Earth Tube Design

Contents

1. Earth Tube Design
2. The Equations!
3. Earth Tube Material:
4. Earth Tube Length:
5. Earth Tube Diameter:
6. Earth Tube Layout:
7. Earth Tube Depth
8. Camels Nose Heat Exchanger?
9. Air Intake:
10. Ventilation Requirements:

Earth Tube Design

Earth tubes (also known as Earth-Air Heat Exchangers, EAHX in professional circles, or as "***Cool Tubes***" in Australia, or by a variety of other names) can be designed many ways. Most home owners who install them realize that, while they are dealing with very ancient and intuitive technology, Earth Tubes are still poorly understood and somewhat "experimental". While specific performance data is somewhat lacking, there are many experts with their own rules of thumb… Here I will try to sort it all out.

Since I plan to invest thousands of dollars in my own Earth-Air Heat Exchangers (a more sophisticated term than Earth Tubes), I have done a lot of research in order to try and optimize my designs. I have found that there are a wide variety of approaches out there. Some earth tube systems are long (hundreds or thousands of feet), others are short (less than 50 feet). Some propose 4 inch diameter PVC, others are using 24 inch diameter cement tubes. Various layouts, depths and other design features (weep holes, insulation, flexible connectors, etc) are talked about with great pride or warning. Many of these designers talk about how their method is the only good method, one particularly rambling blogger warned that any changes from his specific design could only result in disaster. However, almost all of the designers talk about how successful they were *(few have really good data to back it up, but some do and that fraction is growing)*. I have concluded that because of dynamic effects (such as fluctuating operating temperatures and moisture levels), the wide range of parameters and the lack of information regarding material properties or other boundary conditions, it may be difficult or impossible to be sure of an optimal earth tube design (at the current state of the art). However, the wide variety of success indicates that the tolerances for a "***pretty good***" earth tube design are quite flexible and there is good understanding for how the parameters affect performance.

There has also been sufficient experience to make certain "danger zones" clear. As far as I can tell, the main dangers include…

1. Moisture leading to mold and other problems => Make sure to slope your earth tubes and provide good drainage so condensation can exit. Stay above the water table and keep rain water out. Be careful with corrugated flex pipe as it could potentially provide lots of places for water to collect.
2. Blockage rendering the tubes useless => Keep bugs and critters out, design the tubes so they won't cave in, provide multiple paths as a more robust system, etc.
3. Flow resistance making it too difficult to move air thru the tubes => system losses (both friction and dynamic losses) add up. Try to keep the pipe short enough (or large enough diameter) to avoid this problem. Smoother pipes can be narrower or longer. Avoid constrictions in the flow, such as two pipes coming into one of the same cross sectional area. Avoid fittings that try to turn the flow too quickly (such as 90 degree elbows) as these can double the back-pressure…

Other factors, such as how much heat is transferred, etc. are just performance details.

In the end, the key to good duct design (earth tubes are buried ducts) is compromise for economy. The ideal design uses the minimum length of very standard pipes with as few dynamic losses as possible driven by an appropriately sized and affordable fan.

The Equations!

I moved the sections about frictional pressure drop, dynamic pressure drop and Reynolds number to this page.

Earth Tube Material:

When designing an earth tube system, choosing the type of pipe is the most important decision. I recoomend either solid HDPE pipe or double wall (corrigated outside, smooth inside) HDPE pipe.

You can find more details about Earth Tube Material options here.

Earth Tube Length:

Of course, all the parameters (length, diameter, smoothness, path) work together to determine the final performance. But all other things being fixed, increasing the length of an earth tube provides more length for heat exchange, it also increases the friction and back pressure. If it is too short, you have less than optimum heat transfer, but it it is too long, it is much harder to get air to flow thru it at all. At a certain point, the back pressure increases to the point where natural convection can not move the air. At a more extreme length, the back pressure could reach a level that not even a fan could blow the air thru it. Cost is a more complex function. There are certain minimum costs for delivery and getting a crew out to help install the pipes (HDPE pipe requires a professional). There may also be a minimum order to get decent pricing. Once you have a truck making a delivery, there is not much difference in delivery cost if it is a full truck or a half truck. Also, if the pipe needs professional installation, getting someone out for 1 hour usually costs the same as 4.

