Shallow Geothermal Earth-to-Air Heat Exchangers for Enhanced High Tunnel Season Extension: Background and Benefits

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Shallow Geothermal Resources

Unlike deep geothermal resources that are limited to certain geographical regions and accessed deep underground, shallow geothermal resources rely on the insulating properties of just a few feet of soil. Ground-source heat pumps used for home heating and cooling can be installed in trenches as shallow as 4-6 feet underground and earth-to-air heat exchange (EAHX) systems for agricultural season extension are commonly installed at 2-6 feet (USDOE BTO, 2015, Sethi & Sharma, 2008). The soil provides insulation, but at more shallow depths the temperature shifts throughout the year due to seasonal changes. Figure 1 shows how increasing depth of soil narrows the temperature fluctuations throughout the year and gives a longer lag. At these shallow depths, soil is likely to be cooler than outside air in the summer, and the long hot days will 'recharge' the thermal battery of the soil so that the underground temperatures are warmer than outside air through fall. Because of this, shallow geothermal systems can provide both cooling and heating of outside air at different parts of the year.

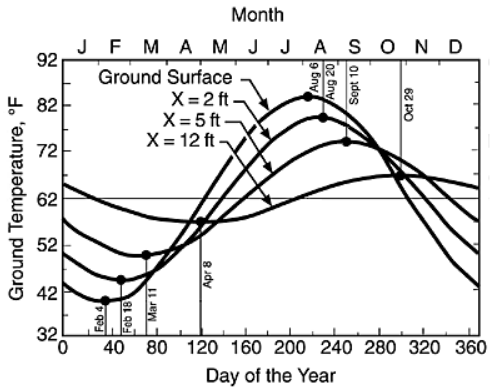

Figure 1 Soil temperature, time lag, and depth. Source: Virigina Tech University

Earth-to-Air Heat Exchangers (EAHX) for Heating and Cooling

The temperature difference between soil and outside air can be harnessed using a heat exchanger. Heat exchanger systems rely on circulating a fluid through a large surface area so that heat can be transferred. An EAHX is a simple form of heat exchanger, using the same air to exchange heat with the soil that is then circulated through the building. An earth-to-air heat exchanger uses a to fan pull air through the underground system and direct it into the structure. These systems are also called earth tubes, cooling tubes, or ground-source heat exchangers.

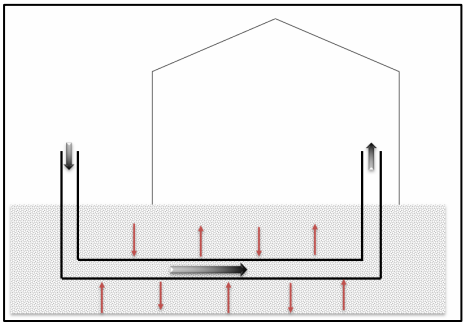

Figure 2 Non-recirculating EAHX with air flow depicted by gray arrows and heat flow depicted by red arrows

Opportunities for EAHX

Because of the capacity to provide both heating and cooling, EAHX are promising for season extension for controlled environment agriculture production in greenhouses or high tunnels. EAHX can help provide heating in the fall and lengthen the production season, while in the summer, exposure to the underground cool environment serves to temper and cool the air, which can help combat extreme high temperatures in high tunnels or greenhouses (Sethi & Sharma, 2008).

Closed loop or recirculating EAHX (Figure 3, top) systems typically have the intake and outflow to the heat exchanger at opposite ends of a high tunnel, which can be useful for maintaining warmer temperatures in the growing environment when outside temperatures drop but will have lower effectiveness for cooling in the summer.

Open or non-recirculating EAHX systems (Figure 3, bottom) bring in outside air, and in addition to greater cooling capacity, effectively increase the ventilation rate which can improve outcomes for plant heat stress or disease from high humidity environments (Watson et al., 2019).

Because of the seasonal constraints depicted above in Figure 1, shallow geothermal EAHX systems alone may not provide high tunnel conditions needed for year-round production, but they can enhance season extension and provide an alternative to fossil-fuel powered heaters. Additionally, the fan and controls of an EAHX system can be powered with a solar panel and battery system, at sites that aren't grid accessible.

