Intro to Year-Round Passive Greenhouses: NAFEX Edition

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Wayward Springs LLC

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Sustainable Agriculture Research and Education

Outline

1. About me, my farm and my research project
2. What are passive solar greenhouses?
3. Fully passive systems
4. Mostly passive systems
5. My prototype & analysis
6. A brief review of 2020 performance data
7. Some of the stuff we are/have grown

About me

Mechanical engineer with 20 years experience doing thermal design, research & testing of electronics mega-systems.

Small farm owner/operator with a fruit obsession.

Wayward Springs Acres

Fruit trees & greenhouse tech.

Scottish Highland Beef

Jacob Sheep Fiber & Products

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:

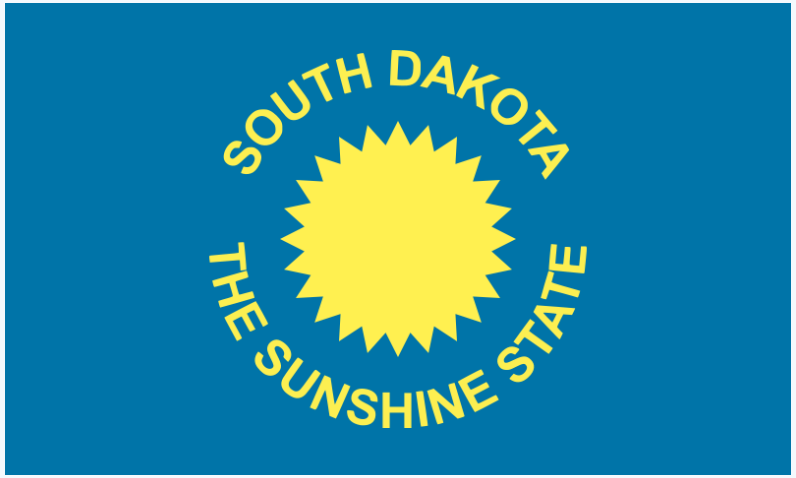
Cold northern climates prevent year-round crop production and make greenhouses too costly for tropical produce. This results in long distance shipping of fruits and vegetables from central America and prevents many types of delicate produce from being available in local markets.

What are passive solar greenhouses?

What is a "passive solar greenhouse"

A good design can:

- Minimize total cost of ownership (construction, operation, maintenance)
- Minimize or eliminate traditional fossil fuels for heat.



1909 State Flag Design

For our climate

What is a "passive solar greenhouse"

They can come in all kinds of shapes and sizes

Grandpa G's, Pillager, MN (DWG – Deep Winter Greenhouse)

REDCO, Mission, SD

Beijing, China (Dr. Wenjing Guan)

Francie Popelka, Wisconsin

Char Graber

NPNRD Scottsbluff, NE

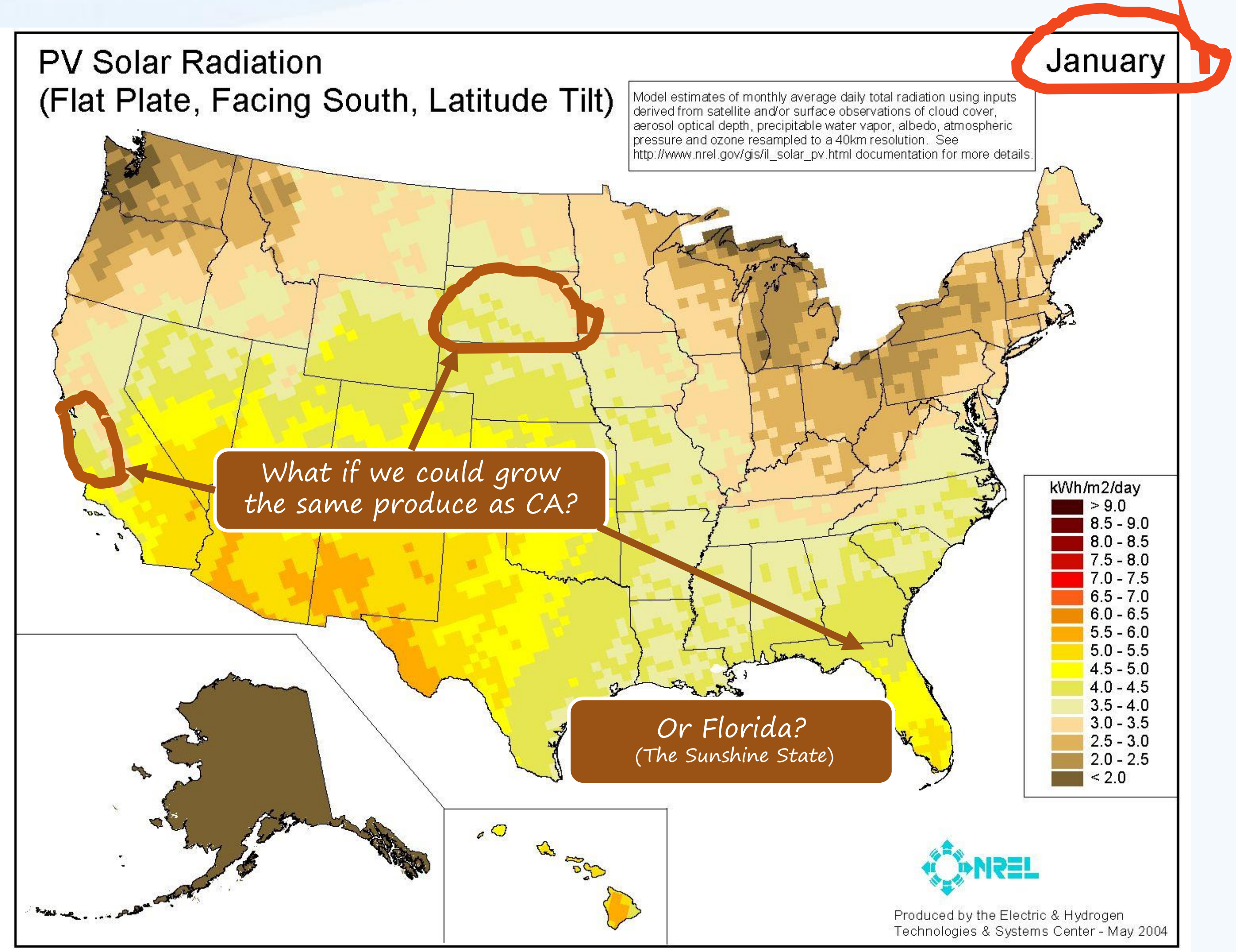
Key elements of a "solar greenhouse"

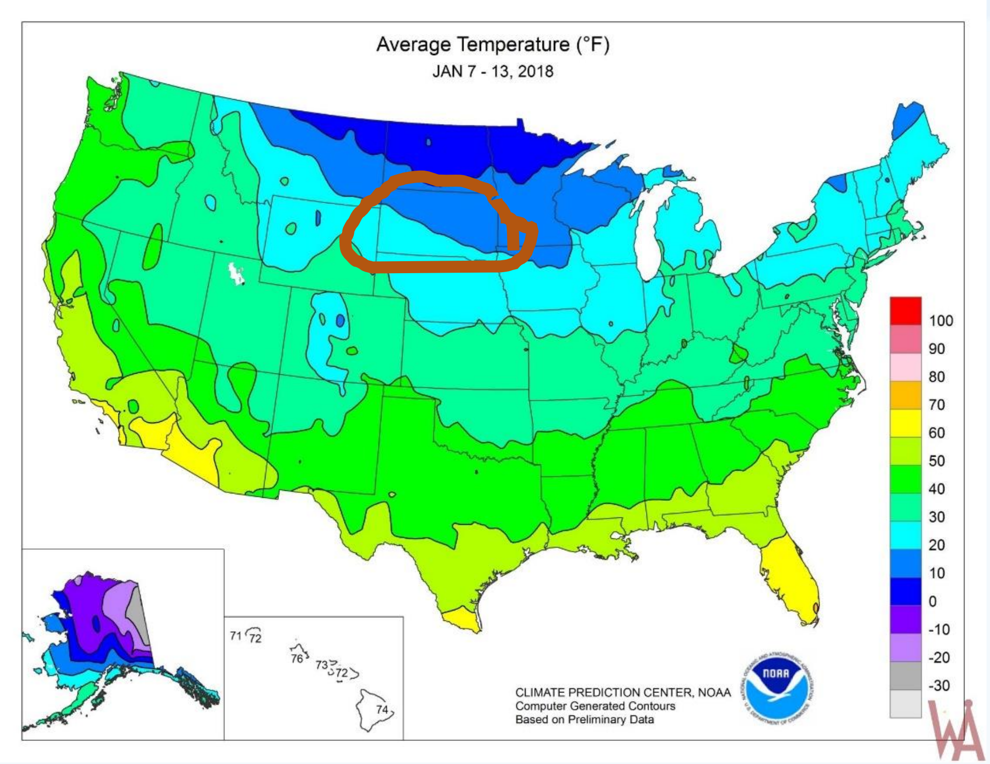
The south facing surfaces are a transparent glazing

The North facing surfaces are opaque insulated

Could it be possible to heat with only the sun?

South Dakota has a lot of winter sunlight!





All we need to do:

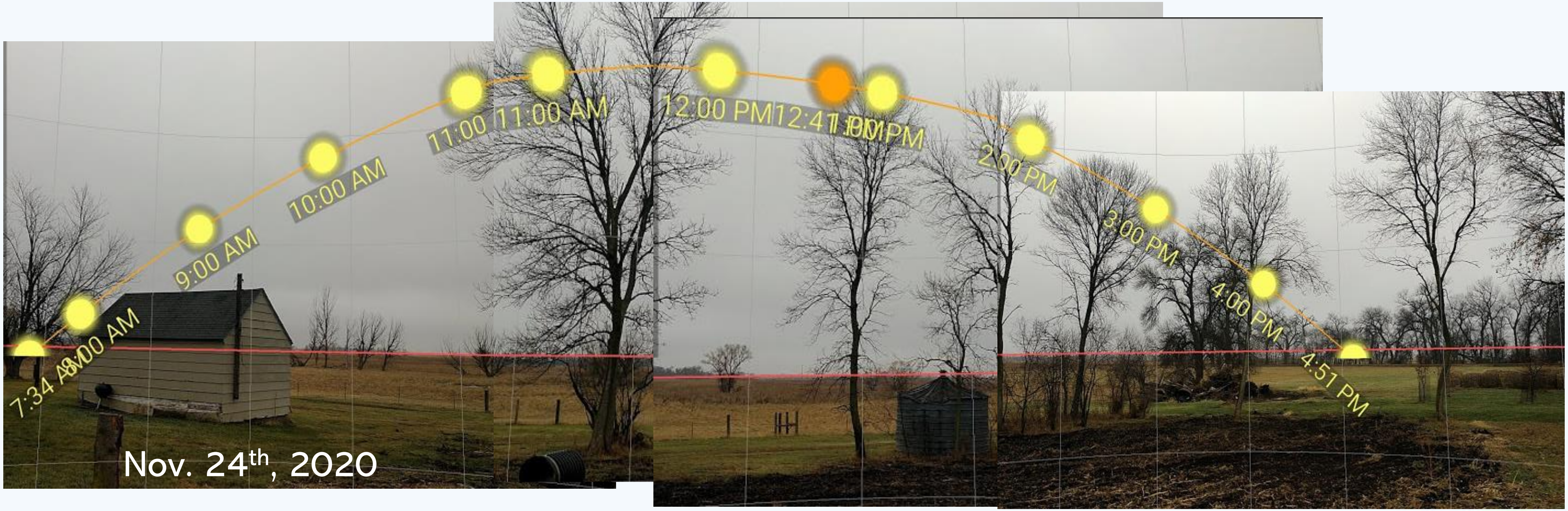
store it during the day to use for our long cold nights

