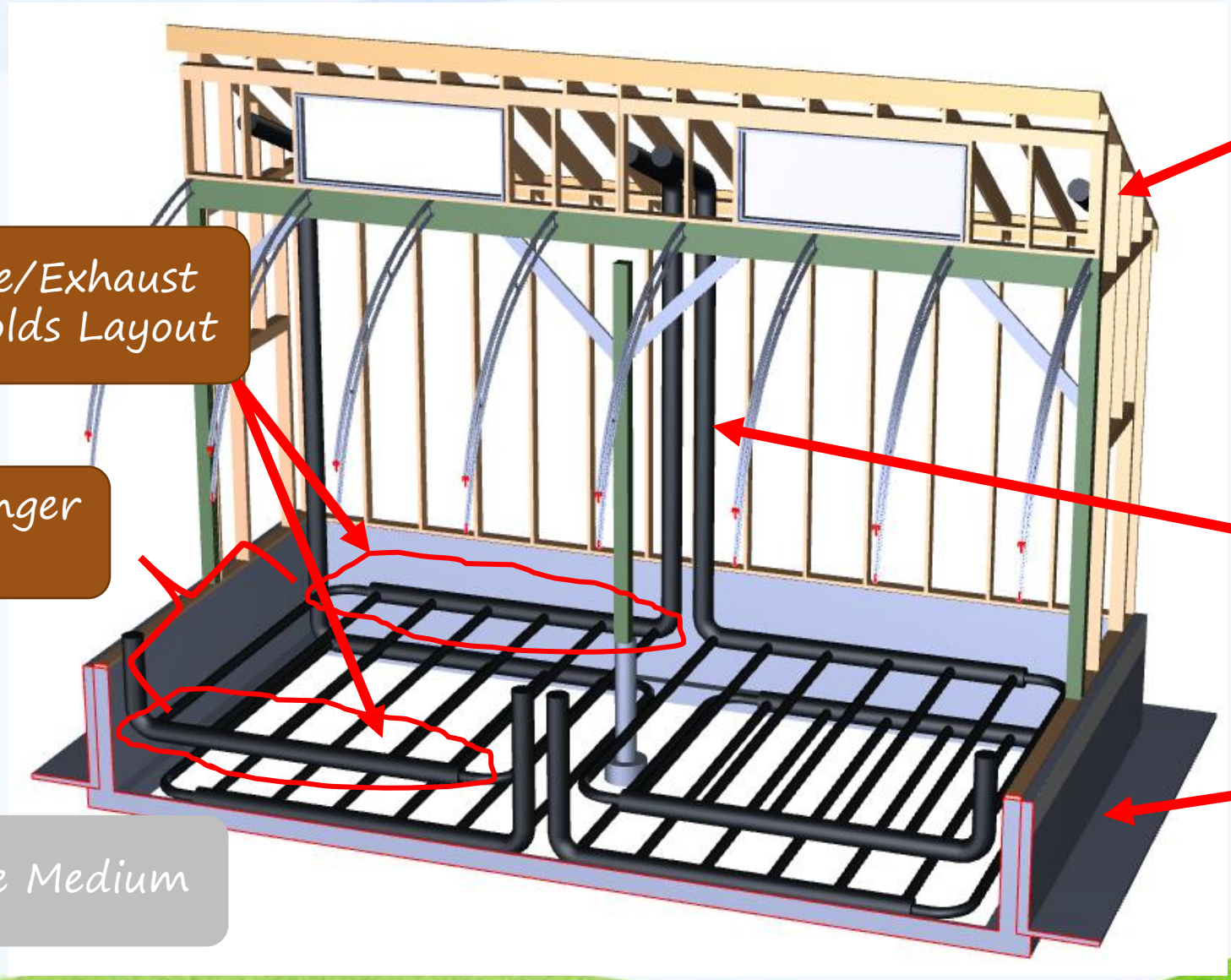


*climate batteries also provides a significant amount of cooling.

2. Stored heat is used at night and cloudy days



Elements of a Climate Battery



Intake Placement

Intake/Exhaust Manifolds Layout

Thermostats /Controls

Heat Exchanger Tubes

Fans/Blowers

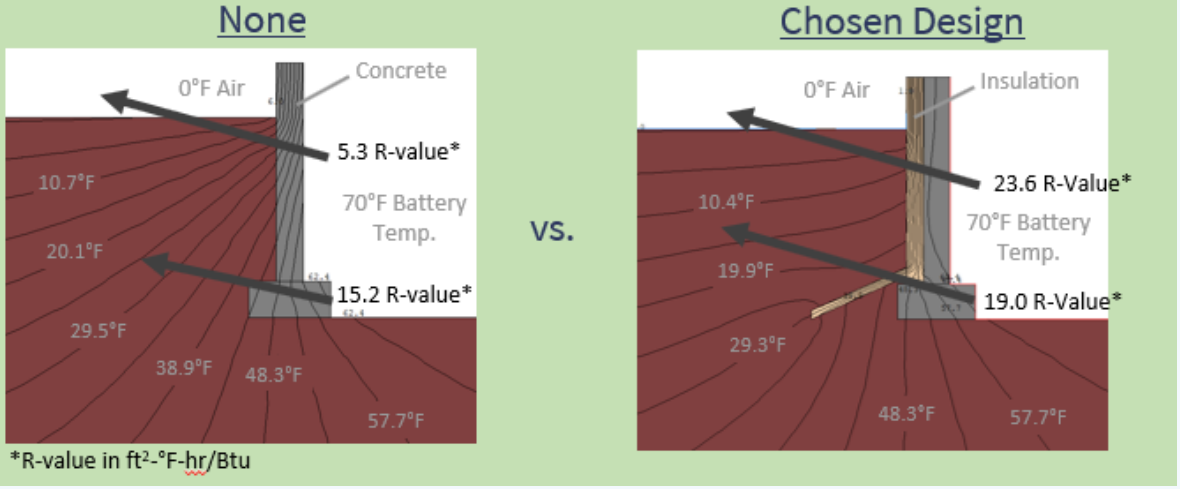
*Fans & tube #/length need to be sized together

Battery Insulation

Storage Medium

Battery Insulation System

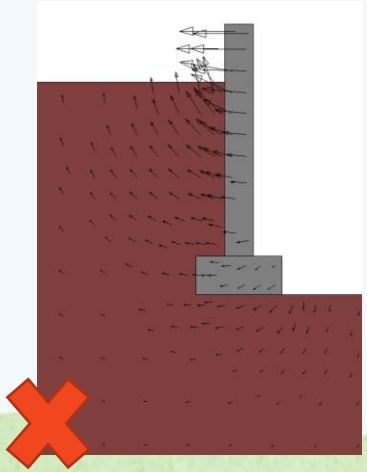
Compared heat loss rate through 6 different insulation methods.



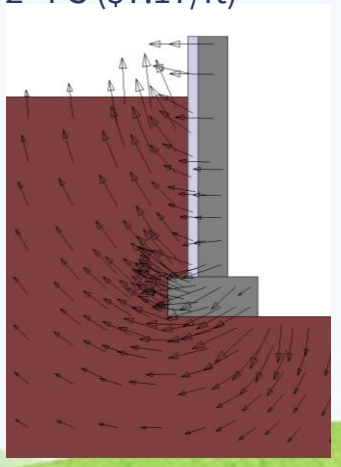
*R-value in ft²-°F-hr/Btu

Polystyrene Foamboard

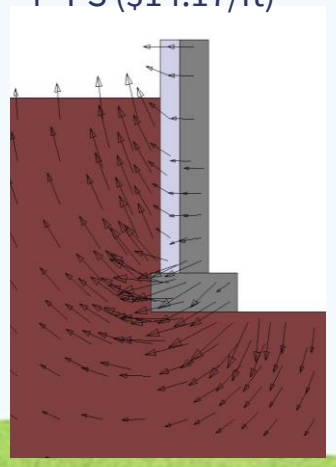
None ($0/ft)



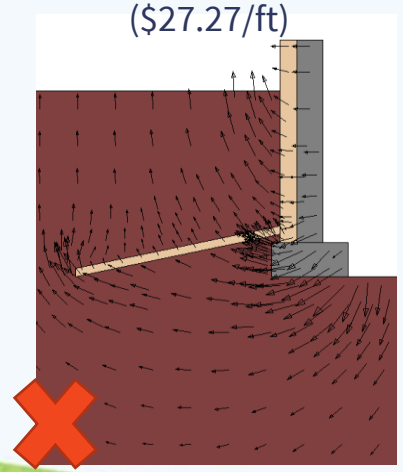
2” PS ($7.17/ft)



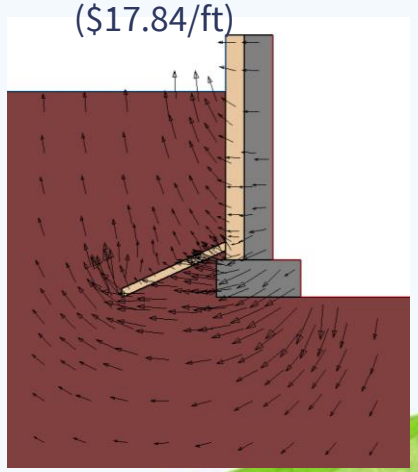
4” PS ($14.17/ft)



4” PS & 4ft of 2” Skirt ($27.27/ft)



4” PS & 2ft of 2” Skirt ($17.84/ft)