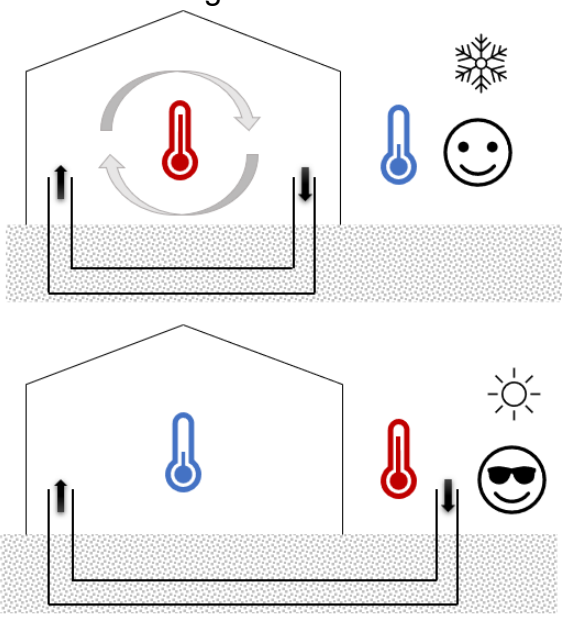

Figure 3 Top: recirculating systems have advantages for maintaining warmer temperatures. Bottom: open system have advantages for cooling

Challenges for EAHX

Air Quality: When high temperature or humid air travels through the underground tubes, condensation will occur. Perforated pipes have been used to allow moisture out, but these perforations also allow moisture and possibly radon gas in. The design for an EAHX system should exclude moisture by protecting the intake from rain intrusion, using solid pipe, and ensuring watertight connections between components. The system should also include a low point and access point to pump out water. In addition, using EAHX in conjunction with fresh air ventilation will reduce air quality concerns.

Costs: Geothermal systems, including EAHX, are often considered cost-prohibitive because of high excavation costs. Rather than large pit excavations under the whole foundation of a high tunnel, this project focuses on trenches installed with common earth-moving equipment and retrofit to existing high tunnels.

Benefits from EAHX System Pilot System

With the support of an Ohio State University Paul C. and Edna H. Warner Grant for Sustainable Agriculture, we designed and install a single-tube EAHX system as a retrofit to an existing high tunnel at Oaks and Sprouts, Limited in Urbana, Ohio in December 2022. The total cost of supplies and system installation was around $2,500, which is comparable to the cost of some propane-powered greenhouse heaters.

The system used 60' of 6" solid corrugated drainage pipe in a 5.5' deep trench. The system's fan was a humid-environment rated in-line blower, which operated at 215 cubic feet per minute, equivalent to about 0.5 air changes per hour for the high tunnel. The fan ran continuously from March 2023 to February 2024.

Figure 4 Top: intake and pump access point of EAHX. Bottom: distribution fan for EAHX

Based on observations from May – November 2024, the following benefits were achieved:

Cooling: The EAHX provided cooler air than ventilation alone in hottest summer months. Compared to outside weather conditions, cooling capacity reached a peak cooling load equivalent to ¼ ton air conditioner.

Heating: Use of the EAHX delayed use of propane heater in fall. The heat provided by the EAHX was equivalent to 4 gallons of propane in first eight weeks of Fall 2023. The EAHX system allowed tomatoes to continue to grow in the high tunnel until the end of November 2023, when external conditions were below 20ºF for extended times.

Resources:

US Department of Energy Building Technologies Office (USDOE BTO). Ground-Source Heat Pumps. Building America Solution Center Accessed Jan 31, 2024. https://basc.pnnl.gov/resource-guides/ground-source-heat-pumps#edit-group-scope

Sethi, V. P., & Sharma, S. K. (2008). Survey and evaluation of heating technologies for worldwide agricultural greenhouse applications. *Solar energy,* 82(9), 832-859.

Virginia Tech University. Earth Temperature and Site Geology. In: Geothermal Heat Pump Technology. N.d.

Watson, J. A., Gómez, C., Buffington, D. E., Bucklin, R. A., Henley, R. W., & McConnell, D. B. (2019). Greenhouse Ventilation: AE-10/AE030, rev. 11/2019. UF IFAS.

Installation Guide for a Retrofit Shallow Geothermal Earth-to-Air Heat Exchangers for High Tunnels

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System Description

This guide is developed based on the experience of installing a shallow geothermal earth-to-air heat exchange systems as a retrofit to provide supplemental heating and cooling to a production high tunnel at Oaks and Sprouts Limited in Urbana, Ohio. The system was installed in December 2022 with a 60’ run of 6” solid corrugated drainage tile installed in a 5.5’ deep trench. The system’s fan was a humid-environment rated in-line blower, which operated at 215 cubic feet per minute (max 538 cfm at 0” static pressure), equivalent to about 0.5 air changes per hour for the 30’x96’ high tunnel.