For a reasonable price

Key elements of a “solar greenhouse”

Site selection

Check for & remove sunlight obstructions



Sun Position App. (Free version only works for the current day, so download and scout your site on Dec. 22nd)

Fully Passive Heat Storage Systems

Concrete, Packed Earth, etc

Pros: Not that easy, cheap or durable

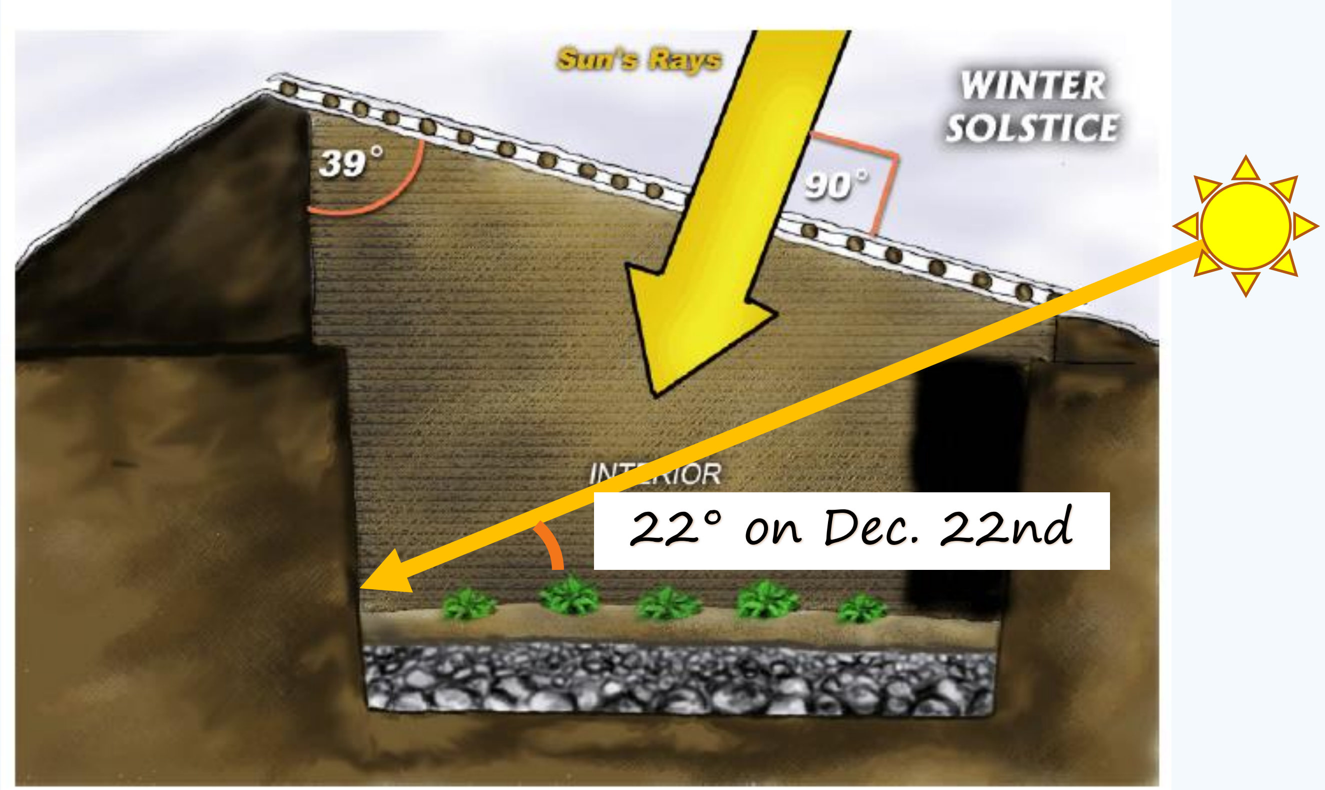
Cons: Doesn't store enough heat

Underground, Walipini, Earth-Sheltered, Pit

Uses the ground on all sides as a "thermal mass" to reduce temperature swings.

Walipini Warnings

****Designed for LaPaz, Bolivia****



Bensen Agriculture and Food Institute, Brigham Young University, 2002

Pros: Thermal storage all around!

Cons:

- Stability, walls must be reinforced
- Water problems & drainage
- Winter sun shading!

The Chinese Solar Greenhouse

China has the highest greenhouse-based vegetable production in the world.

By 2010 china already had 1,970,000 acres under solar greenhouses! (17% of their total)

By 2020 there has been a lot of research on optimization and improvement of the design

HortiDaily.com 2017

Energy performance optimization of typical Chinese solar greenhouses by means of dynamic simulation (Alessandro Deiana et al., International conference of agricultural engineering, 2014, Zurich.

How the Chinese Solar Greenhouse Works

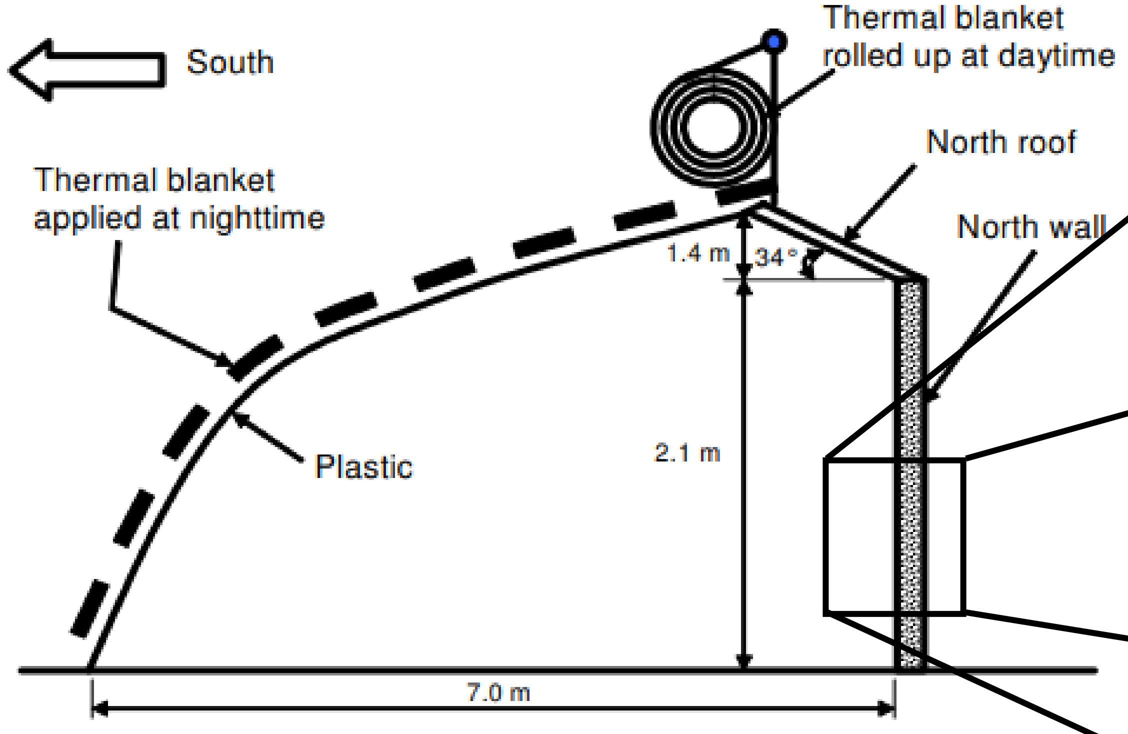


Fig. 1. Side view of the solar energy greenhouse. The greenhouse length was 30 m.

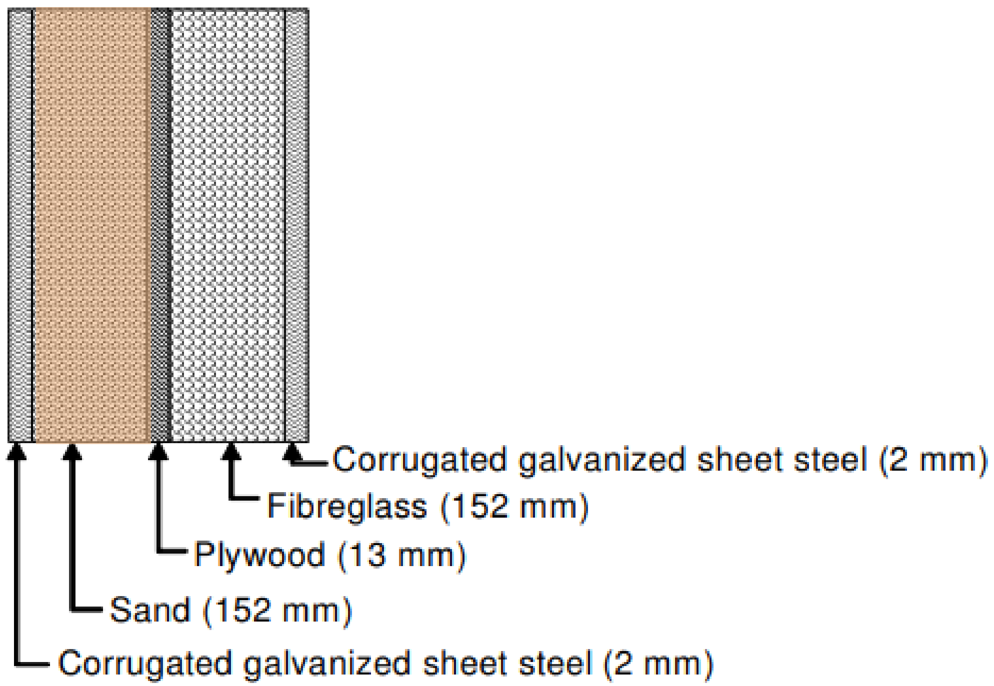


Fig. 2. Structure of the solar energy storage (north) wall.

Winter performance of a solar energy greenhouse in southern Manitoba (E. Beshada et al., Dept. of Biosystems Engineering, Univ. Manitoba, 2006

Fruit in the Chinese Solar Greenhouse

Figure 2: Cherry trees inside a Chinese half-greenhouse. (Photo: Greg Lang)

In 20yrs China has gone from a minor cherry producer to at least #3 in the world.

>2,500 acres of sweet cherries were being grown in solar greenhouses to fill the market gap between southern & northern hemisphere cherries.

Fruit in the Chinese Solar Greenhouse

V-trained peach trees after post harvest pruning.