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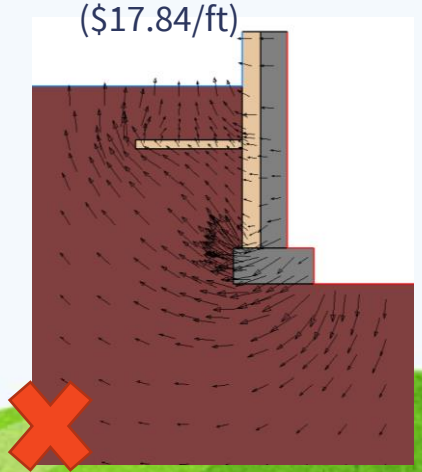
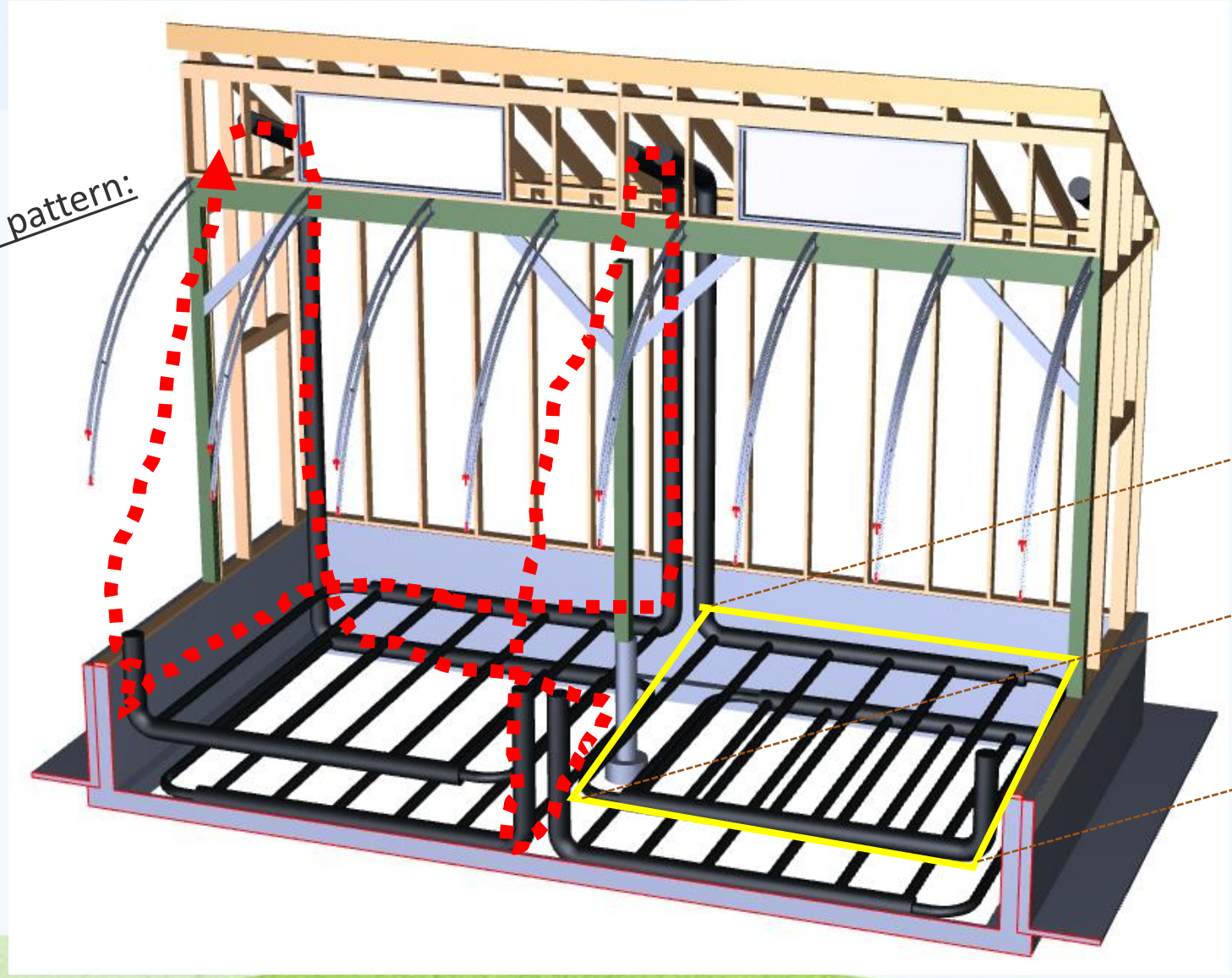


* Concrete foundation is NOT required. See UMN Farmscale Design guide for good alternatives

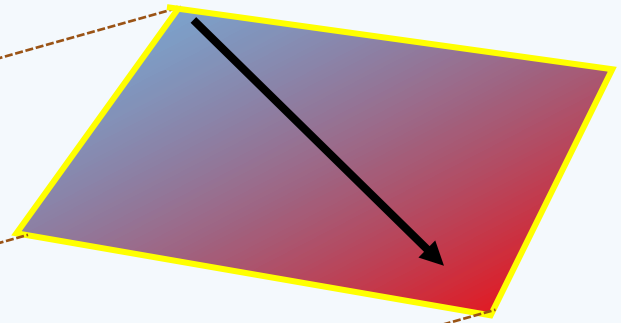
Manifold Layout

Airflow pattern:

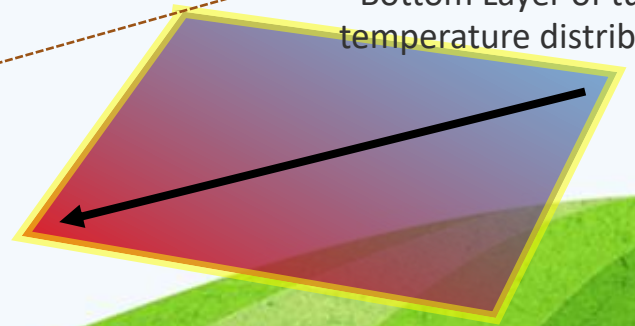


<u>During heat withdrawal periods:</u>

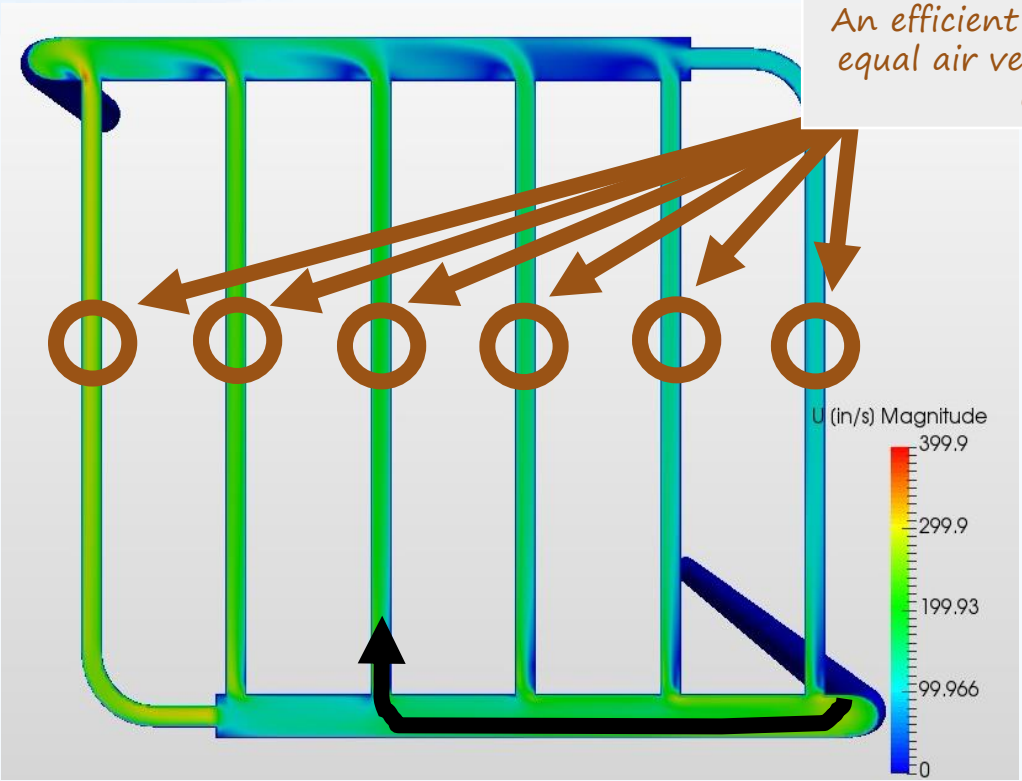
Top Layer of tubes
temperature distribution



Bottom Layer of tubes
temperature distribution



Heat Exchanger Layout



An efficient design will have near equal air velocity (color) through each tube.

Other simulations were used to determine:

- the heat transfer rates from tubes to the soil storage system
- the pressure drop curves to help select the right size fans
- the heat loss rates through the building structure

Bottom layer of heat exchanger tubes

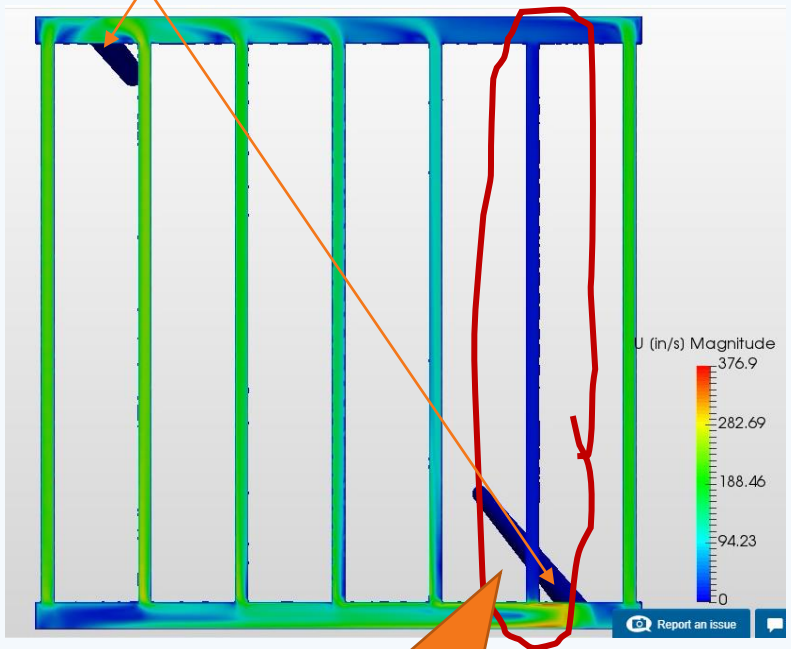
Wayward Springs Acres, Aurora SD

My Prototype System

Heat Exchanger tube layout

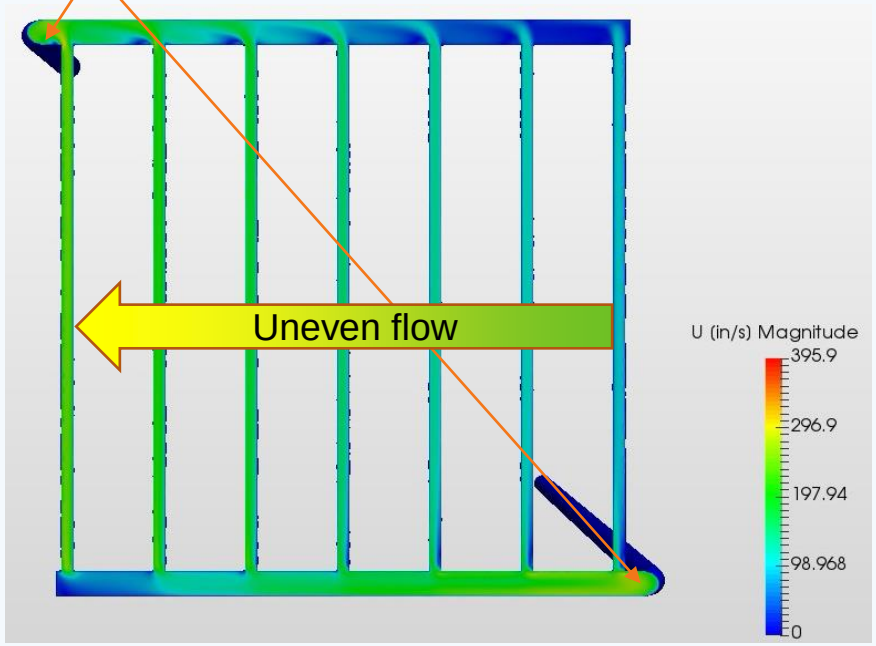
Colors show the speed/velocity of the air. Equal velocity through all cross tubes is desirable.

