and does not noticeably increase efficiency. Make sure all parts of heat exchange tubing are at least 12 inches below the soil surface to avoid accidentally puncturing the climate battery while planting, tilling or reforming the beds. A good 9-12 inches between each tubing exchange layer is preferred (there are three layers) to maximize efficiency.

Air Exchange Rate: Ideally the entire air volume in the tunnel turns over completely 5 times per hour or 5 feet per second, meaning air is kept in underground heat exchange tubing for 3-5 seconds to allow it to cool to dew point.

Figure 5: Inside the climate battery, newly installed just in time before the snow. Notice the black air intake riser to the left (before mylar ducting is attached to draw warm air from higher up in the high tunnel).

Ground Insulation: 2" thick rigid foam insulation is laid in a 2' x 2' "bat wing" configuration (see diagrams). This is ideal for maximum heat loss prevention underground and ease of installation.

Supplemental Heat: Ideally use supplemental heat for the occasional string of excessively cold nights in a row in winter that can reduce heat storage capacity of the climate battery for an extended time period.

Some Additional Resources:

Design and Consulting:

Eco Systems Design, Inc • http://www.ecosystems-design.com/

Central Rocky Mountain Permaculture Institute • https://crmpi.org/

Climate Battery Calculator • www.ecosystems-design.com/climate-battery-calculator.html

CERES Greenhouse Solutions: Customized Climate Battery Design • www.ceresgs.com

Greenhouse Construction:

Vineripe Greenhouse Construction (Roxbury, VT) • https://www.vineripe.net/

Climate Battery Specifics:

The Forest Garden Greenhouse by Jerome Osentowski

Presentation PDF by Jim Schultz for his 30" x 72" tunnel • bit.ly/climatebatterypdf

Time Lapse Video of Climate Battery Construction on Red Shirt Farm • bit.ly climatebatterymov

Potential Grant Information:

NRCS High Tunnel Initiative • https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/eqip/?cid=stelprdb1046250

Berkshire Agriculture Ventures (applicable to those in the Berkshires) • https://berkshireagventures.org/funding-assistance/grants/

Energy Efficiency Division of MA • https://www.mass.gov/energy-rebates-incentives

Rural Energy for America Program (REAP) • https://www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency

Climate Battery Greenhouse:

Energy Efficient and Sustainable Winter Growing

Jim Schultz at Red Shirt Farm

Jim Schultz of Red Shirt Farm in Lanesborough, MA built his climate battery greenhouse in the fall of 2017 to save propane costs and trial an elegant solution to a more climate-friendly strategy for winter growing in New England.

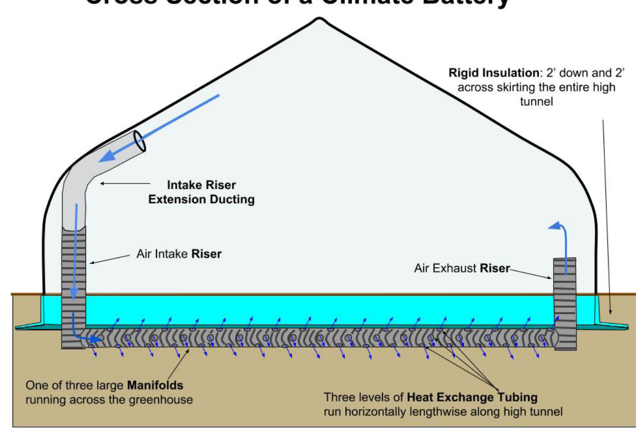
What is a Climate Battery?

A climate battery is a ground to air heating system comprised of a series of underground tubes that circulates air several feet below the soil surface. The circulating air helps regulate temperature and moisture in the greenhouse, minimizing (or eliminating) the need for propane heat in winter as well as helping reduce disease pressure by keeping air moisture low. The climate battery is a unique system built using low-cost materials, requires minimal maintenance and can be fitted to any size tunnel. Jim Schultz's high tunnel is 30 feet x 72 feet.

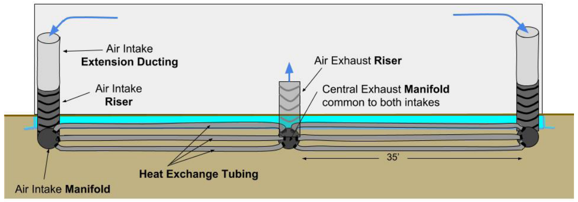
How Does It Work?