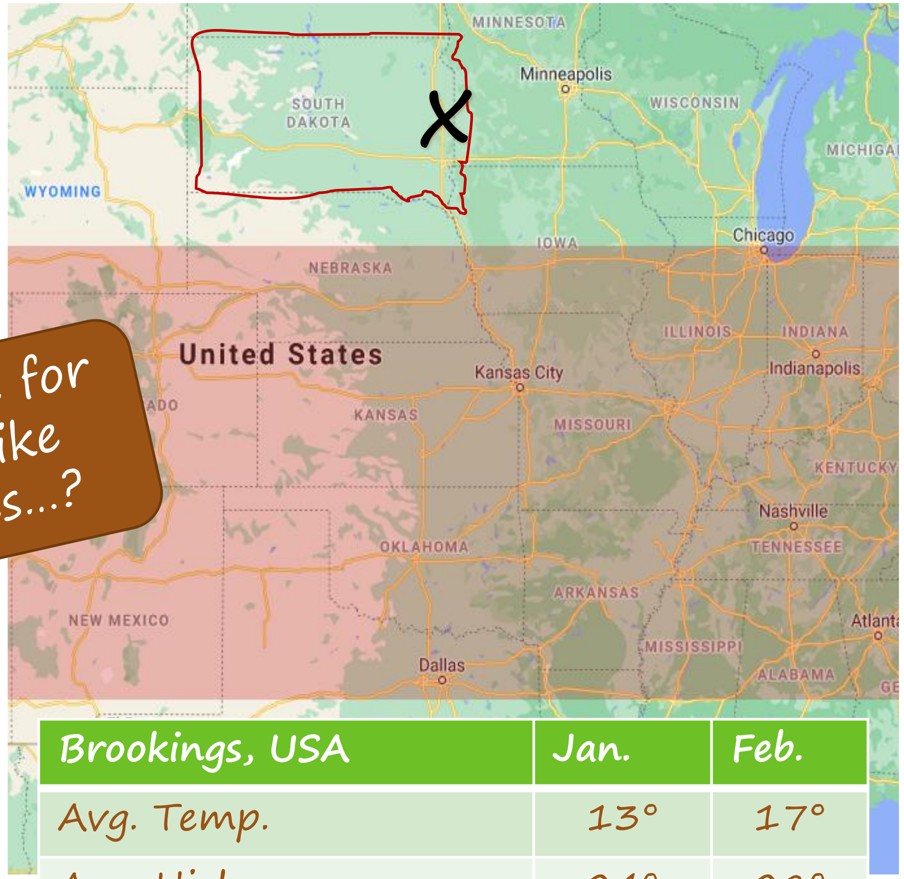
>40,00 acres of low-chill greenhouse peaches & nectarines.

A typical, south-facing solar lean-to greenhouse with sunken floor. The side and back walls are made of earth. Note the nontransparent insulation rolled up at the top of the house. **(Courtesy Desmond R. Layne, Ph.D./Washington State University)**

Undercover production in China – GoodFruitGrower – www.goodfruit.com (July 1, 2013)

Can Fully Passive Systems Work in SD Year-Round?

Could they work in SD?



Probably not…maybe for cold season crops like brassicas & lettuces…?

Shenyang, CN	Jan.	Feb.
Avg. Temp.	13°	20°
Avg. High	22°	28°
Avg. Low	4°	11°
Highest Recorded	46°	57°
Lowest Recorded	-19°	-14°

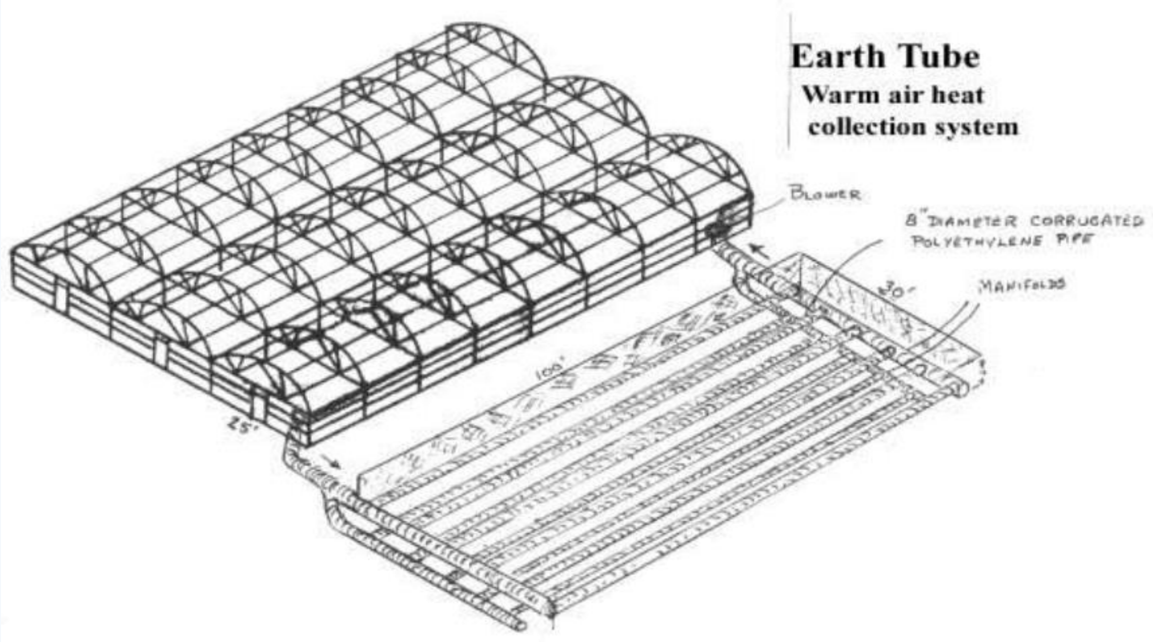
Brookings, USA	Jan.	Feb.
Avg. Temp.	13°	17°
Avg. High	24°	28°
Avg. Low	3°	6°
Highest Recorded	61°	69°
Lowest Recorded	-41°	-41°

What are mostly passive solar greenhouses?

Mostly Passive Systems (uses fans)

1. Direct Use Low-Grade Geothermal (LGG)

(aka. Earth Tubes)



John Bartok, Jr., University of Connecticut

2. Ground based Heat Storage Systems

(Climate battery, GAHT™, GETS, SHCS, earth tubes etc.)

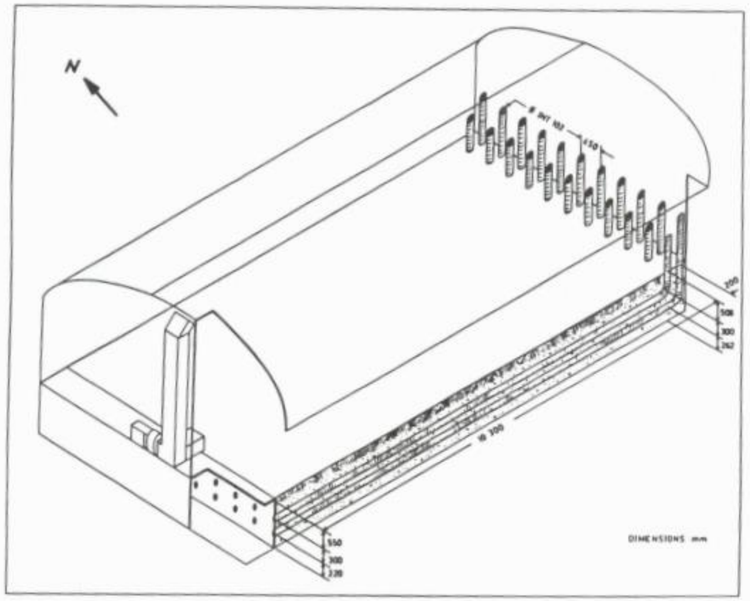


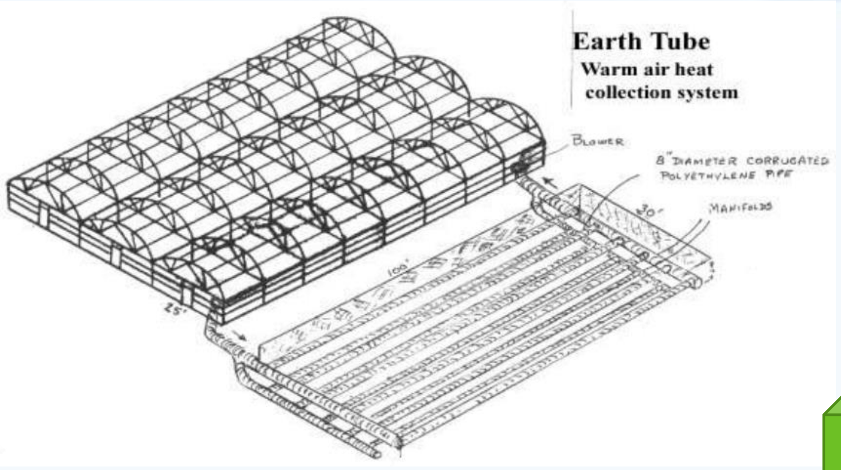
Fig. 1. Soil heat exchanger and storage system.

Evaluation of soil heat exchanger-storage system for a greenhouse.
H. Bernier, 1991 Canadian Ag. Engineering

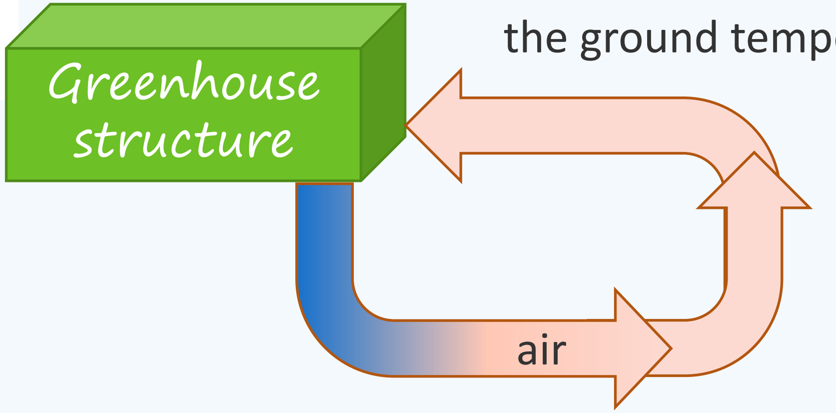
Mostly Passive Systems

Direct Use Low-Grade Geothermal (LGG)

Extracts the natural heat accumulated in the ground to provide heat to the greenhouse.



The return air will be heated to the ground temperature.



Typically air is blown through a series of perforated drain tile tubes.