T-tube supply/return joint

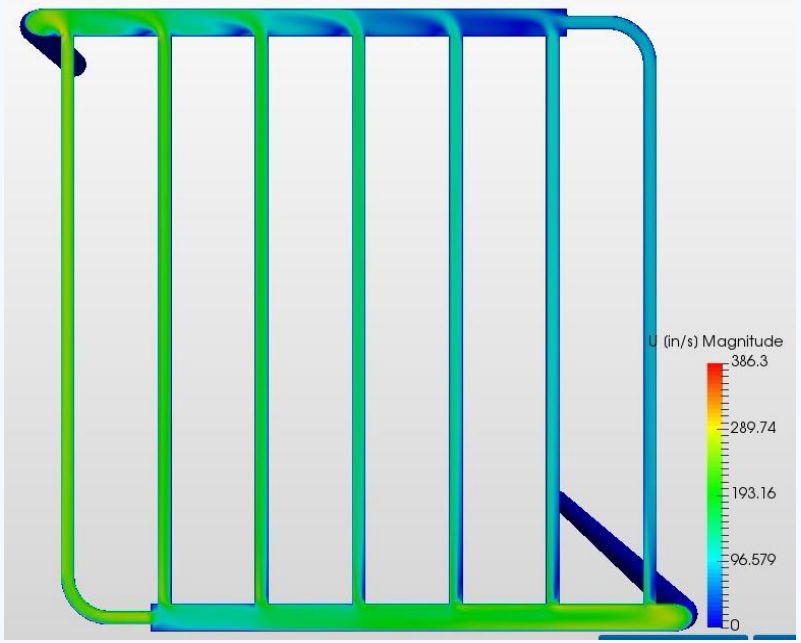


Tube near intake is starved of flow

90° Elbow



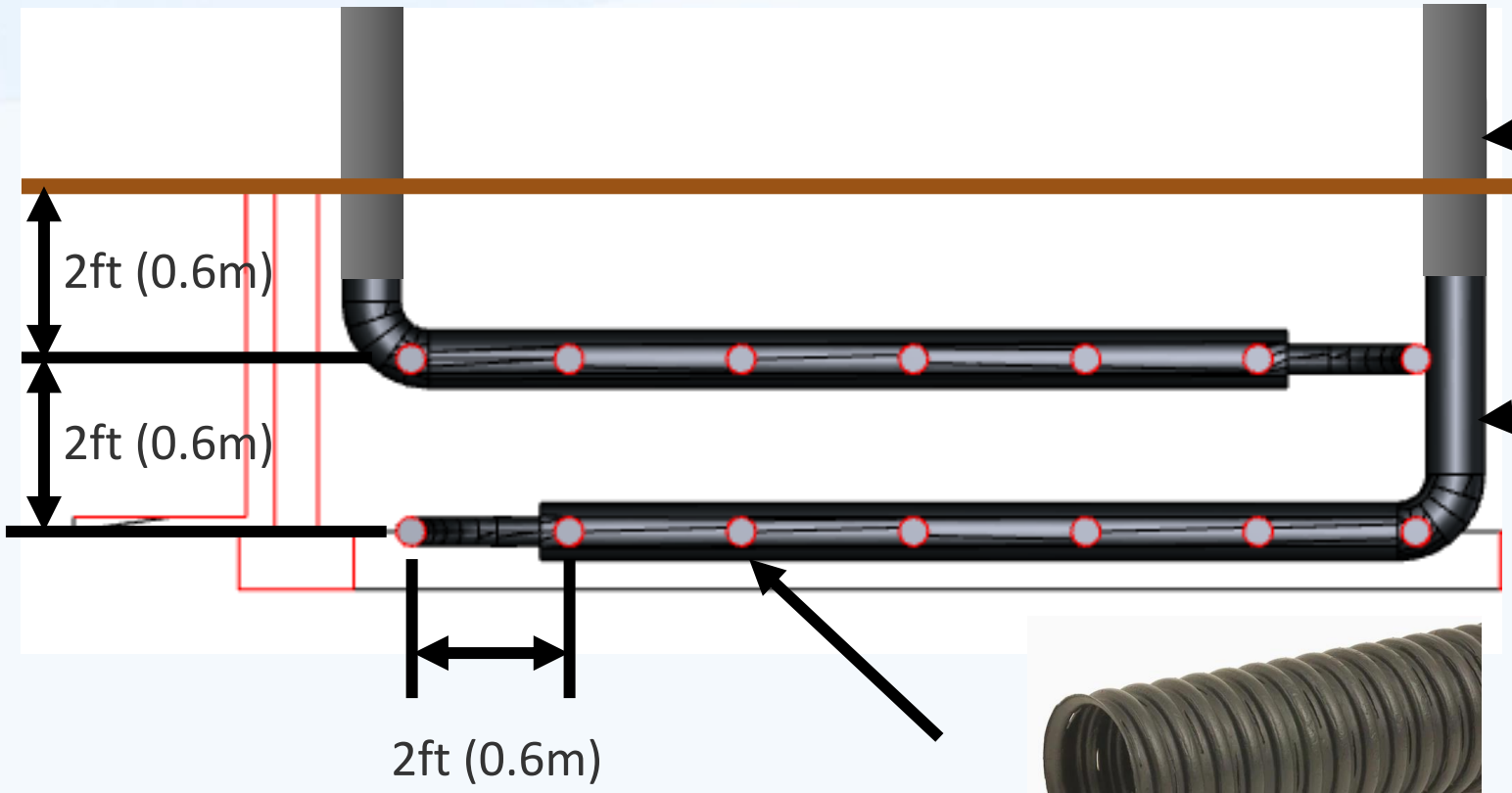
Reasonably even flow, but could be better



Most even flow possible without extra cost.

Heat Exchanger tubes

This is what I built as a reasonable “estimate”



4” Corrugated Perforated Pipe

What is the best tube spacing?

- Closer spacing will increase the speed that the battery will “charge/discharge”.
- But it displaces more of the storage medium (soil).

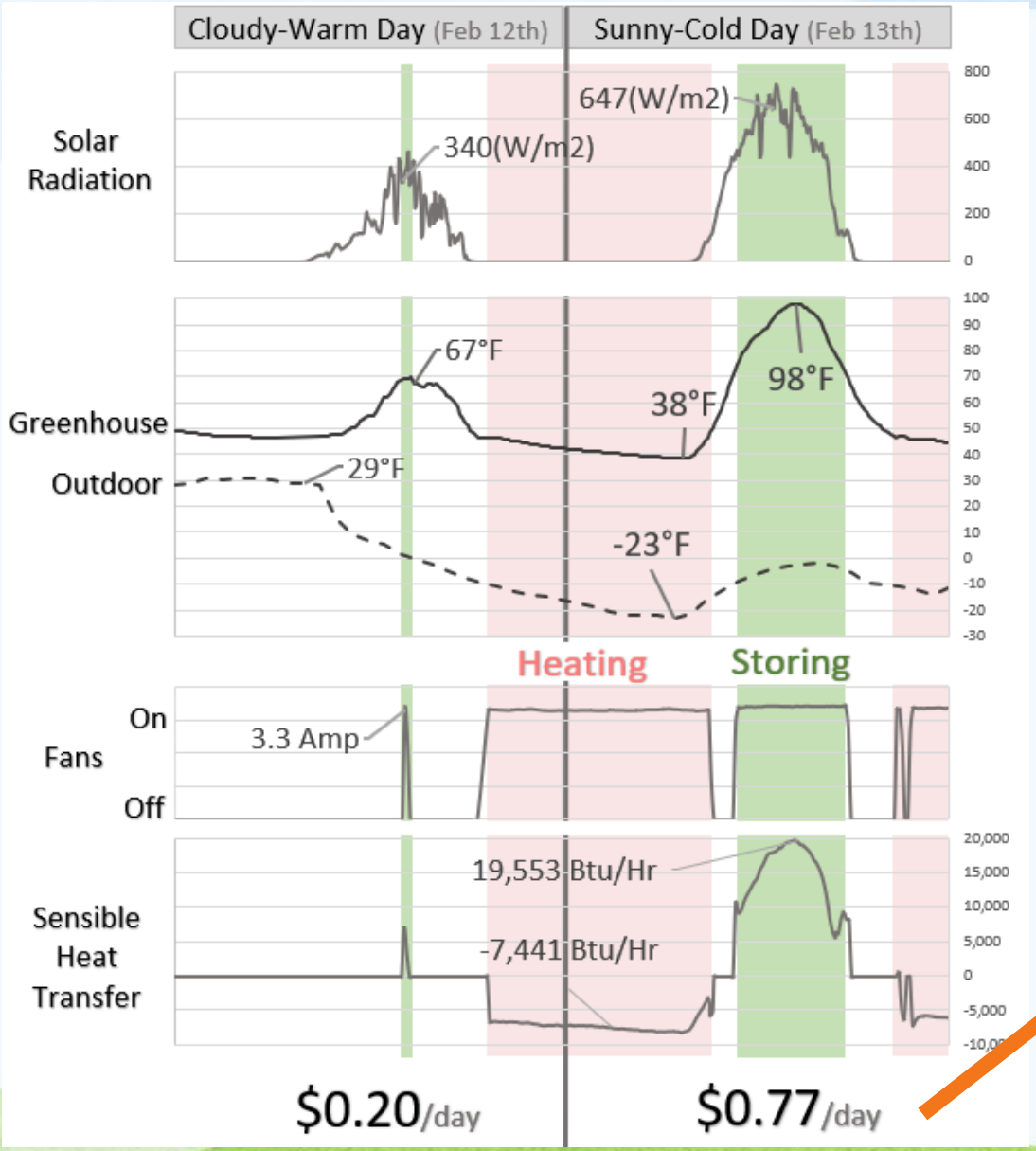
Heat Exchanger

Bottom 4ft(1.2m) deep layer of tubes

Upper 2ft (0.6m) deep layer of tubes

2020 performance data

Daily Performance Example (Feb. 2020)