EAHX System Design Considerations:

Fan Selection & System Sizing: The heating and cooling capacity delivered by the system will depend on the depth of the EAHX piping and the airflow rate through the system. The deeper the EAHX system is installed, the more insulated it will be from external conditions. The higher the airflow rate, the more capacity the system has to deliver tempered air, but at higher airflow rates, a larger fan (able to operate at higher pressures) is needed. A rule of thumb based on the systems we’ve designed is to plan for a ventilation rate around 0.5 air changes per hour (ACH). Ensure that fans are rated for high-humidity environments.

Pipe Length and Diameter: The pipe selection impacts the system’s thermal exchange efficiency and the fan requirements. Greater surface area in the pipe leads to greater heat transfer and can be increased through lengthening the system or by using corrugated pipe which has higher effective surface area. The fan must overcome higher pressures when using corrugated pipe, when the system is longer, and when the pipe diameter is smaller. Corrugated pipe is commonly used in EAHX systems as it has a low cost per ft, is rated to be buried under soil, and the corrugations provide high effective surface area for heat exchange to take place. Solid (non-perforated) corrugated pipe should be used, and care taken at each joint and connection point to ensure moisture isn’t able to intrude into the system. Of commonly available sizes, 4” corrugated pipe and its fittings are the most readily available with the lowest cost per foot, but 6” corrugated provides more airflow and reduces pressure drop.

Longevity: To promote the longevity of an EAHX system, care should be taken at install to avoid crushing the pipes by manually backfilling the trench until pipes are covered. Additionally, pests should be excluded from the underground pipes with barriers at the intake and output point. Finally, there should be a designated access point for moisture removal where the system slopes to a low point, and at installation all joints should be made water-tight.

Installation Considerations:

Controls: Because of the seasonality of the soil temperature that the EAHX relies on, it is beneficial to include thermostat control of the EAHX fan. A humidistat control can also turn off the EAHX when it is raining or high humidity conditions outside.
Intake/Output Placement: The EAHX system's intake should be made visible and located in a low-traffic area. The system output should be directed towards circulation fans or distributed along the center length of the tunnel.
Moisture exclusion: Mold-promoting conditions could develop in tubing due to water intrusion or natural condensation. Ensure watertight connections in the piping, use solid (non-perforated) piping, and exclude rain at intake. Plan for moisture removal by installing a pump access point at the low point of the system. Additionally, we suggest using an EAHX in conjunction with plenty of fresh air ventilation.
Pest exclusion: It is a good idea to secure pipe openings against any bugs or larger pests who may try to move in. Wire mesh can be used, but we have noticed that pollen, bugs, and other materials can build up on the surface, similar to a lint trap in your clothes dryer. This makes your fan work harder, so clean off the mesh surface regularly. Another way to reduce problems from lint build up is to have a larger surface area of mesh compared to the opening area of the intake pipe.
Follow applicable regulations: Always call 811 before you dig and follow all relevant local regulations and requirements before performing an excavation. Caution: trenches deeper than 4' pose a potential hazard from the collapse of the earth walls on workers. Follow the required code and only attempt electrical work that you can safely and legally perform in your zoning and skill level.

Key Installation Details:

Trenching Equipment: For installations, we have used a backhoe with 18" bucket and a walk-behind trencher. Note that trenchers must have a cut width larger than the pipe size and may excavate shallower than their rated depth in wet and high-tilth soils.

Tools

Project	**Tools**
Trench	Spade shovel, cutter mattock, spud bar
Electrical	Standard electrical toolkit. Follow the required code and only attempt electrical work that you can safely and legally perform in your zoning and skill level.
HVAC	Impact driver and with bits, drill with associated bits, scissors, straight-cut aviation snips, ladder, metal chop saw, ratchet set.
Pipe Fitting	Impact driver with associated bits, sharp scissors for pipe tape, 6' level, reciprocating saw and/or PVC hack saw, rubber mallet.
PPE	Cut resistant gloves, disposable gloves, safety glasses, caution tape and safety cones for trench perimeter.