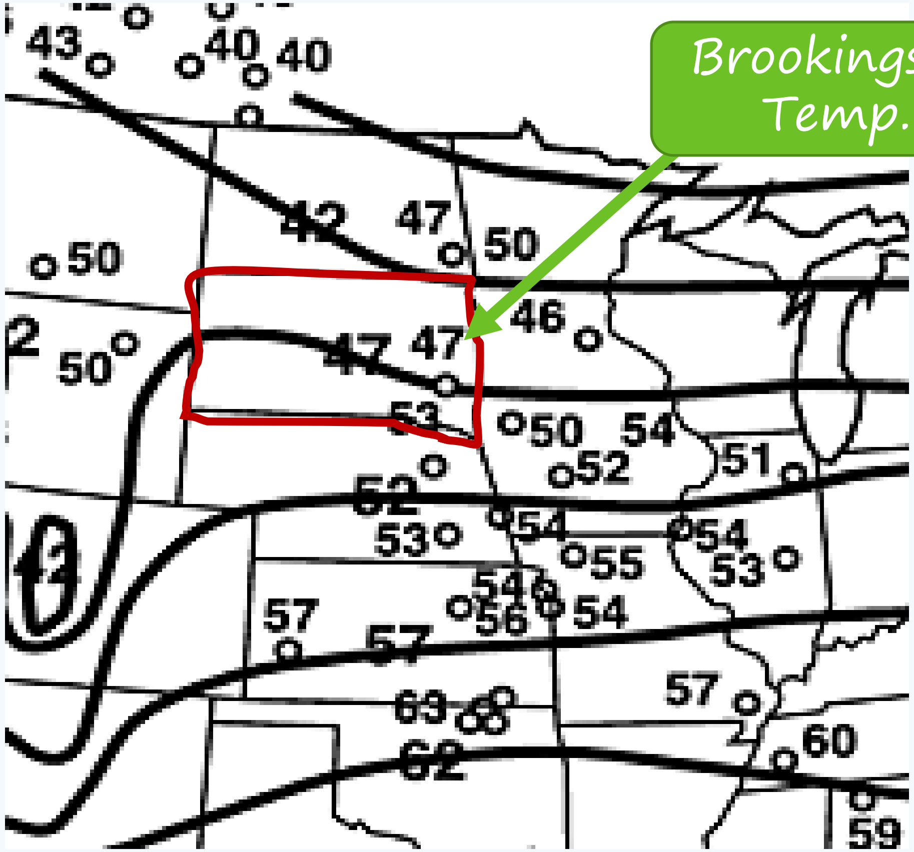
John Bartok, Jr., University of Connecticut

NPNRD Scottsbluff, NE "Citrus In the Snow" system

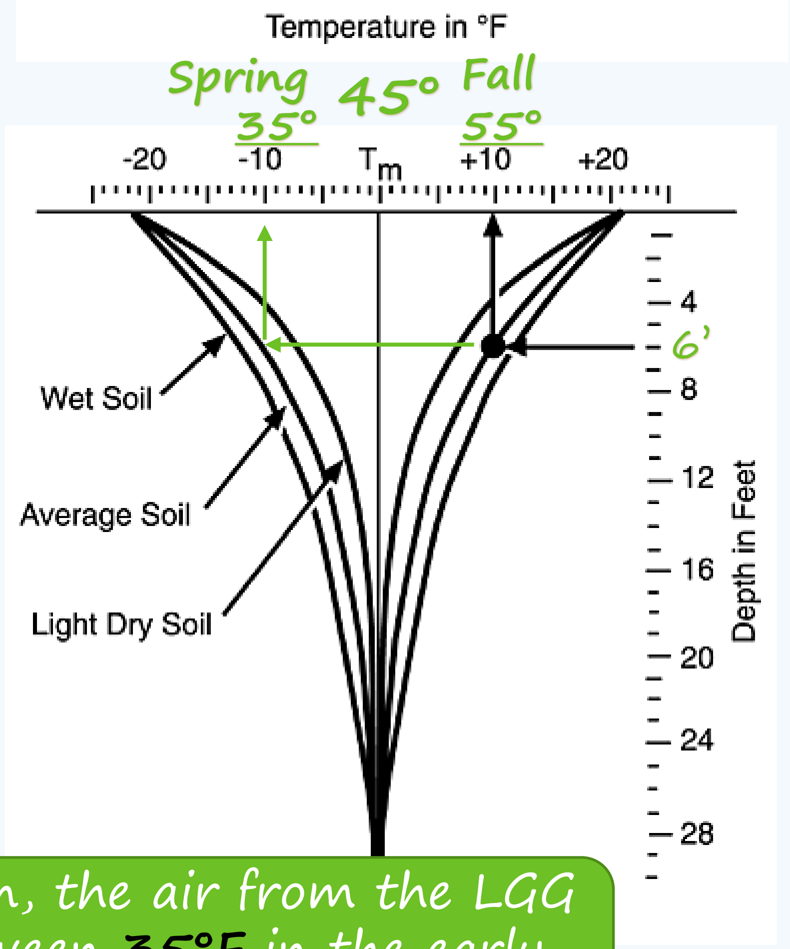
Mostly Passive Systems

Direct Use Low-Grade Geothermal (LGG) Limitations

Mean earth temperature (30ft down)



Brookings, SD Mean Temp. is 45°F



For my location, the air from the LGG would be between **35°F** in the early spring to **55°F** in late fall.

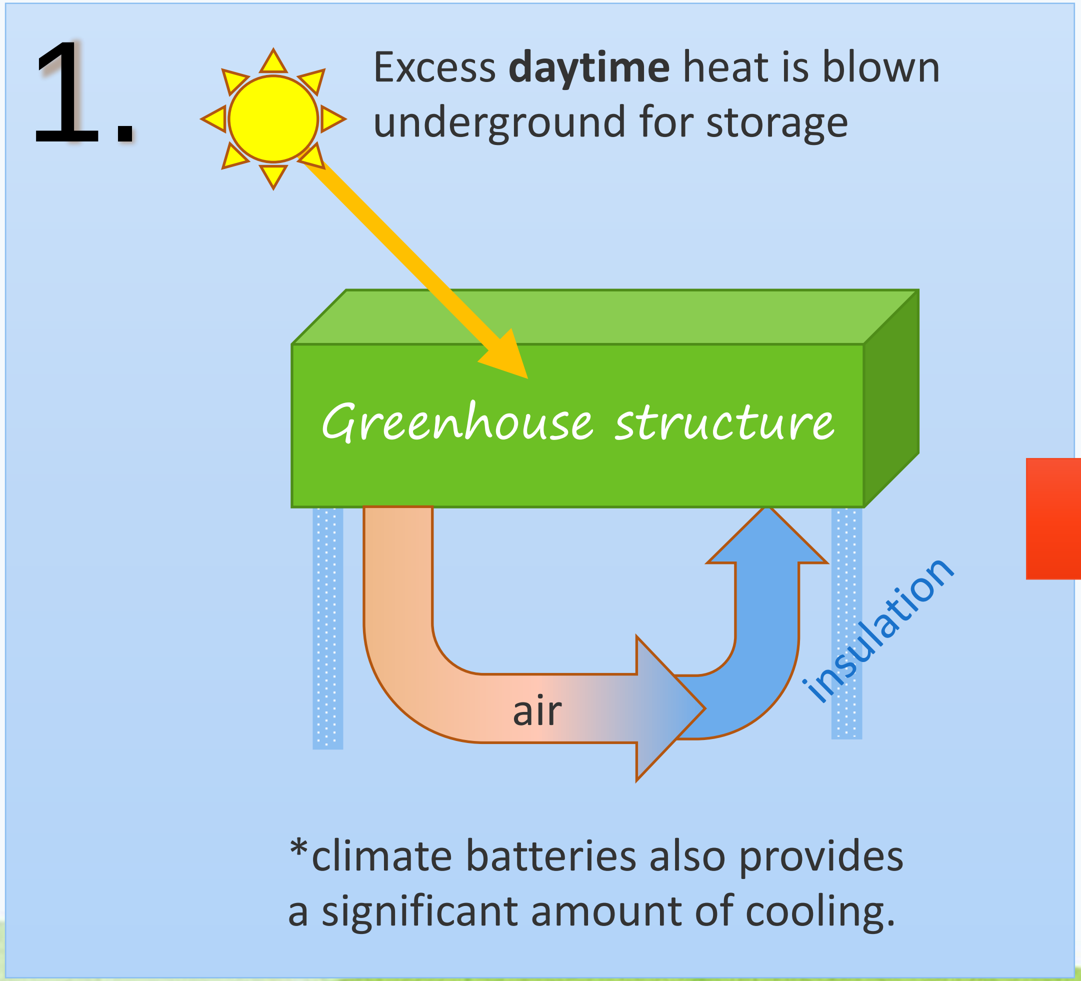
*Other variations are possible:

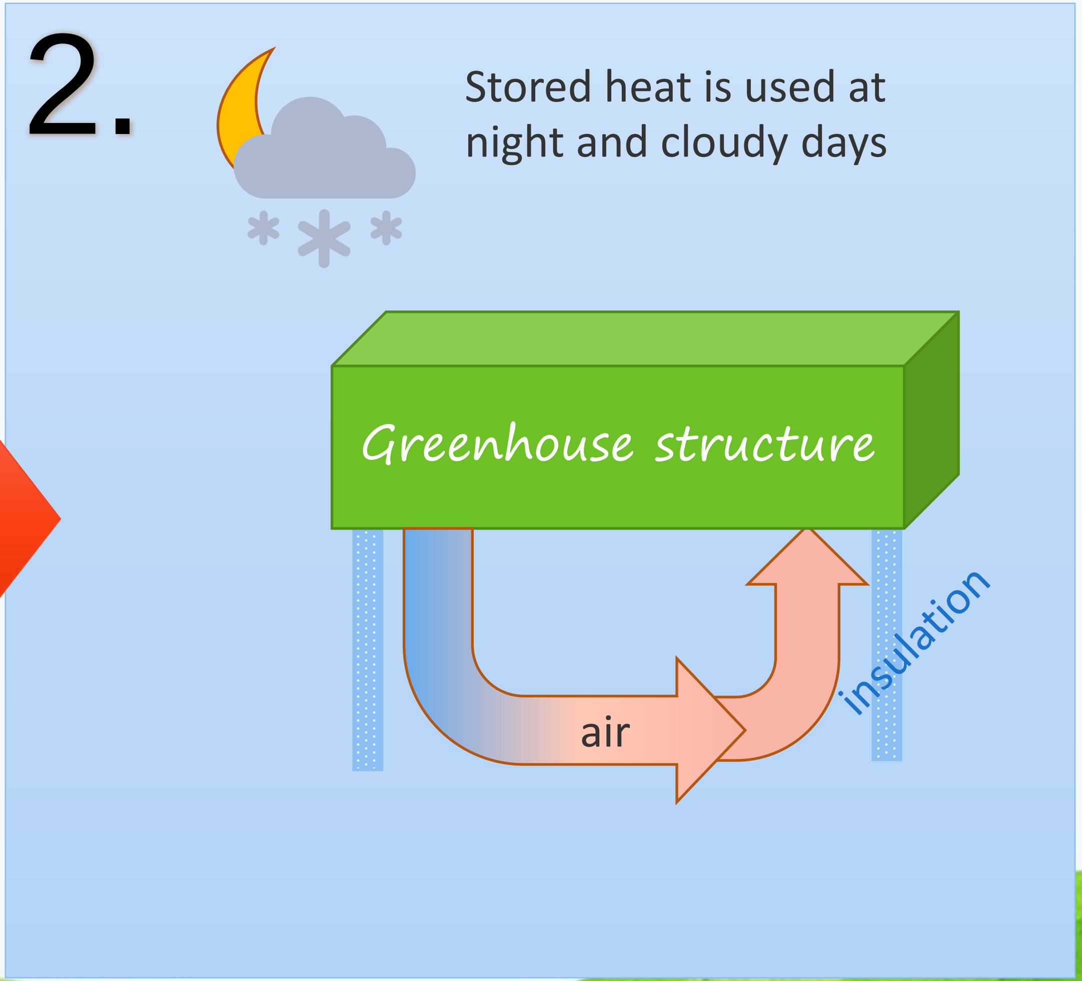
- water-air (adds heat exchanger, $$)
- Indirect use LGG (adds heat pump, $$$)