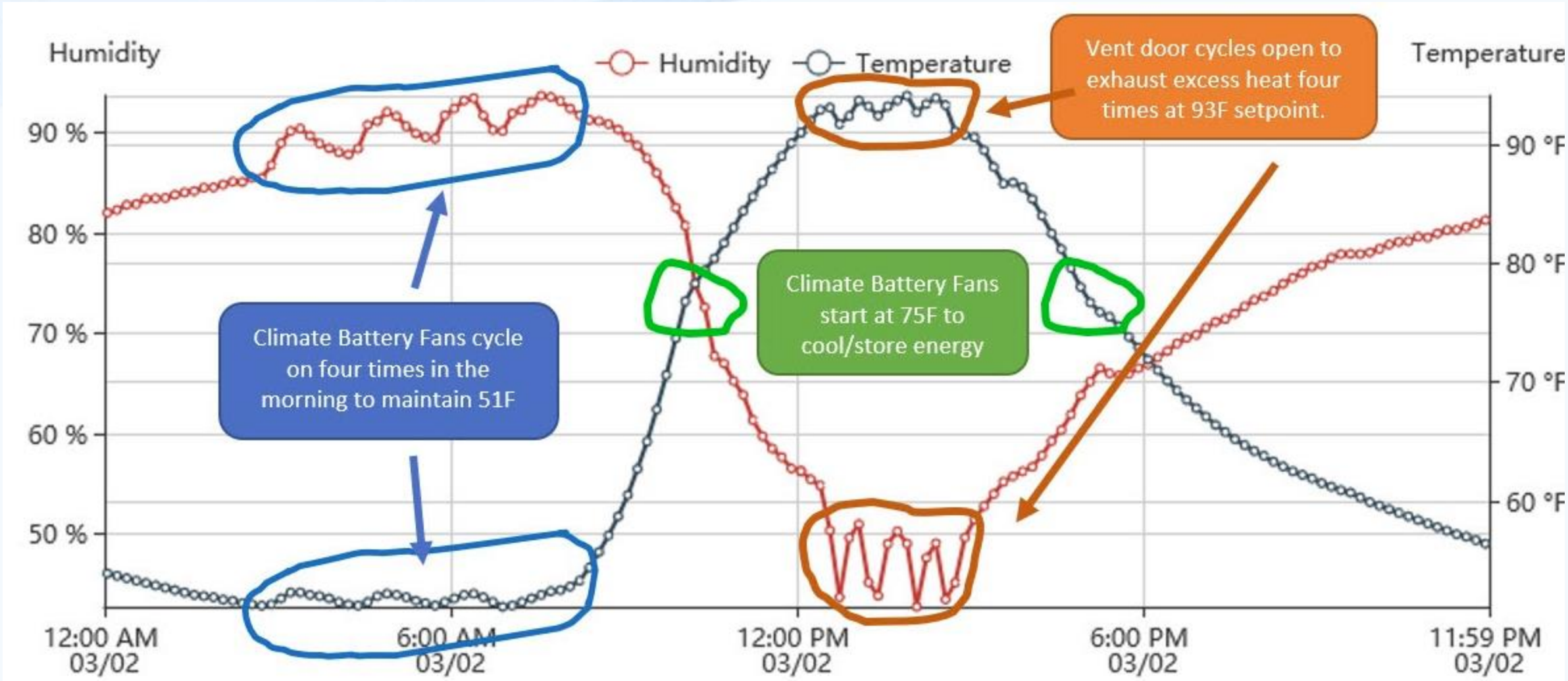


Traditional Greenhouse cost would be:

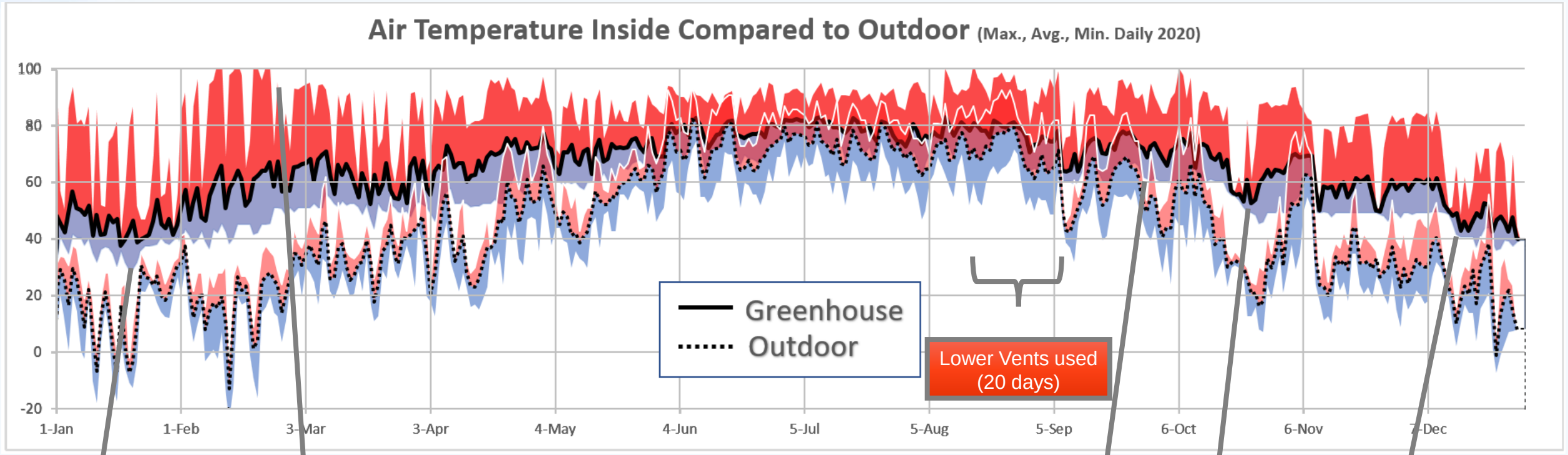
$5.40/day to propane heat an equal **glass or 6mil polyethylene** structure

$2.11/day to propane heat an equal **triple-wall polycarbonate** structure

Daily view: March 2nd 2020



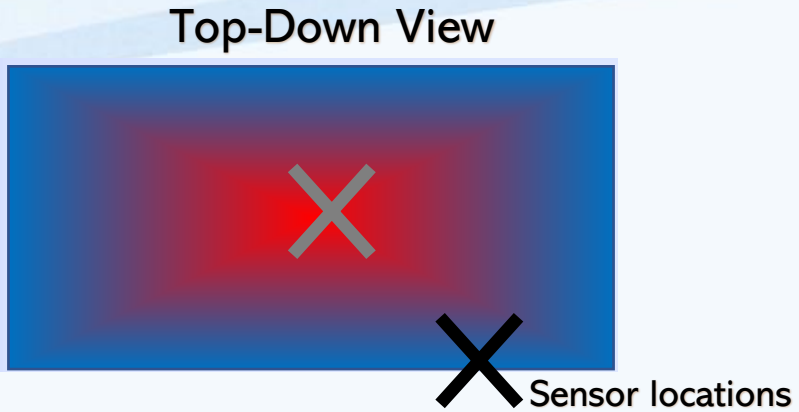
2020 in Review

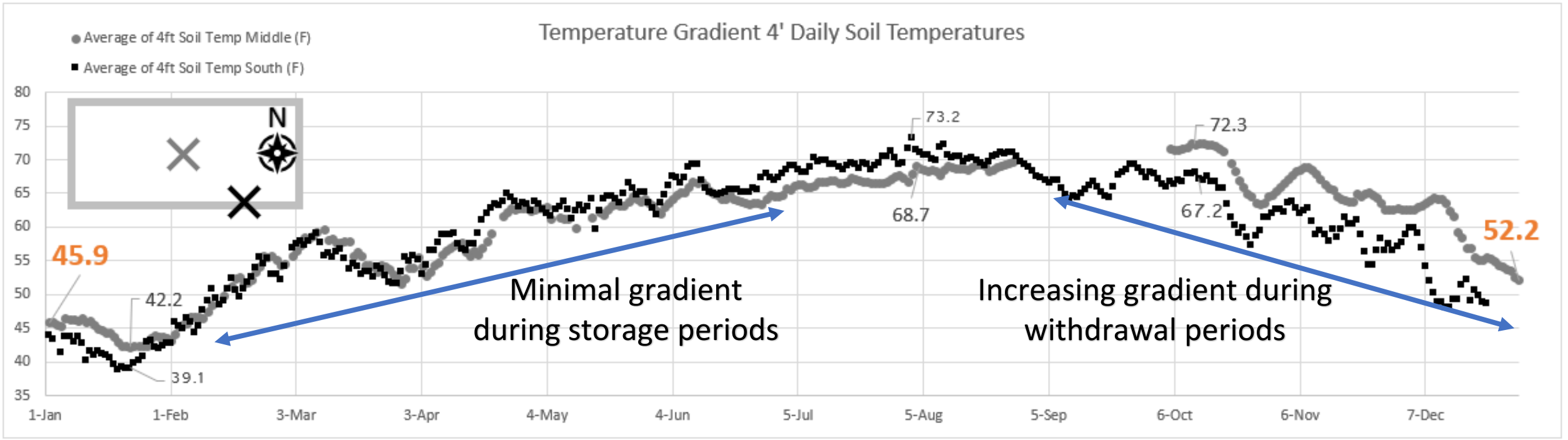


Only operating cost is electricity for fans: Total was $131 or $0.29/sqft

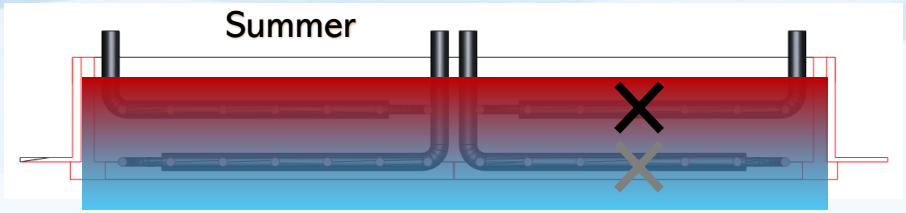
Horizontal Soil/Thermal Battery Temperature

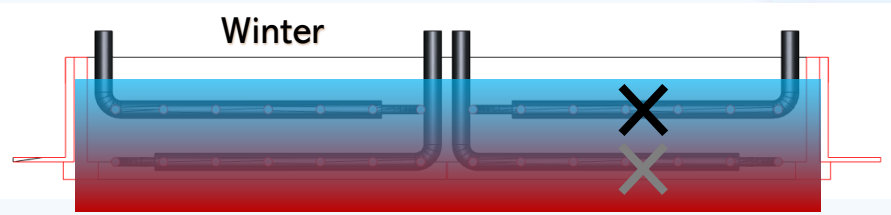
The temperature distribution should on average look like this:

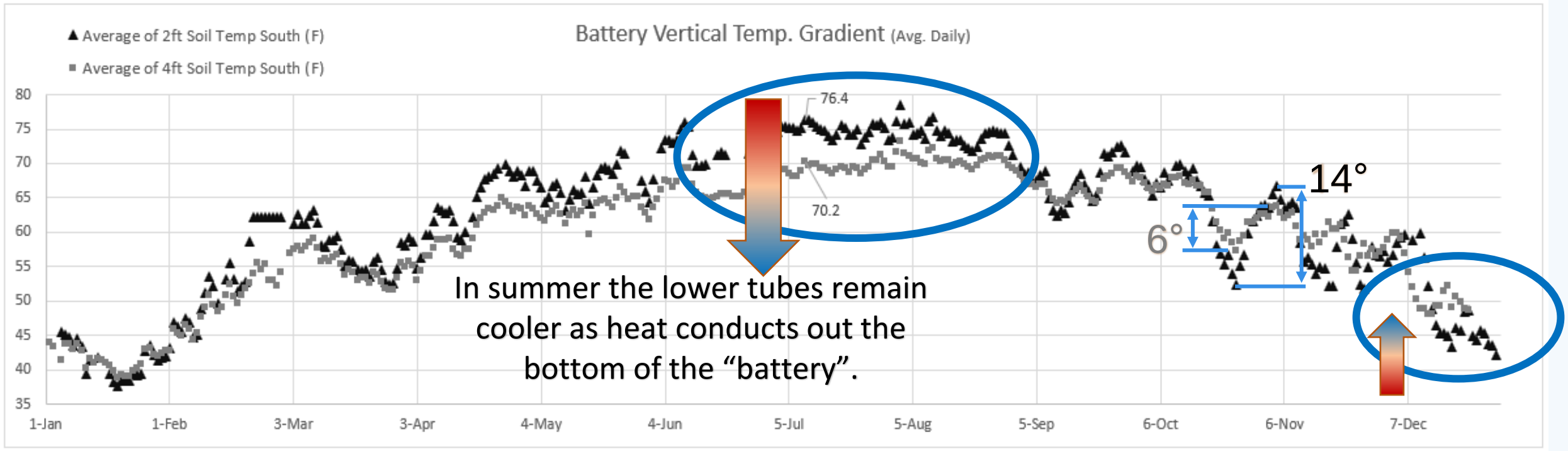




Vertical Soil/Battery Thermal Temperature







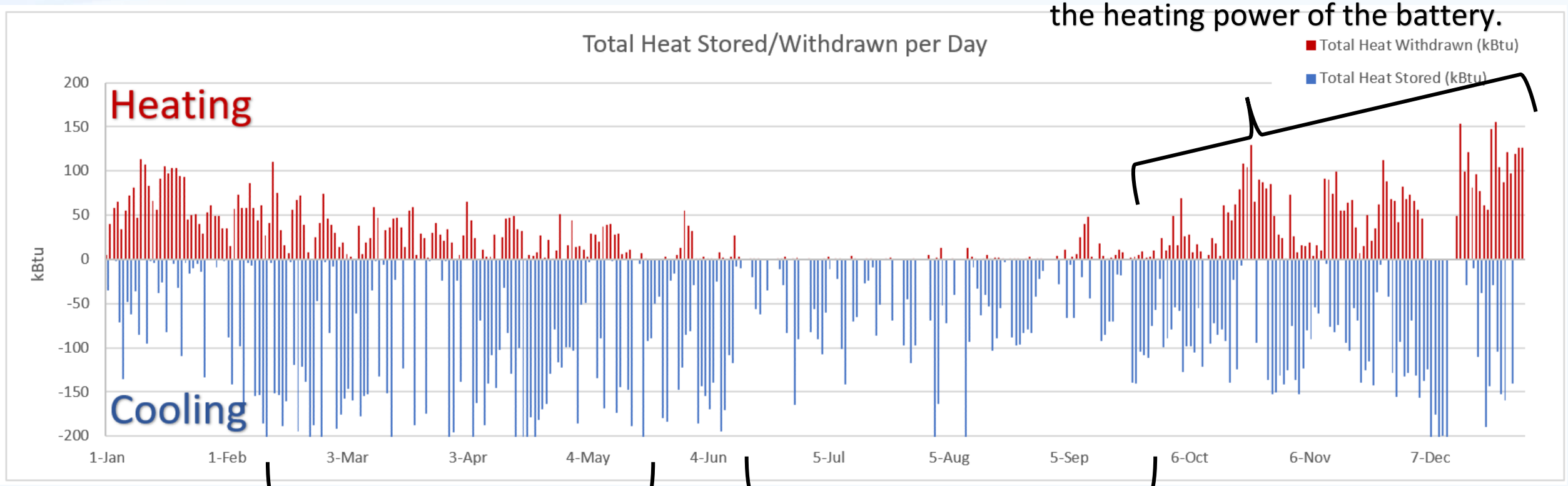
- The shallow tubes provide faster heat and cooling.
- The deeper tubes provide longer, larger quantities of heat and cooling.

In winter, the lower tubes remain warmer as heat conducts up from below the “battery”.

Total Heat Energy

20# Propane tank holds 433 kBtu
(457 MJ)

Stored heat from the summer increases the heating power of the battery.

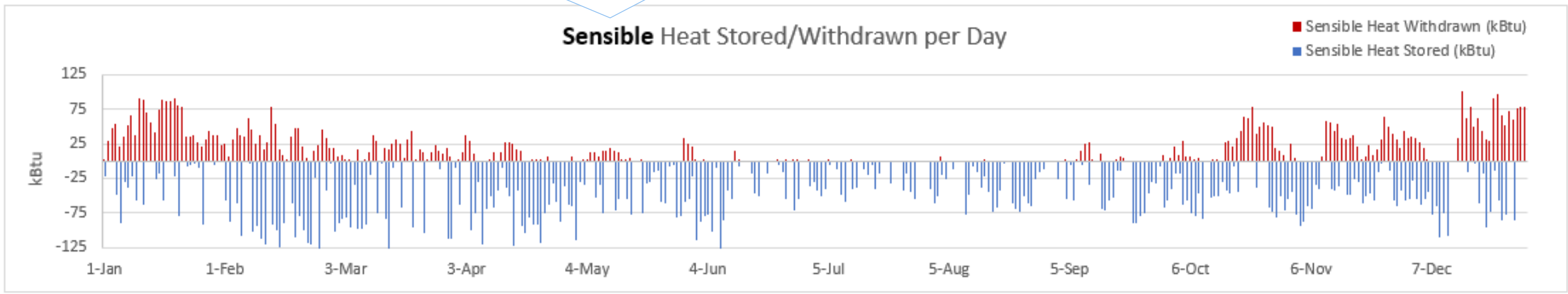


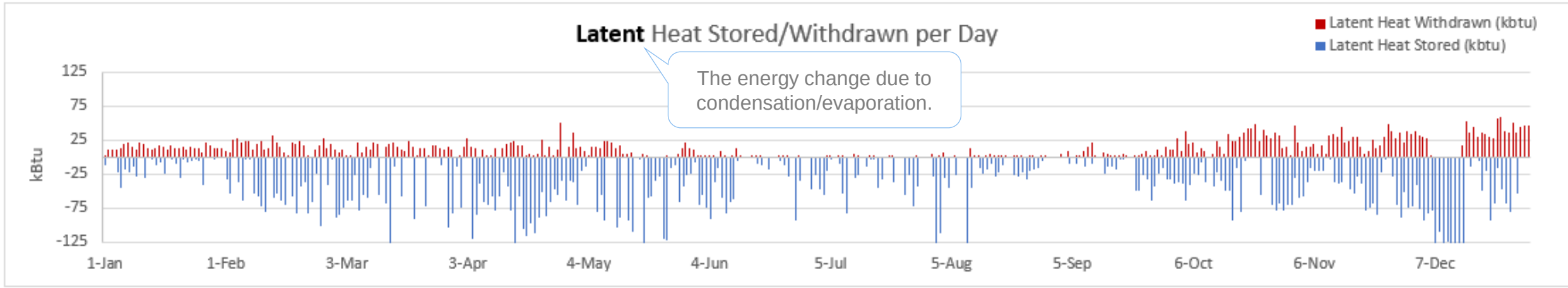
When the ground is “cool” it can absorb a lot of heat

By summer-time the battery is no longer able to absorb as much heat

Sensible vs. Latent Heat

The energy required to heat air without condensation/evaporation.



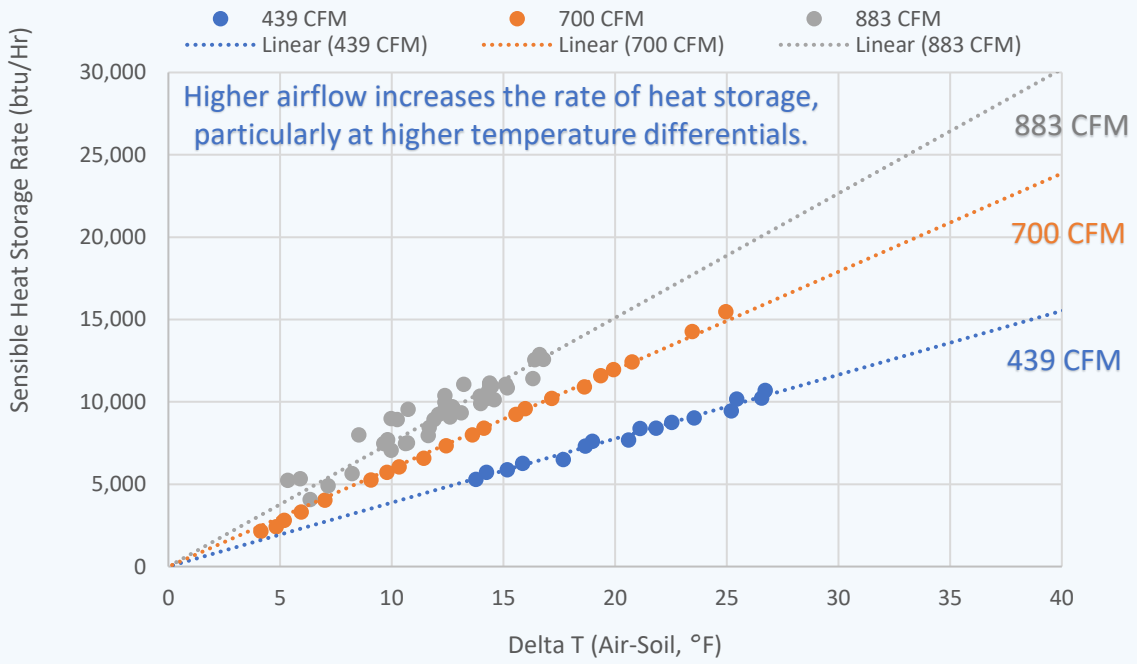


The energy change due to condensation/evaporation.