Materials: Intake and Underground System

Corrugated Pipe: 6” solid corrugated pipe was purchased in a roll of 100’. We wanted non-perforated pipes to protect against water intrusion.
PVC Pipe: Sewer/drain type PVC pipe was used for the risers of the EAHX system.
Connections: Multiple methods were used to ensure watertight connections: Corrugated pipe internal couplers (Figure 1) are designed to connect two corrugate pipes but can be friction fit into PVC pipe. Moisture resistant pipe wrap tape or ‘tile tape’ (Figure 2) was wrapped several times over the coupler connection point – this thin tape is able to contour to the pipe’s corrugations. Finally, a 6” rubber flexible coupling was secured over the wrap point. An impact driver was needed to tighten the rings around the flexible coupler.
Water and Pest Exclusion: In one system, a 90° elbow and 45° elbow were attached to the riser PVC pipe so the opening would be angled down (Figure 3). To protect against pest intrusion at intake, fine wire mesh was secured around the intake opening with a length of hanging strap wrapped around the outside of the PVC and secured with self-tapping screws (Figure 3). In another system, an appropriately sized chimney rain cap already outfitted with wire mesh was used to prevent moisture and pest intrusion.
At the ground level, the riser was cut, and a wye installed and fitted with a cleanout adapter and sewer cleanout plug.

Figure 5: Left: EAHX Intake Riser with wye at ground level and elbows and mesh at intake. Note supporting lumber before backfilling. Center: cone top chimney cap with screen used in other EAHX systems. Right: Corrugated to PVC connection showing tile tape, rubber coupler

Insulating EAHX Riser

The pipe should be insulated or stay buried before entering the high tunnel, so the heat exchanged isn’t lost. Corrugated pipe can easily make some gentle curves to come up

into the tunnel, or solid PVC pipe with 45 elbows can be used. At the Oaks and Sprouts high tunnel, the section under the wall had to be hand-dug to meet up with the trench.

Materials –High Tunnel Structure and Distribution

Fan support: The fan was mounted on a strut which was secured with two points of contact to a support beam of the high tunnel. Brackets were secured around the high tunnel support with self-tapping metal screws. A threaded rod was attached to the brackets with an I-bolt and threaded rod coupler. The threaded rod was secured to the strut with strut channel cone nuts. This set-up gave some flexibility in adjusting the strut to a level position before the fan was mounted

Air distribution: A duct boot at the top of the system directs air from the EAHX system towards the nearest circulation fan. A few flex duct elbows were needed to match the curvature of the high tunnel and keep the ductwork out of workspace as much as possible. Large size hose clamps were used to secure the ductwork to high tunnel supports. Specialty duct reducers were used to convert between the diameters of the PVC pipe, the fan, and the ductwork (Fig 6). Additional wire mesh was secured around the duct outlet with hanging strap and screws.

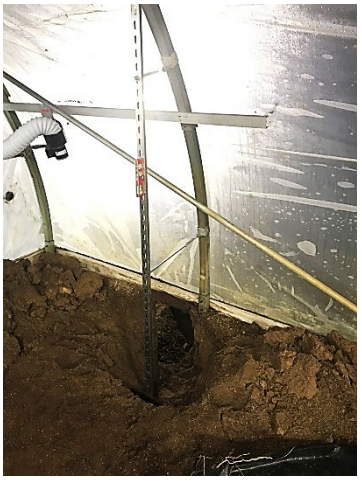

Figure 6 Top: Strut assembly before fan mounting. Note hand-dug trench under high tunnel wall. Bottom: fan and ductwork for air distribution

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Summary Materials for Oaks and Sprouts Installation

Parts	**Cost**
In-Line Fan: high flow (754 cfm max) can overcome high pressure	$550
100’ roll of 6” corrugated pipe	$180
PVC Pipes and fittings: (2 sticks) 10’ PVC, (3) 90º and (2) 45º elbows (1 Roll) Tile Tape (2) 6” Corrugated couplers (2) 6” Rubber flexible coupling (1) Sewer Cleanout Plug, (1) Cleanout Adapter, and (1) Wye	$620
Electric: (3) 45º and (3) 90º ½” Schedule 40 Conduit elbows (2 sticks) 10’ ½” Schedule 40 Conduit 20 Amp Single-Pole Plug-On Neutral Dual Function Circuit Breaker (100 ft)12 AWG thermoplastic high-heat resistant nylon-coated (THHN) Solid Core Stranded Wire	
Securing to high tunnel: (1 stick) 10’ strut (10) strut channel cone nuts 3/8” Threaded rods and nylon lock nuts	
Air distribution: Flex elbow ducts as needed Duct boot (direct air outflow) Fine bug mesh, pipe strap, and self tapping metal screws	
Labor and Equipment: Backhoe for one half-day	$500
Provided by Oaks and Sprouts – 4 2x4s sacrificial lumber, 6” duct fittings, small hardware, wiring supplies (ex. wire nuts, electrical PVC glue, PVC terminal adapters and parts, light switch, outdoor rated light switch box and cover).	$200 (est)
Total	$2,050