Mostly Passive Systems

Ground/Soil Based Heat Storage Systems

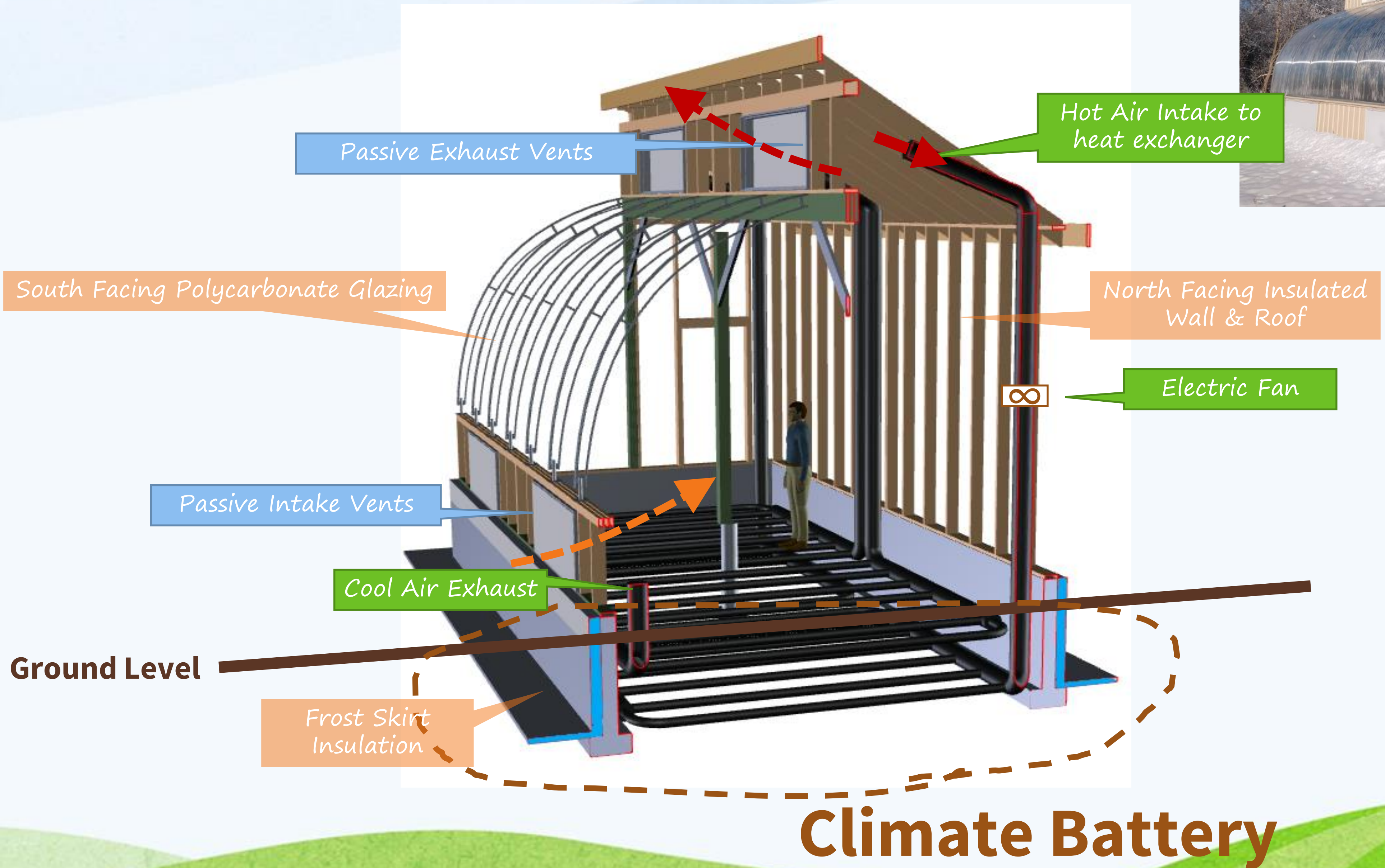
(**Climate/Earth battery**, GAHT™, GETS, SHCS, earth tubes etc.)





My prototype & analysis

My Prototype Structure

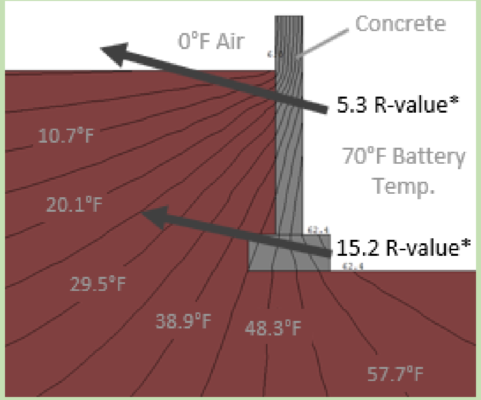


My Prototype System

Heat Storage System Insulation

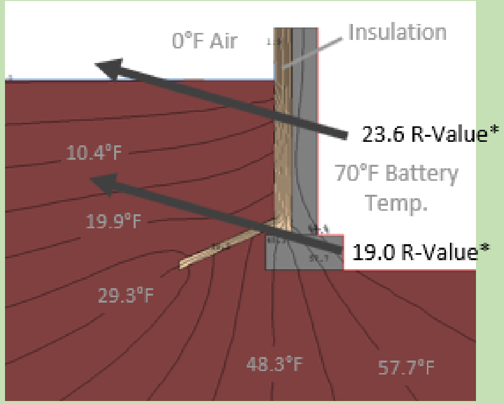
Compared heat loss rate through 6 different insulation methods.

None



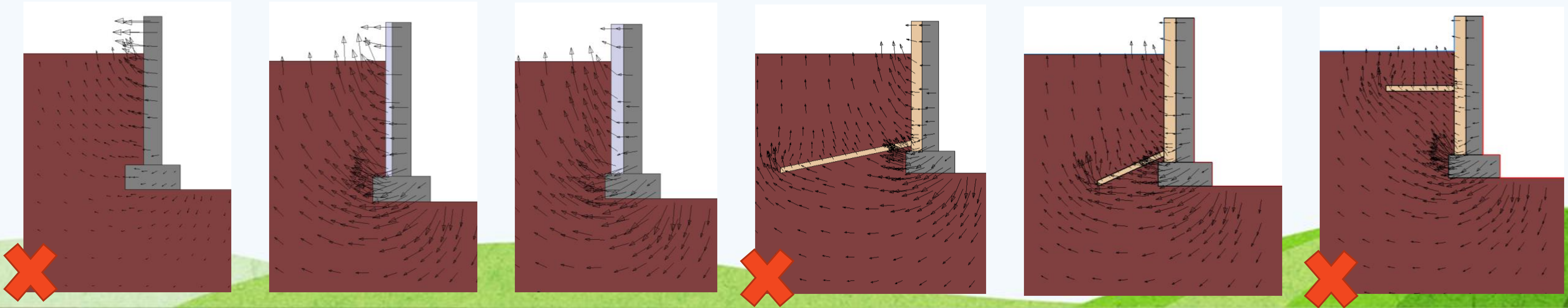
vs.

Chosen Design



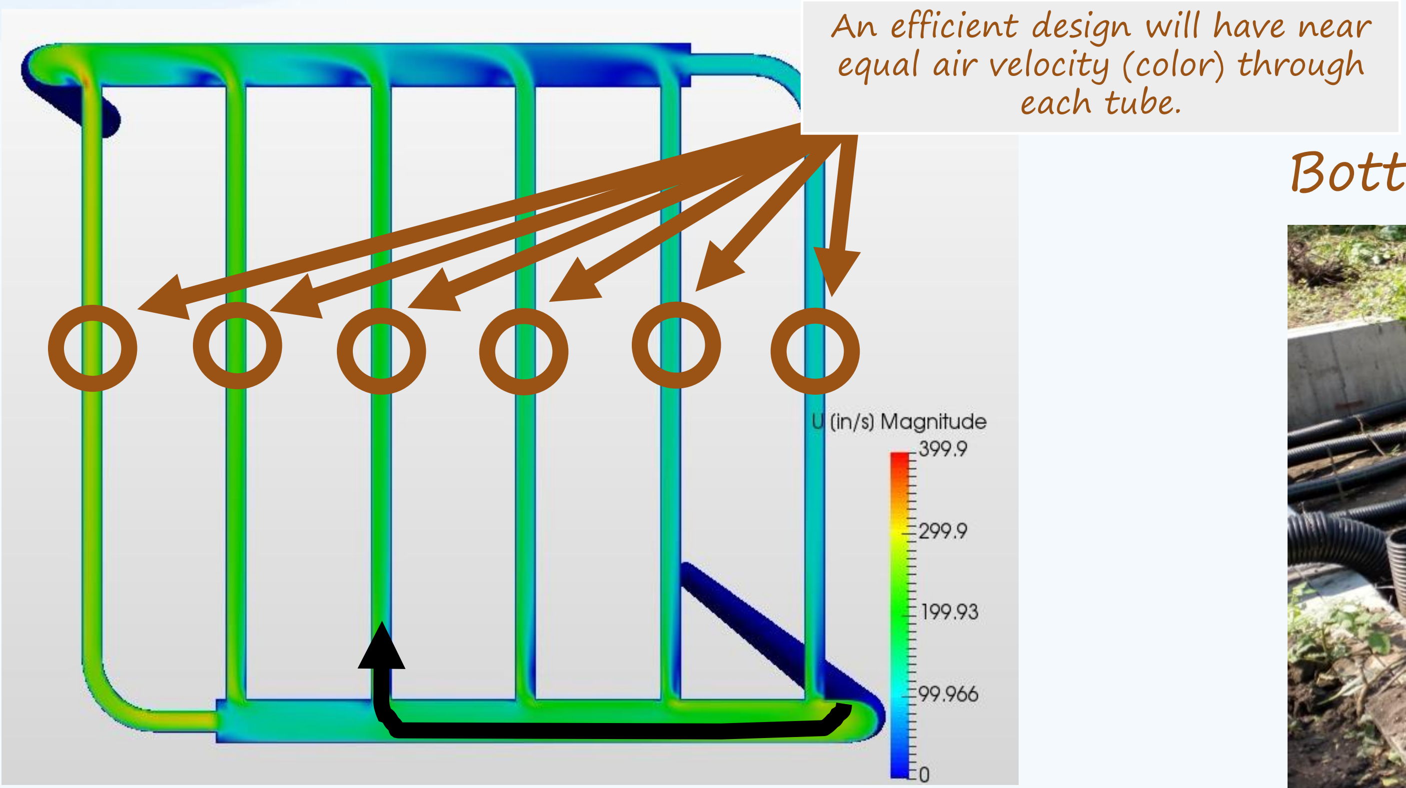
*R-value in ft²-°F-hr/Btu

None | 2” | 4” | 4” & 4’ | 4” & 2’