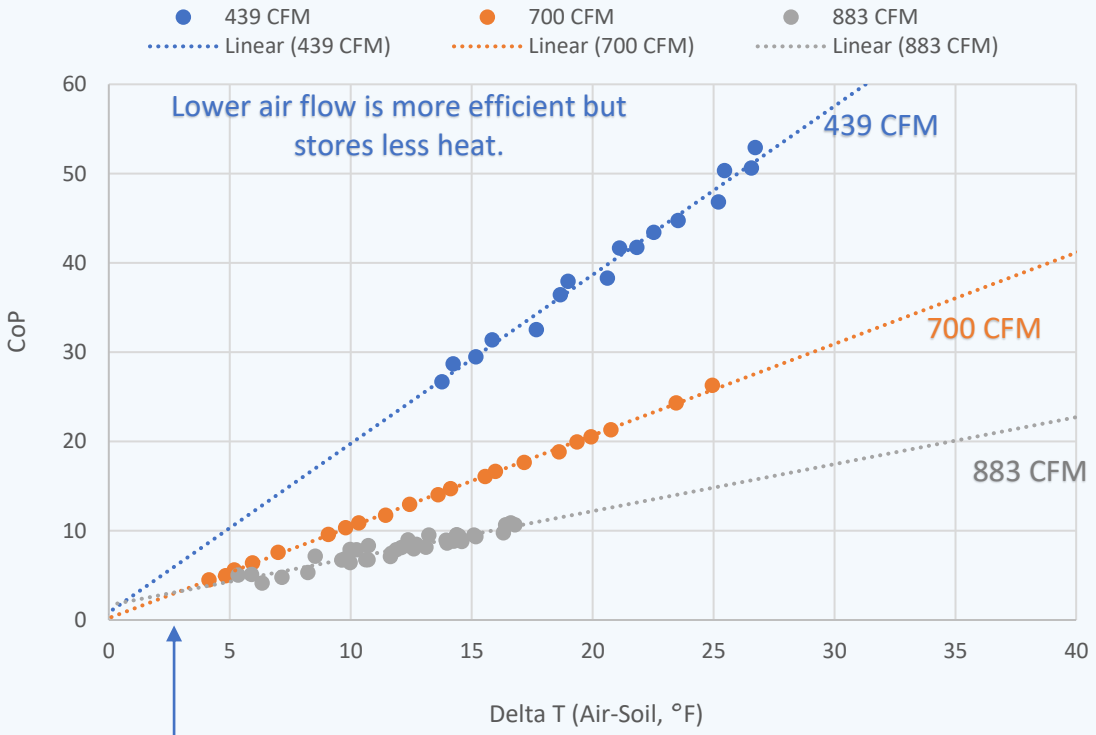
Significant Latent heat transfer is occurring. (Some guidelines suggest long tube runs (>20') are necessary for this, but that doesn't appear to be the case (14' system)

Fan Speed & System efficiency

Effect of Air Flow on Heat Storage Rate



Coefficient of Performance (Storing/Cooling)

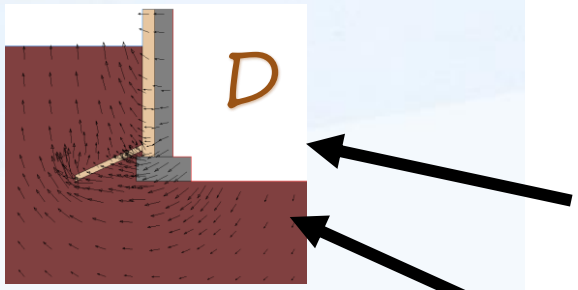


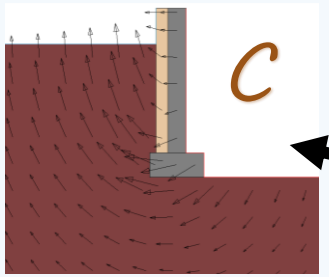
With 28 4" tubes, 883 CFM is 32CFM/tube. (These are measured values at tube outlet, NOT fan ratings.

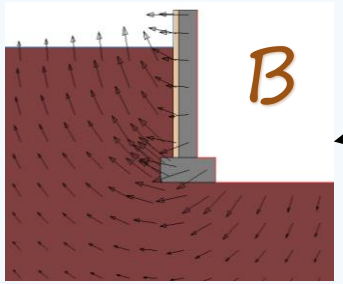
There is minimal value to running fans when battery-to-air temperature differs by less than 3°F (1.6°C)

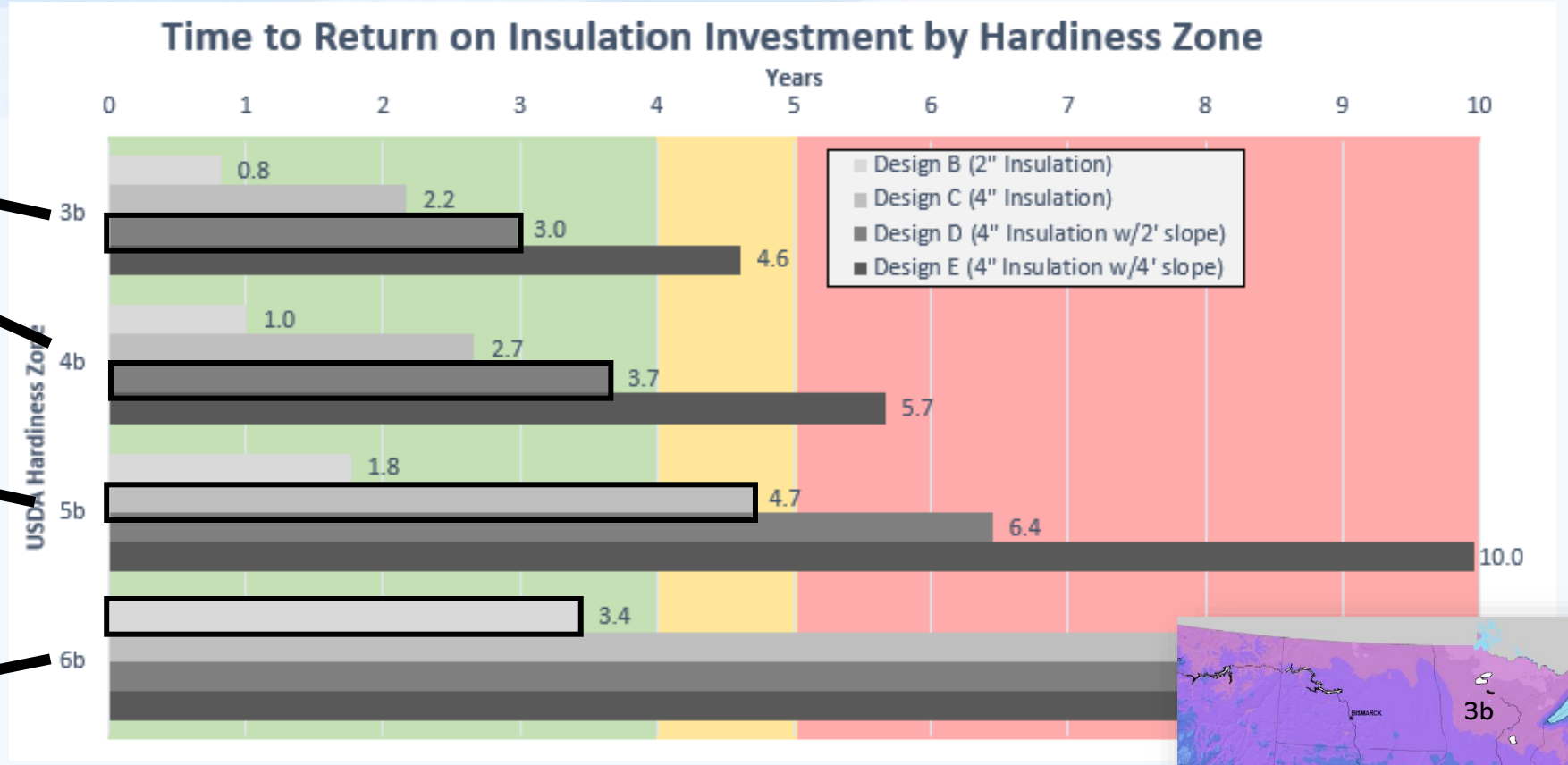
Some Design Guidelines

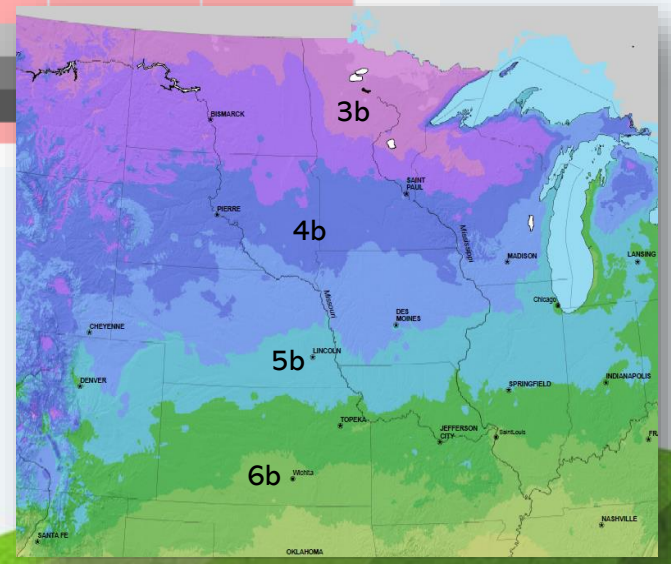
Recommended Insulation Level by Climate Region