As the sun heats the air in the greenhouse during the day, the climate battery fans push the warm air from high inside the greenhouse several feet underground. The warm, moist air is pushed through a series of underground tubes transferring heat and moisture to the subsoil, essentially charging the large underground soil reservoir with latent heat. Cooler, drier air emerges into the greenhouse. When the sun isn't shining or when it is especially cold, the climate battery fan system can be turned on to supply warm air from the heat stored underground to the rest of the greenhouse. The underground tubing of the climate battery is 3-4 feet underground.

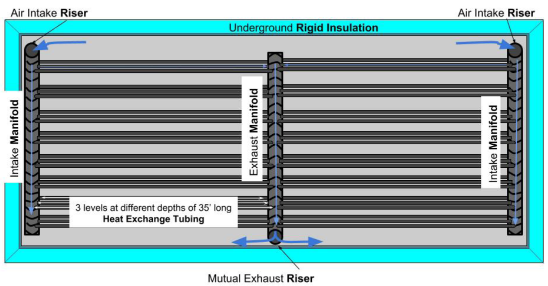
Cross Section of a Climate Battery



Lengthwise View of a Climate Battery



Overhead View of Climate Change Battery



<u>Components of a Climate Battery</u>

Climate Batteries have relatively few, inexpensive parts. Here are the materials that Jim used in constructing his climate battery inside his 30′ x 72′ tunnel. See the diagram of the Climate Battery crossection, overhead and lengthwise view to determine the placement of each of the components listed here.

Heat Exchange Tubing: Jim's tunnel used 3570 feet of 4″ perforated ADS plastic drainage pipe with sock cover

Manifolds: Three lengths at 25′ 6″ of 12″ ADS N12 dual-wall HDPE drainage pipe

Risers: Vertical sections of pipe for pulling air in and out of underground tubes. 15″ ADS dual-wall HDPE drainage pipe: 2 pieces at 6′8″ and 1 piece at 4′11″

Rigid Foam Insulation: Insulating the ground under the high tunnel is absolutely essential for the Climate Battery to function efficiently. Twenty-six sheets of 4′ x 8′ x 2″ foam board were used.

Intake Riser Extension Ducting: 18″ flexible Mylar ducting

Intake Fans: Two 12″ greenhouse HAF fans

Variable Speed Fan Controllers: Two

Climate Battery Controls: Jim used hard-wired commercial greenhouse thermostats to monitor and manage his climate battery system. Wireless network monitoring is available, but must be built able to withstand a greenhouse environment.

Extra Components To Consider:
All-in-one controller: Have all monitoring equipment in one set of controls. This option is more expensive, but simpler to use.
Automated roll-up sides: Automate temperature regulation for your tunnel.

Solawrap plastic: Solawrap is a higher grade plastic, a "bubble wrap" for your tunnel with increased insulation rating, less glare, easier to install, longer lasting (20 + years), and extremely high rating to withstand damage (including hail, high wind and snow).

Figure 1 Installing Solawrap on a high tunnel, one 4 foot plastic panel at a time. Each panel is secured to the high tunnel frame.

<u>Costs:</u>

These costs are, of course, unique to Jim Schultz's site, location, and design, however costs will be comparable to other New England farms.

Material expenses: $6,301.14
Service expenses (Excavation, Labor, Engineering Design): $5,832.00
Grant support: $9,118.00

Total cost: $3015.14

Propane Savings estimated:
$1400/year ($1.90/gal)

Payback period with grant:
2.15 years; without grant: 8.6 years

Figure 2 Laying out the first of three layers of heat exchange tubing.

<u>Design Considerations:</u>

Underground Heat Exchange Tubing Length: 25-35′ is what is recommended to maximize heat transfer underground and take advantage of latent heat of condensation for the climate battery design.
Radon Testing: Do a radon test to ensure your underground soil is radon free.

Figure 3: Backfilling soil onto the last layer of the heat exchange tubing. This last layer must be at least 12 inches below the soil surface.

Soil type considerations: Heavier soils will store more heat allowing for closer heating arrays while lighter sandy soils require more spacing between underground tubes. A sandy loam is ideal for the spacing in the design represented. Soil with too much clay (more than 20-25%) can be problematic for climate battery systems as water condensing underground can sometimes cause a clay "shell" to form around the underground heat exchange tubing, ultimately clogging the system.

Figure 4: Installing the rigid insulation after the underground climate battery installation is complete.

Depth: In climatic zones 4 and 5, the heat exchange tubing array is buried 3′-4″ for optimal performance. Going deeper is prohibitively expensive