My Prototype System

Heat Exchanger



Bottom layer of heat exchanger tubes

Wayward Springs Acres, Aurora SD

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

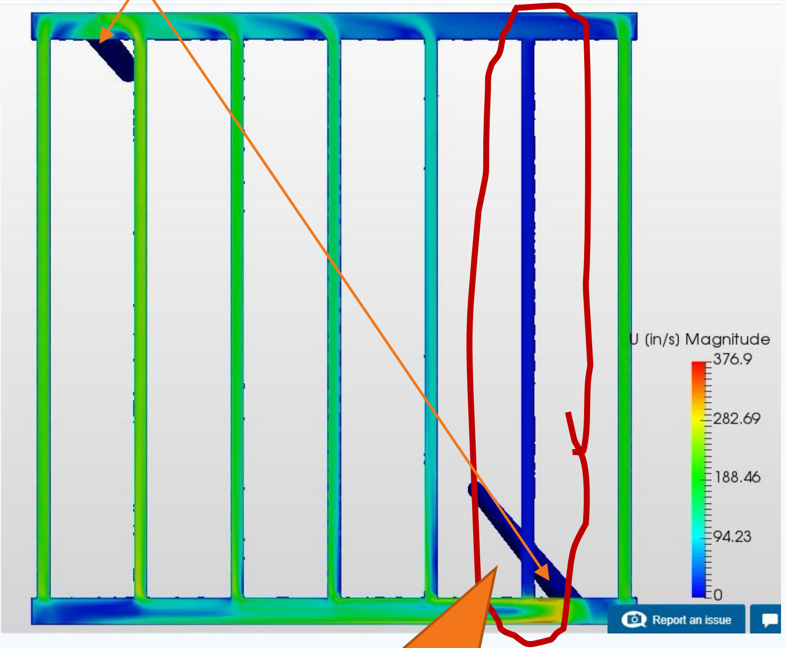
My Prototype System

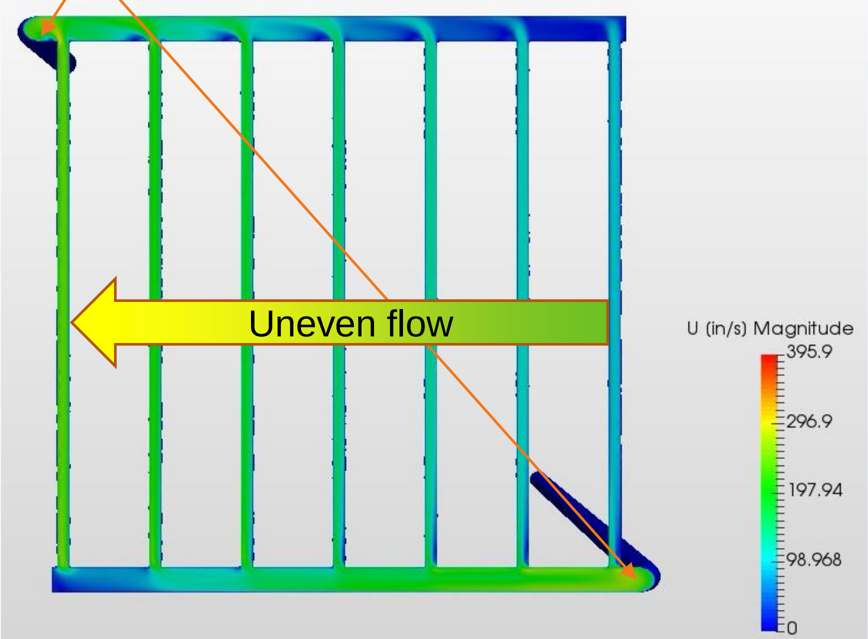
Heat Exchanger tube layout

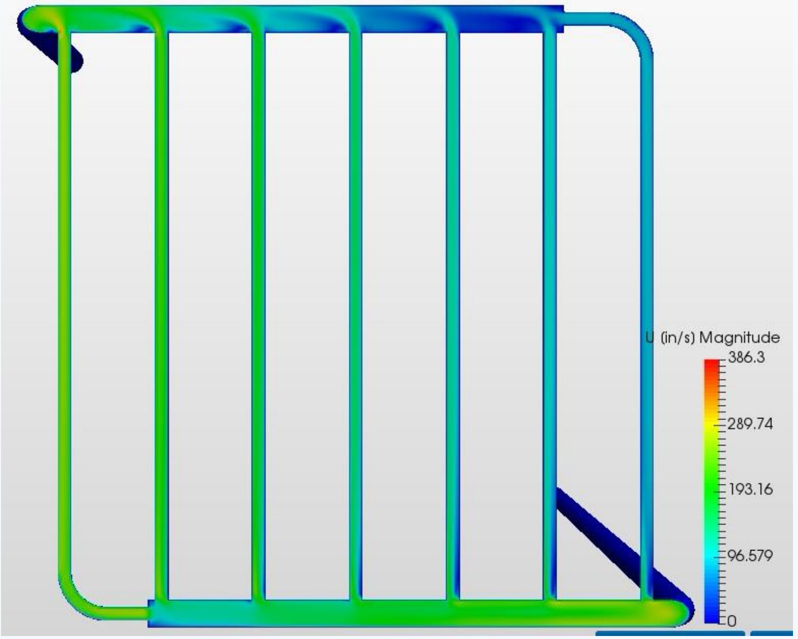
Colors show the speed/velocity of the air. Equal velocity through all cross tubes is desirable.

T-tube supply/return joint

90° Elbow







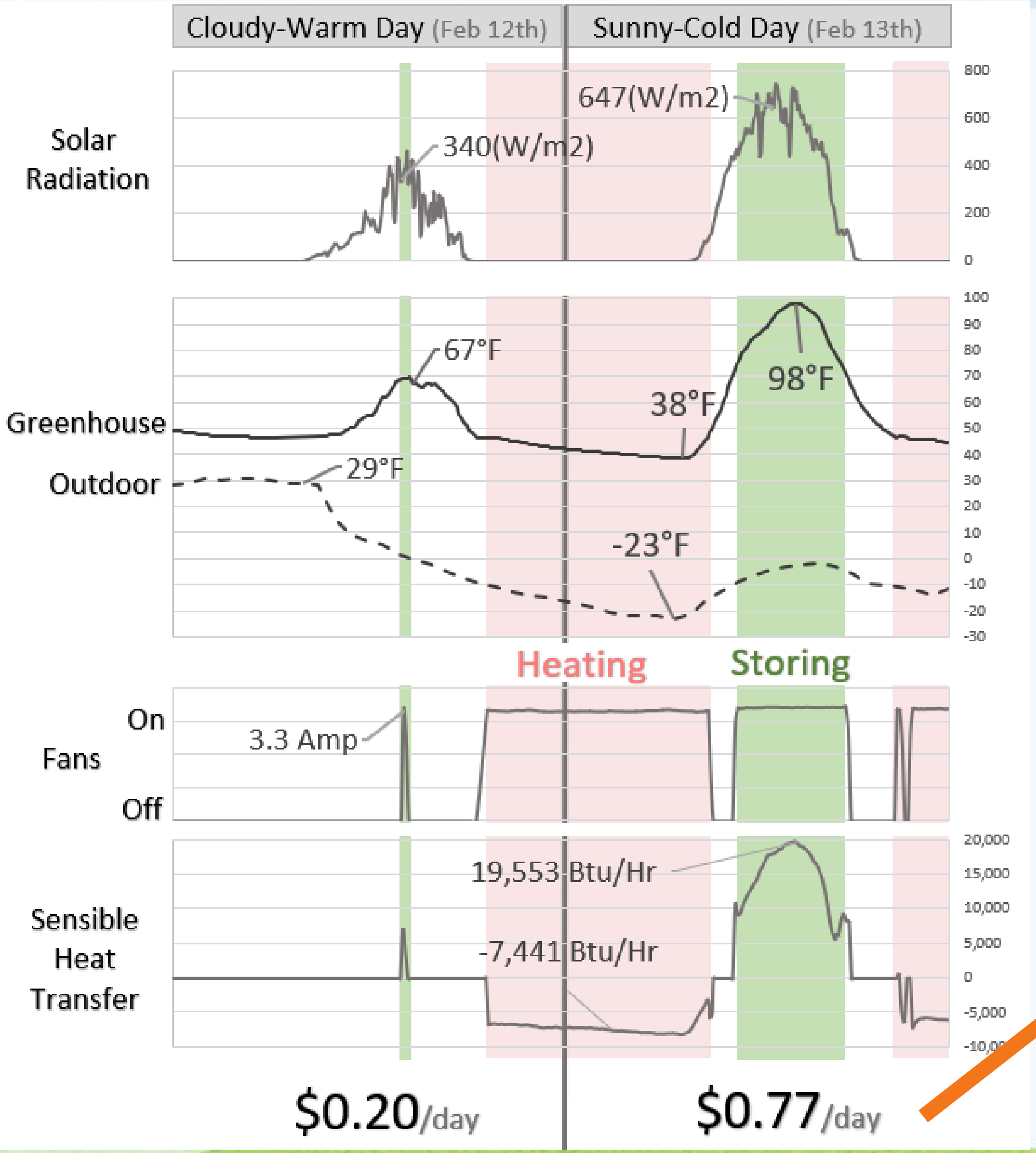
Tube near intake is starved of flow

Reasonably even flow, but could be better

Most even flow possible without extra cost.

2020 performance data

Daily Performance Example (Feb. 2020)

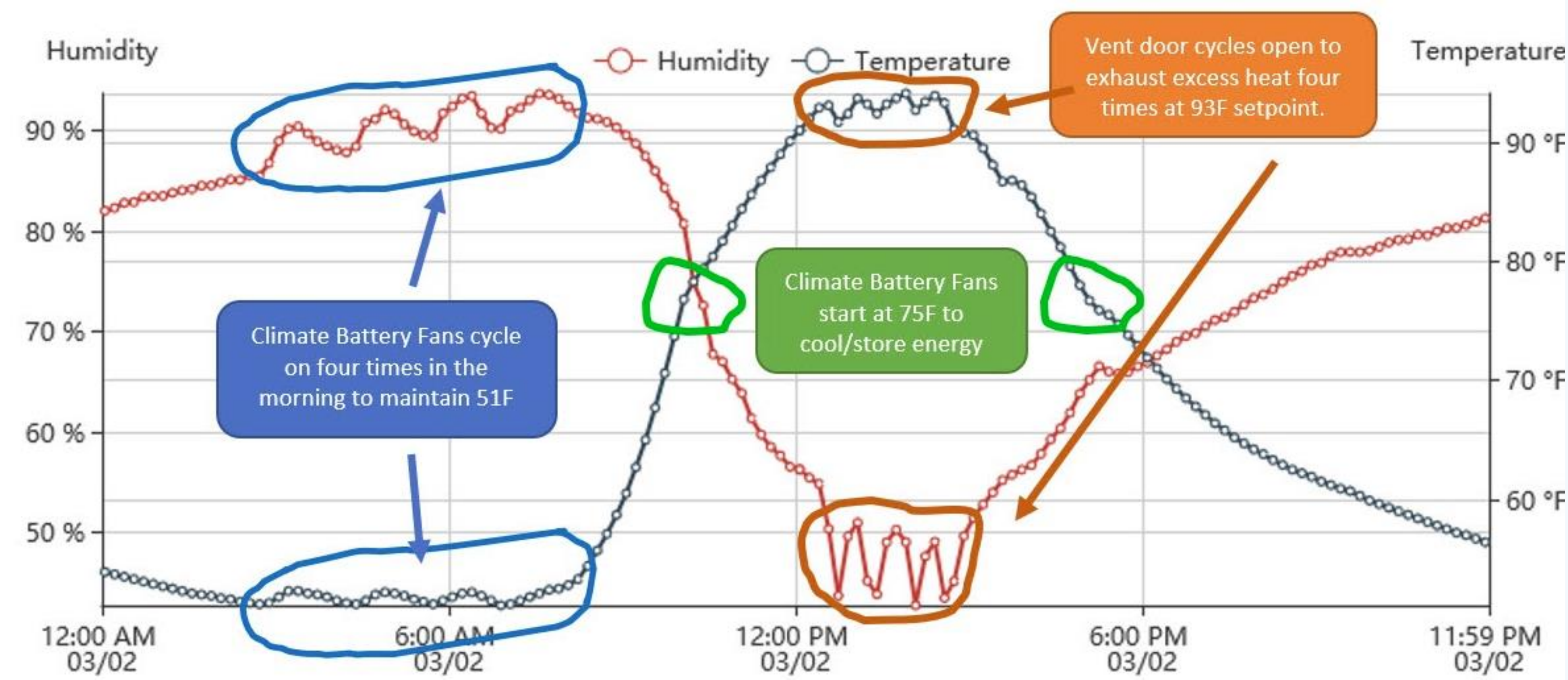


Traditional Greenhouse cost would be:

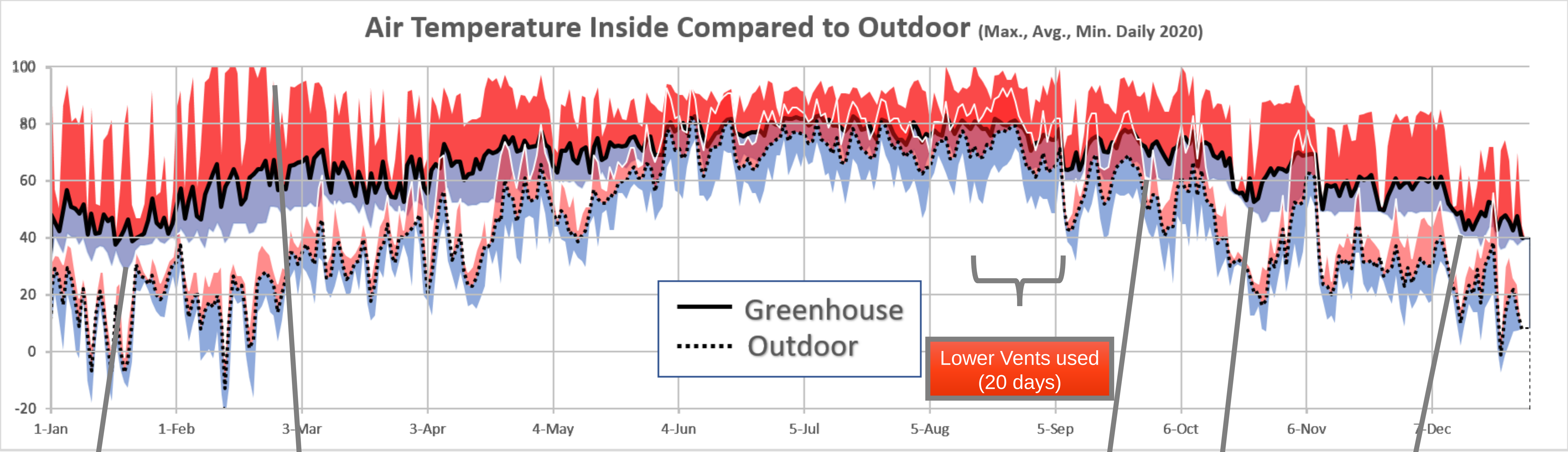
$5.40/day to propane heat an equal **glass or 6mil polyethylene** structure

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

Daily view: March 2nd 2020



2020 in Review



Coldest Point 29.1°F

Roof Vents Automated (90°F)

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

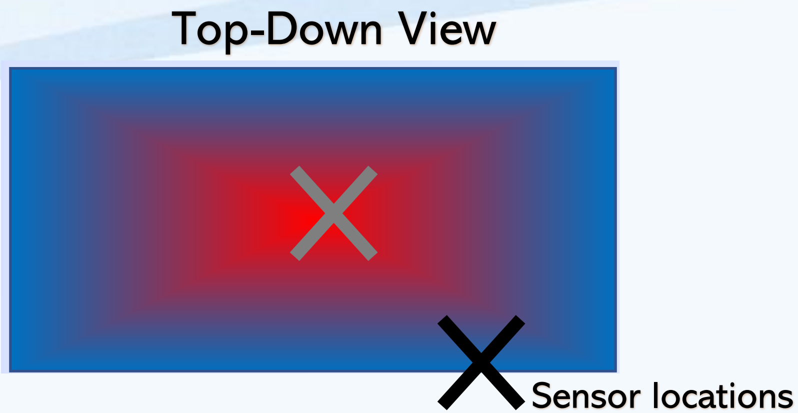
Heat Tstat @ 60°F

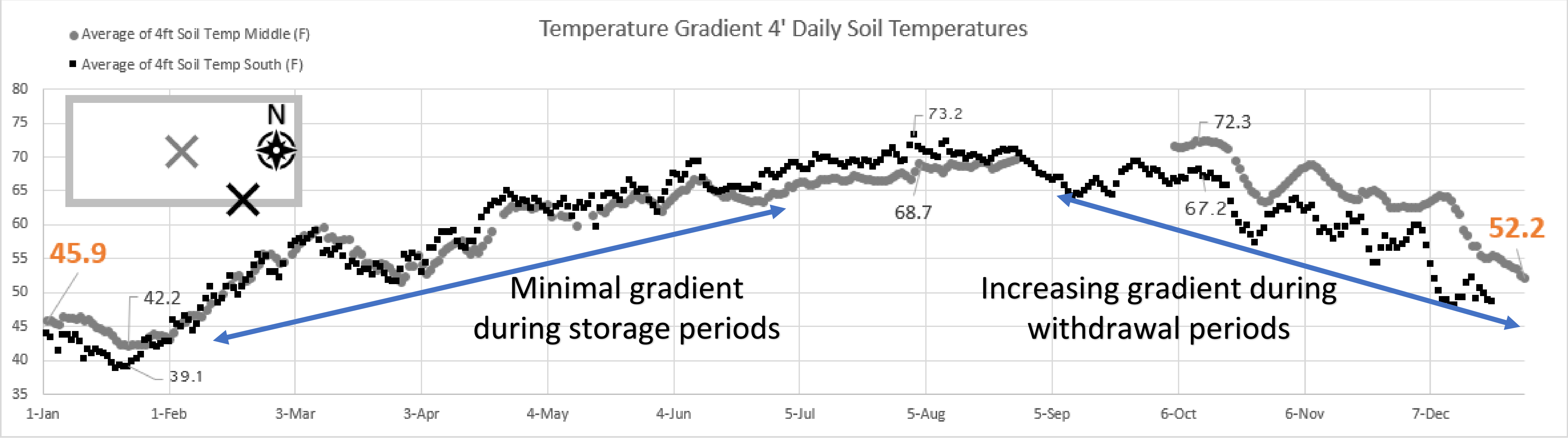
Heat Tstat @ 50°F

Heat Tstat @ 45°F

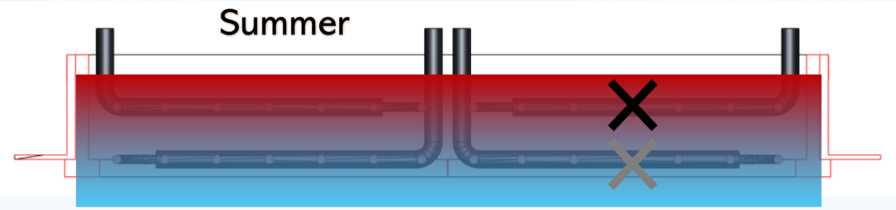
Horizontal Soil/Thermal Battery Temperature

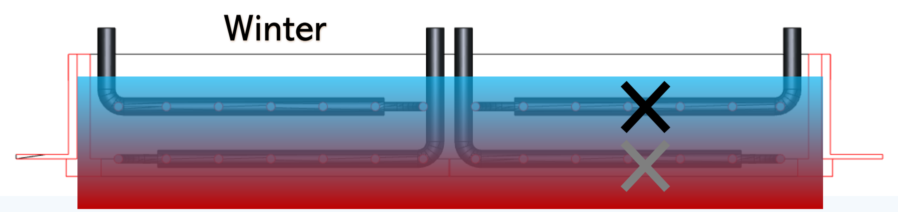
The temperature distribution should on average look like this:

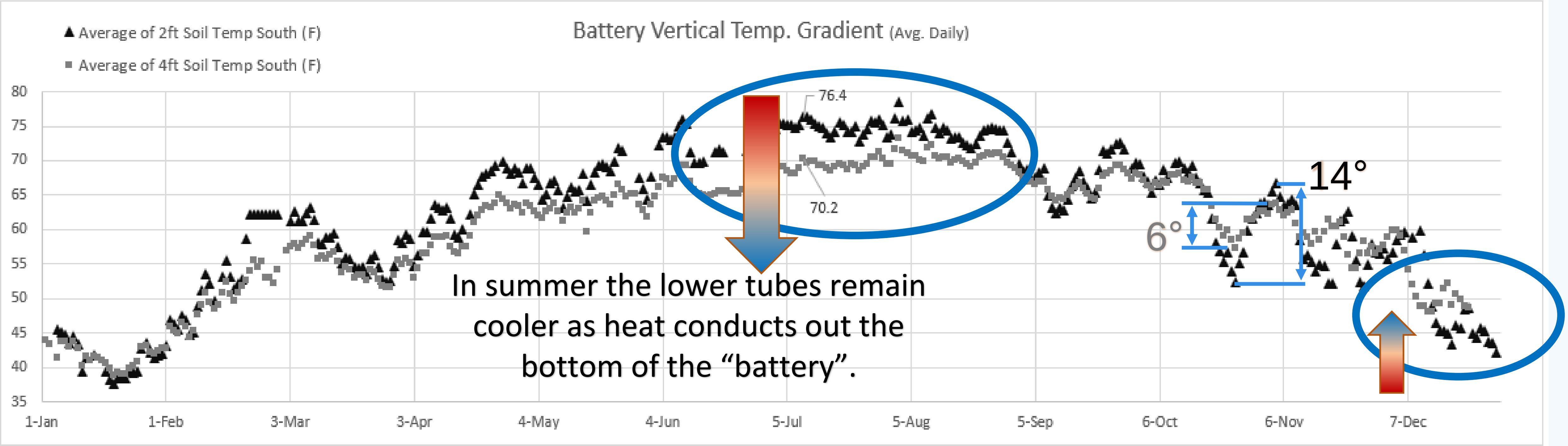




Vertical Soil/Battery Thermal Temperature





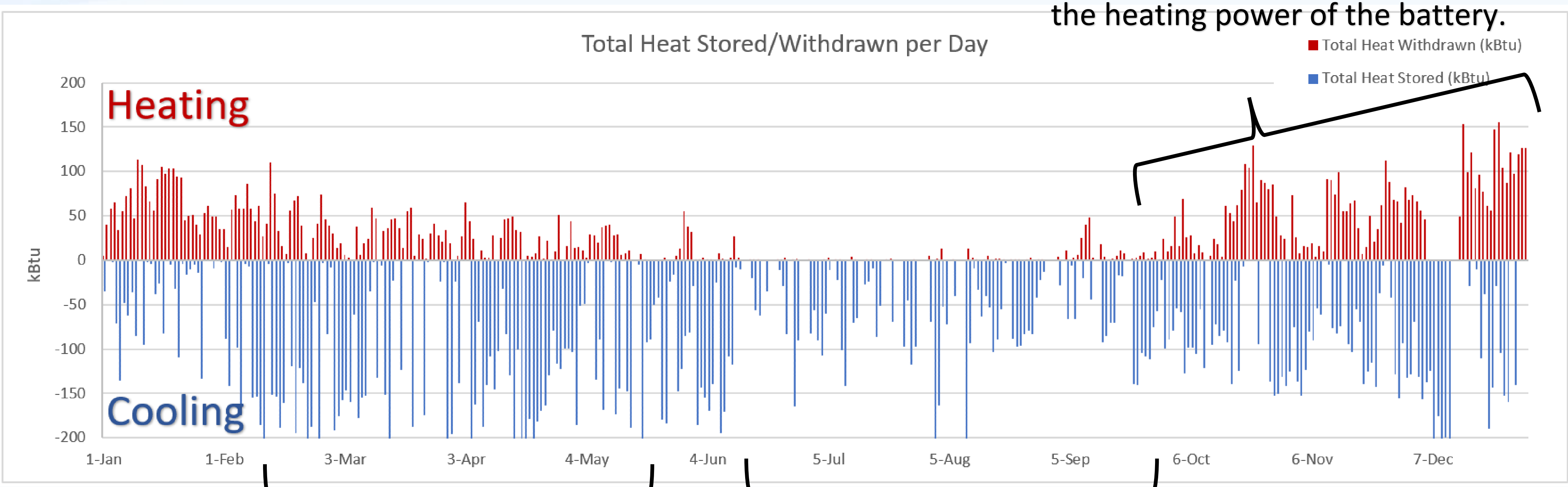


In winter, the lower tubes remain warmer as heat conducts up from below the "battery".