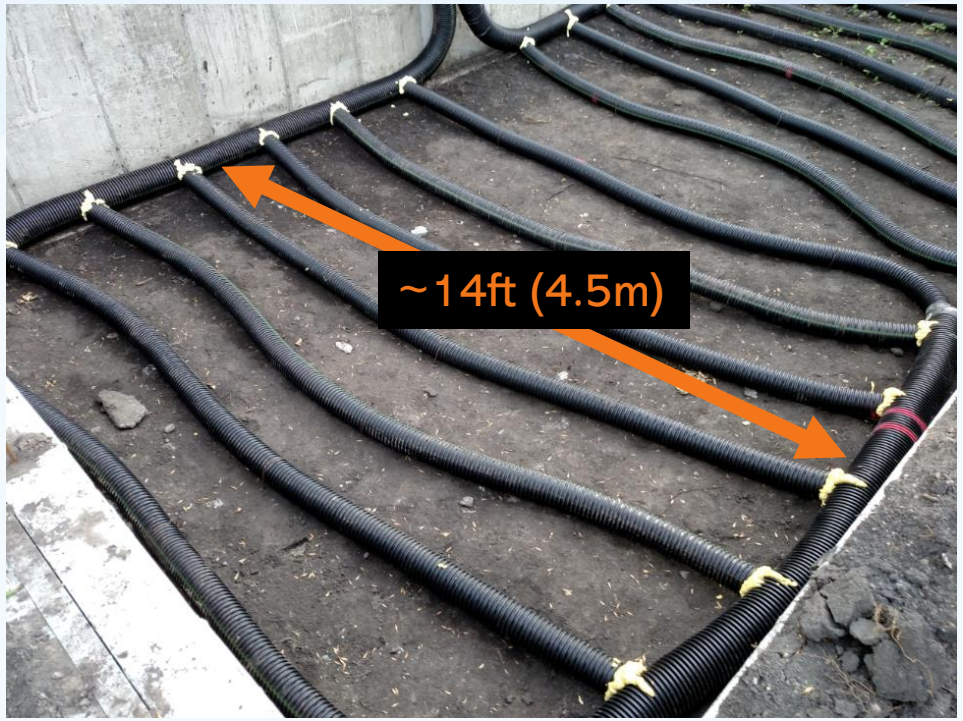


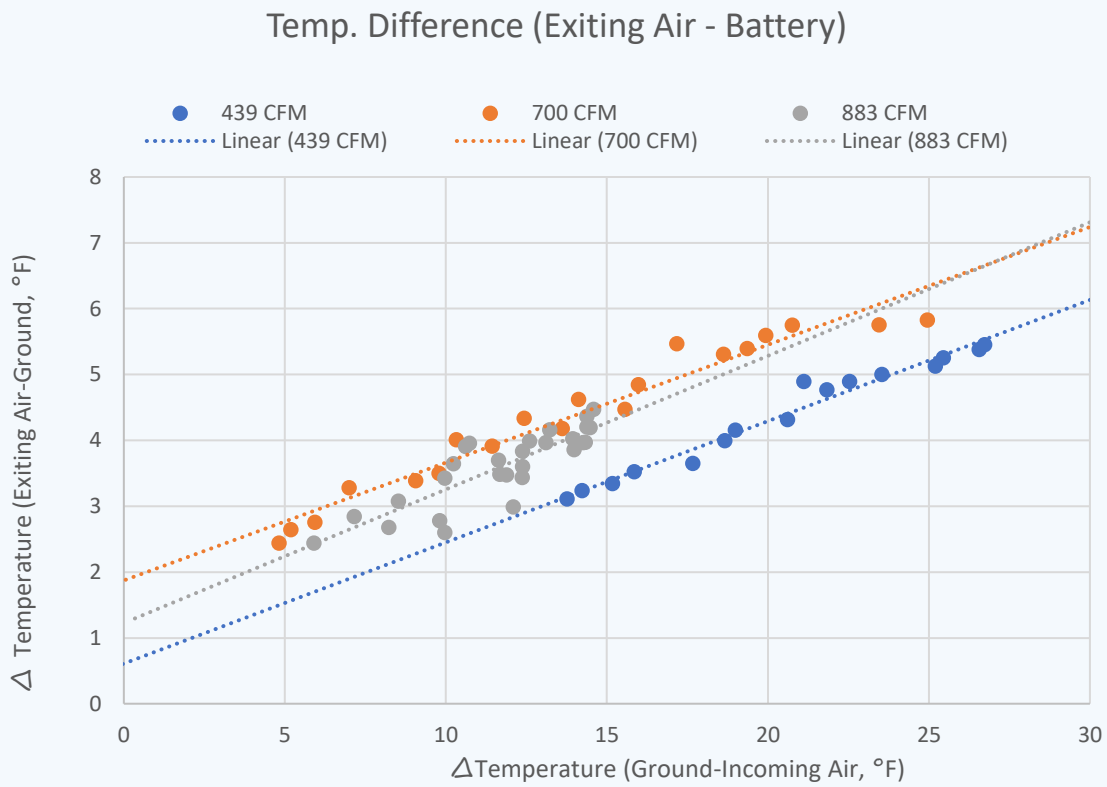
Assuming heat lost through ground/foundation would be replaced with propane heat ($1.30/gal)

Assuming construction costs are materials for insulation & some extra excavation for 4ft skirt.

Heat Losses based on recorded ground temperatures of typical locations in each hardiness zones & my measured internal ground temperatures.

Heat Exchanger Tube Length (Heat Exchanger Efficacy)

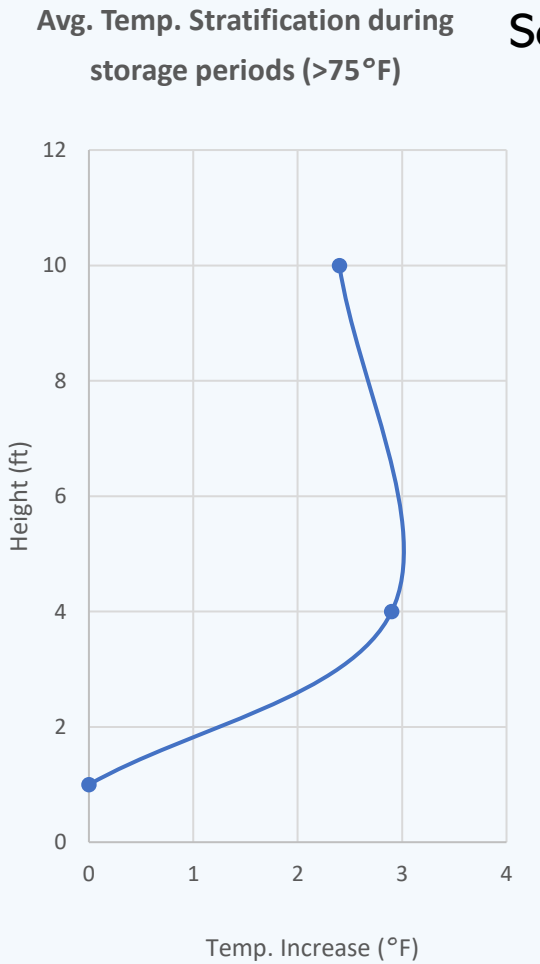




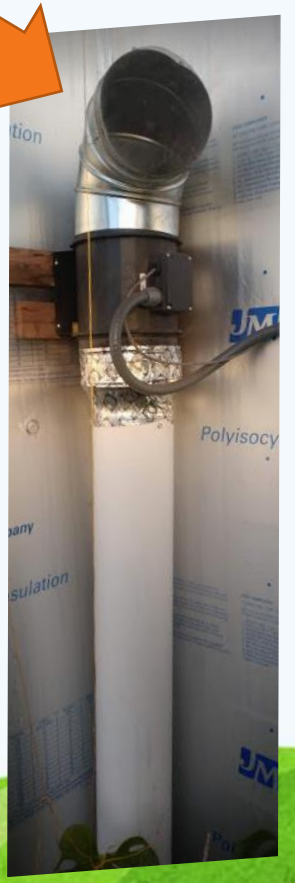
- It is desirable to keep tube length short to reduce friction/pressure, but long enough to allow the air to get close to the soil temperature.
- Tubes that are too long will transfer all heat to soil before passing the full length, wasting some of the battery volume.
- 14ft performs well, but a little more length would be OK, but not more than 30ft.

Climate Battery Intake

I observed that the intake temperature was substantially lower when storing heat than my main central air sensor.



So, I removed the excess ducting.



Things I'd do differently (Climate Battery)

- Decrease spacing between exchanger tubes (14" on center)
  - Store heat faster during intense sunny days w/o venting.
  - But maintain the 2' depth for the top layer.

- Manifold tubes
  - Reevaluate the diameters of manifold tubing (reduce pressure drop, match fan diameter better)
  - Consider less-perforated manifold (some air leaking through them)

Things I'd do differently (Structure)

- Eliminate the "knee wall" & Intake vents.
  - Improved ground level light during winter
  - Fewer pests get in top vents
  - Use shade cloth instead for short time needed.
  - Better condensation management

- Change the roof structure (Not clerestory)
  - Upper vents could be built into north roof instead
  - Simpler construction, less cost
  - Less heat loss with less exposed surface area
  - Easier to seal & keep water/ice out of the vent seals

Things I'd like to investigate further

- A reliable, automatic insulating curtain to reduce glazing heat loss.
- Alternative structures (More space), CSG or DWG Farmscale?
- Layouts for climate battery tubes for other sized structures. Can a simple guide be made for most applications?
- More space! It's too small.

Some of the stuff we have/are growing

Some of the things I have/am growing:

Tomatoes:
"Ponderosa Red", "Sweetie", "Edox"

Started seeds Jan 2nd, 2020.

Observations:

- **Still producing (>1yr)**
- **Growth/Production slowed a lot mid-December (40°F night temps & lower light)**
- **Ponderosa cracked a lot mid-late summer (too hot)**

Things I'd do different:

- **Start tomatoes earlier (planted Feb. 3rd this year)**
- **Trellis properly for vine management**
- **Try grafted greenhouse varieties (Shin Cheong Gang)**

January 4th, 2021

Some of the things I have/am growing:

Vegetables:

Radishes, lettuces, broccoli, cauliflower, turmeric, peas, green beans

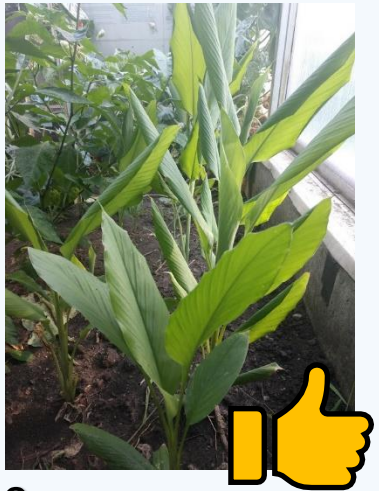
Observations:

- Lettuces were awesome (esp. for COVID)
- “Depurple” cauliflower grew great
- Broccoli was average
- Brussel sprouts never “sprouted”, too warm?

Things I’d do different:

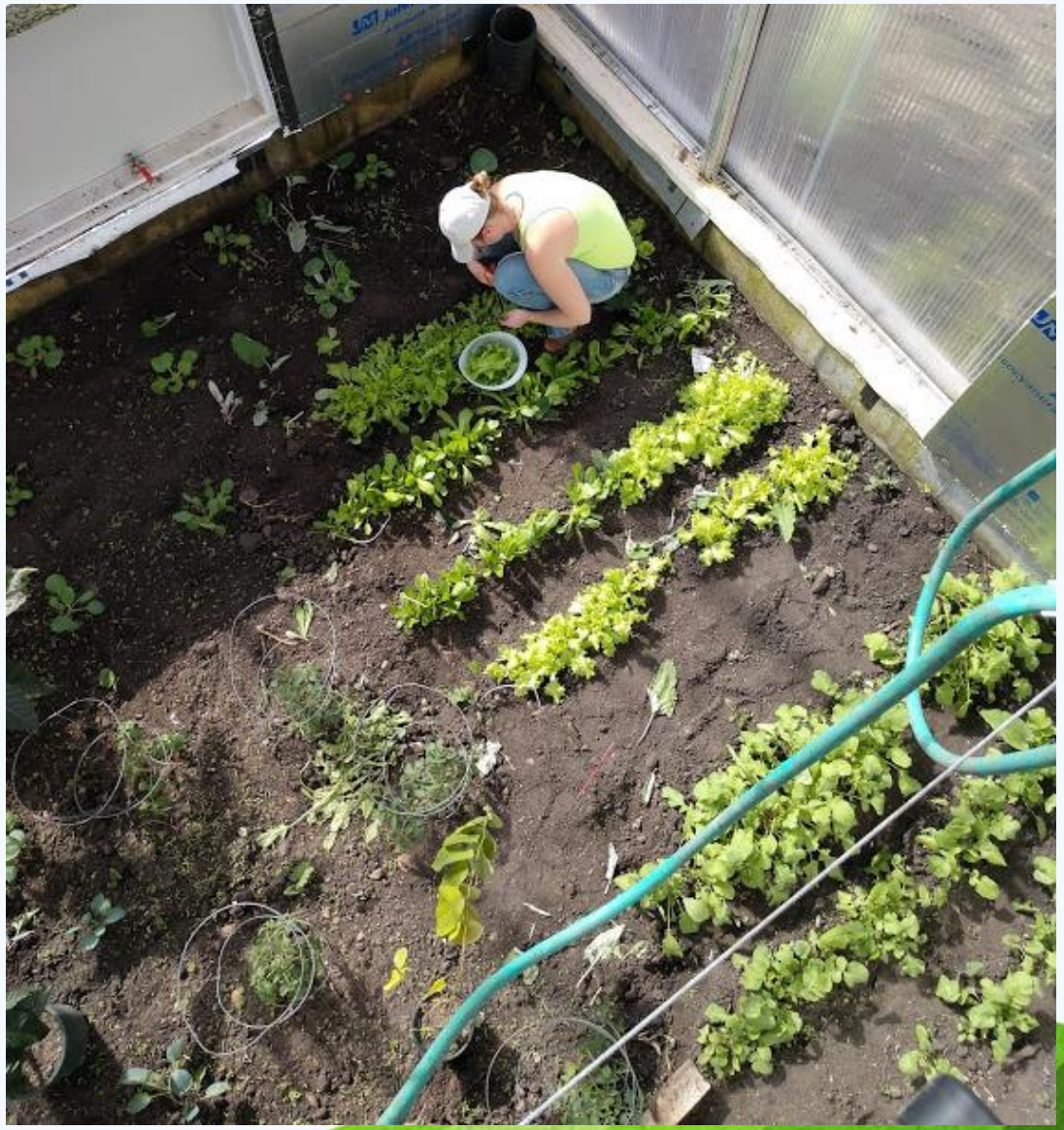
- Start brassicas sooner (no brussel sprouts)
- Use less space on vegetables
- Try lettuces in “gutters”