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

Total Heat Energy

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

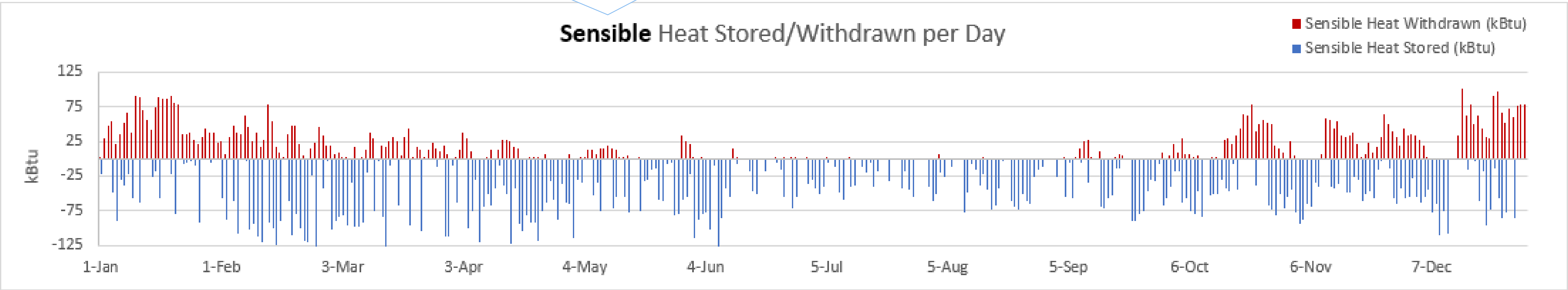


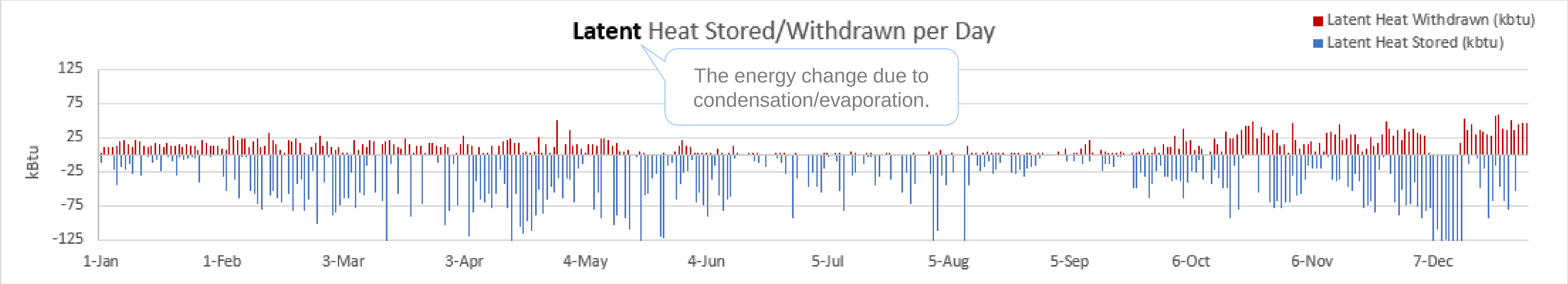
When the ground is “cool” it can absorb a lot of heat

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)

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

Things I’d do different:

- **Trellis properly for vine management**
- **Use grafted greenhouse varieties for crack resistance**

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

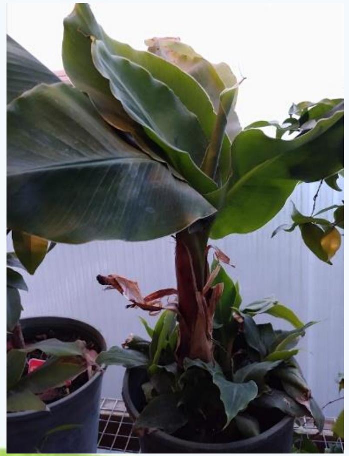
Some of the things I have/am growing:

Apocalypse Scorpion (Capsicum chinense)

dwarf Moringa oleifera

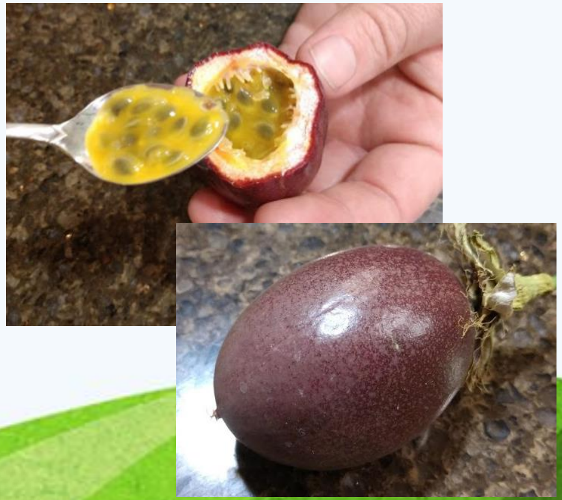
Monstera deliciosa “Swiss cheese plant”

Super dwarf banana



Melothria scabra “cucamelon”

Passion fruit “Passiflora edulis”



Some of the things I have/am growing:

Black Sapote (Diospyros nigra)

Pitanga (Eugenia uniflora)

Canistel (Pouteria campechiana)

Loquat “Big Jim” (Eriobotrya japonica)

Charichuelo (Garcinia madruno)

Longan (Dimocarpus longan)

Some of the things I have/am growing:

Anonaceae:

Cherimoya (Annona cherimola)

Soursop (Annona muricata)

Mountainsop
(Annona montana)

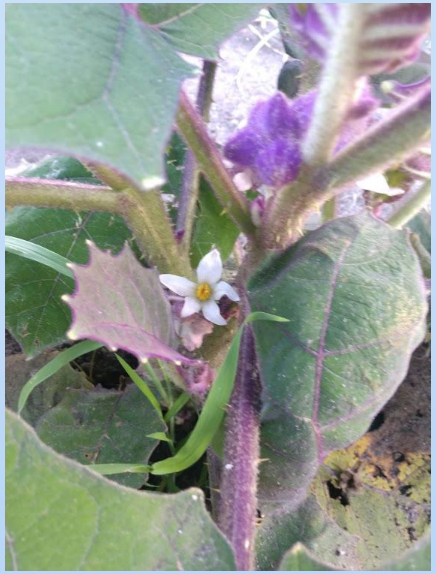
Sugar apple
(Annona squamosa)

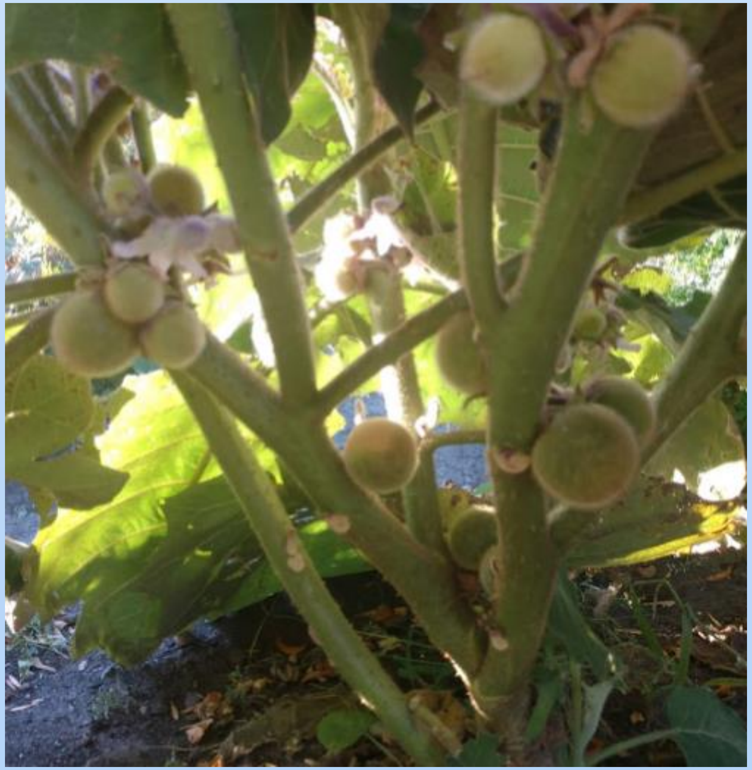
Atemoya
(squamosa x cherimola)

Bullock's heart (Annona reticulata)

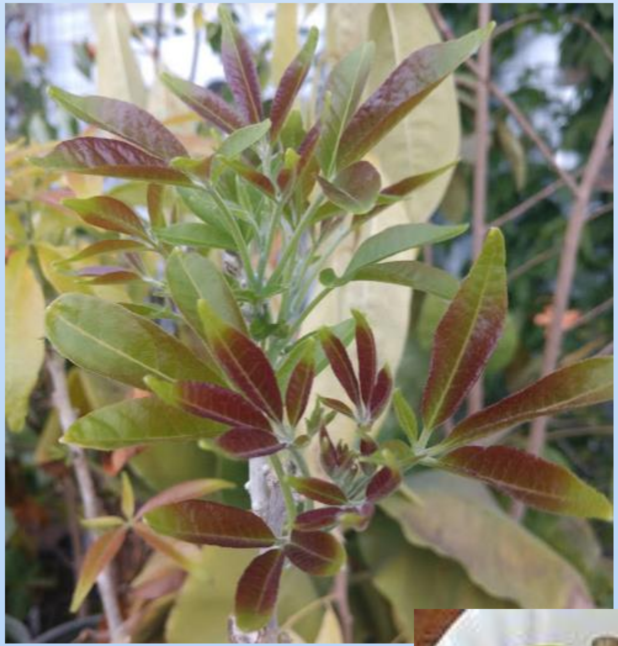
Some of the things I have/am growing:

Naranjilla (Solanum quitoense)





White Sapote (Casimiroa edulis)



Questions?

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