Turmeric



May 5th, 2020

March 7th, 2020



Some of the things I have/am growing:

Apocalypse Scorpion (Capsicum chinense)

Observations:

- Picked last ones Jan. 6th (Plants are dormant now)
- Super hots are a good option, too slow for outdoor

Things I'd do different:

- Trellis & prune correctly

Observations:

- Grew exceptionally well, covered entire north wall
- Pollination is challenging/not worth it

Things I'd do different:

- Not grow them again

Melothria scabra "cucamelon"

Some of the things I have/am growing:

dwarf Moringa oleifera (Zone 9-10)

Observations:

- Did extremely well (10ft growth in 10 months)
- Continued to grow through Jan. (semi-dormant now)

Things I'd do different:

- Prune it shorter to stimulate branching

Monstera deliciosa "Swiss cheese plant" (Zone 10-12)

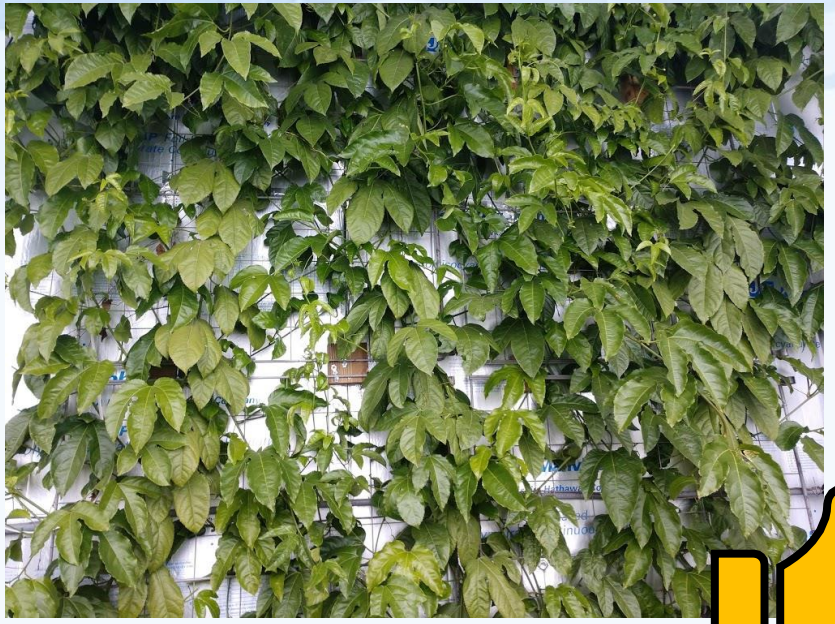
Observations:

- Have done well through the whole season
- Nice to put in lower light areas

Things I'd do different:

- ? – Could I get them to fruit?

Some of the things I have/am growing:



Passion fruit “Passiflora edulis” (Zone 10-12)

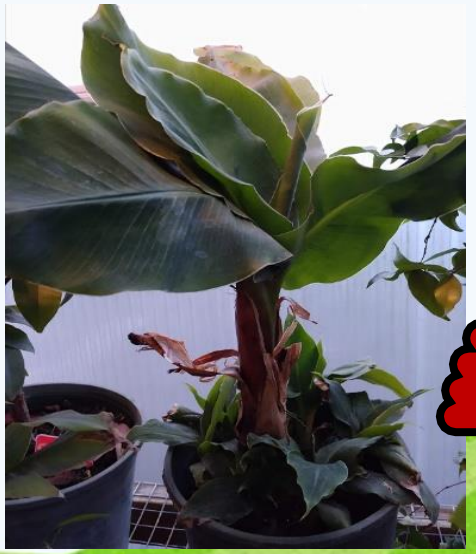
Observations:

- Growth was vigorous & healthy.
- Continued to grow through Jan.

Things I’d do different:

- Hasn’t bloomed yet….
- I’m gonna wish it was easier to reach to pollinate

Super dwarf cavendish banana (zone 9-11)



Observations:

- Really taken a beating in cool Jan weather

Things I’d do different:

- Investigate other varieties to try with better cool weather hardiness

Some of the things I have/am growing:

Black Sapote (Diospyros nigra) Zone 10-11

Observations:

- Seedlings are doing very well
- Not hindered by low Dec./Jan. temperatures

Observations:

- Seedlings & grafted ones are doing great
- Not hindered by low Dec./Jan. temperatures

Things I'd do different:

- Hasn't bloomed yet….
- Wish I had space to put one in the ground

Loquat "Big Jim" (Eriobotrya japonica) Zone 8-10

Some of the things I have/am growing:

Pitanga (Eugenia uniflora) Zone 9-10

Observations:

- All of these are looking really good so far

Canistel (Pouteria campechiana) zone 10+

Charichuelo (Garcinia madruno) Zone 10-12

Longan (Dimocarpus longan) zone 9-10

Some of the things I have/am growing:

Anonaceae:

Cherimoya (Annona cherimola) zone 8-12

Observations:

- Looks great so far! All cultivars I have are doing well.
- Even Atemoya on Cherimoya look good (better than own root)

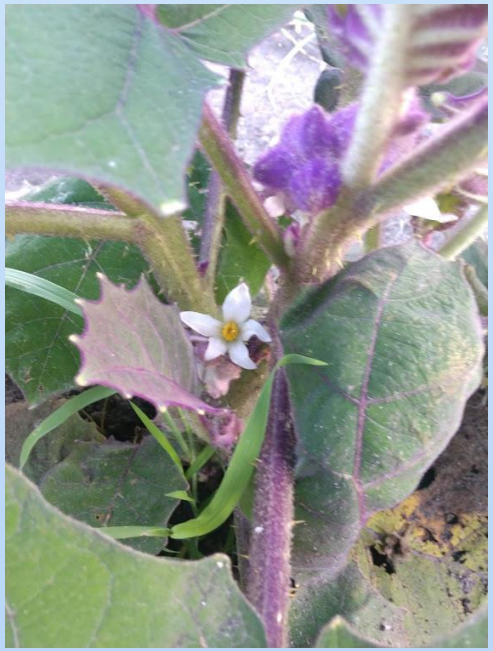
Sugar apple
(Annona squamosa) zone 9-10

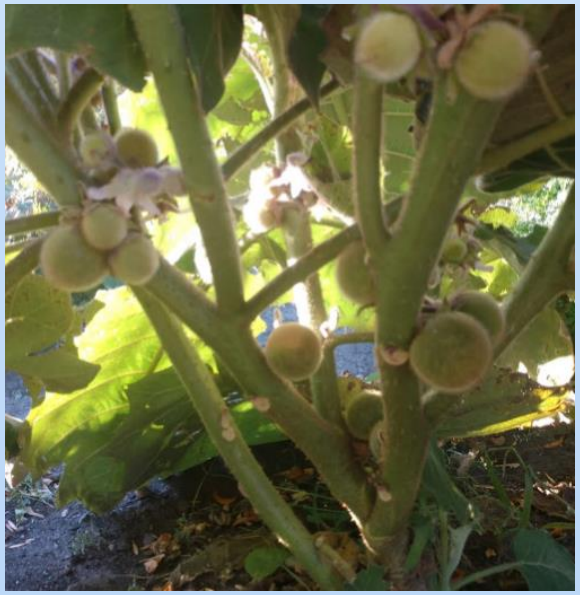
Atemoya
(squamosa x cherimola) zone 9b+

Soursop (Annona muricata) zone 9-11

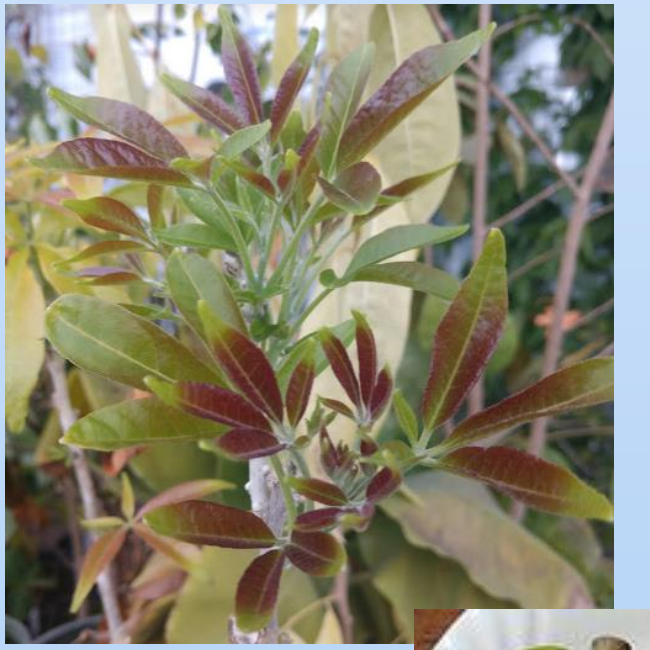
Some of the things I have/am growing:

Naranjilla (Solanum quitoense) zone 10-12





White Sapote (Casimiroa edulis) zone 9-11



Questions?

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Wayward Springs