There are many tools for calculating the length of pipe that you need. Problem is they usually assume a certain flow rate and don't take back pressure into account. They also don't take the ability of the soil into account. I will link to some calculators here eventually, but for now I found that rules of thumb based on working examples are just as good. Passivhaus builders will tell you the diameter tubes that worked for them. I often see 6 inch pipe used in 250 ft lengths with a fan to keep things moving.

Talking with Adam Bearup recently and he mentioned some experience with the Earth Shelter Project Michigan. They setup a number of 6 inch diameter PVC earth tubes, each had a fan, but each was only about 50 ft long. He says the tubes didn't moderate the temperature of the incoming air for very long after the fans were turned on. They were probably not long enough for the size of the fans. The air was moving too quickly thru the tubes and stripped the heat from the tube walls faster than the soil could conduct it. It was not a thermally stable system. Even so, the ventilation was insufficient (*such a large earth sheltered home would have needed 26 passive tubes running at 175 fpm or 7 tubes at high fan speed of 700 fpm*) and so there were problems with humidity, etc. Adam acknowledged that **longer** or deeper tubes may have worked better, but at a greater expense. If he could do it again, he would probably just use a Heat Recovery Ventilator (HRV) instead, the cost would have been a fraction of the cost of the earth tubes. The HRV is an active system that requires electricity, but at least it is predictable technology. The HRV exchanges (averages) heat in real time without any thermal storage capacity.

Earth Tube Diameter:

Again, this is only one of several parameters, but all others held constant, increasing the diameter reduces the back pressure (resistance to flow) by increasing the cross sectional area ($\pi*R^2$) faster than the perimeter ($2\pi*R$) (proportional to surface area). Hydraulic Diameter is cross sectional area over perimeter and is in the denominator of the D'Arcy equation, which means that increasing diameter reduces pressure losses. Having a larger diameter means you can get more flow volume at a lower velocity which allows for more heat transfer. There is also more surface area (for a given length) which also helps increase heat transfer.

Many discussions on this topic will point out that smaller diameter pipe has a larger surface area to flow volume and therefore more **heat transfer**, but that argument assumes the same flow velocity (reduced flow volume). If the length and ***flow volume*** are held fixed, the larger diameter pipe has greater heat transfer than a smaller diameter pipe. However if you change the configuration and switch from a single 8 inch to four 4 inch pipes, you would have the same flow volume but double your surface area and therefore increase your heat transfer for the same flow rate. Changing to the smaller pipes would also increase your back pressure. Looking at the cost of this configuration, at least for HDPE pipe, the four 4 inch pipe configuration costs 8% less than the single 8 inch pipe configuration.

Increasing diameter appears to increase cost at a higher rate than increasing length. I noticed that prices also increased at a higher rate than the radius and even slightly higher than the cross sectional area. So while I would probably prefer to have 16 inch diameter pipe, I will probably install 6 inch diameter to get a lower price per inch of cross sectional area, even though this limits my total length.

Certain types of pipe, such as HDPE pipe, have a thickness that is proportional to the diameter. For instance, HDPE SDR 17 pipe has a wall thickness that is 1/17th of the diameter. The weight of the pipes is therefore proportional to the square of the diameter which means it increases at a faster rate. This means larger pipes are proportionally heavier (and also harder to bend), and therefore harder to work with, than smaller pipes. Six inch HDPE SDR 17 pipes are 3.34 lbs/ft, but 8 inch equivalents are 5.66 lbs/ft. That weight can add up quickly when moving around long sections of pipe.   The insulative properties of the wall would also increase with thickness and reduce heat transfer.

There is a thinner HDPE SDR 32.5 pipe… Half the thickness of SDR 17 pipe, but it is very non standard and must be ordered from the factory in a large enough batch to make it worth their while (min 1000 ft). There is also a 6 inch HDPE pipe that comes on a 500ft coil, but I couldn't find anyone with that in stock either. I was told that it takes 2 men to wrestle a 4 inch pipe off the coil, but no one I spoke to had actually tried the 6 inch pipe. One distributor told me that 6 inch coiled pipe has a tendency to kink rather than bend. The benefit of a coil would have been not needing to hire a professional to fusion weld the pipe. You could just lay it in one long piece.

Earth Tube Layout:

The layout of the **earth tubes** is an important decision. Some prefer a system with a manifold that separates the flow into parallel lines using T-connections or Y connections. These connections are usually more expensive than 10 ft of pipe and severely degrade the flow properties.   It is very difficult to balance the flow thru a system of branching connections, and even more so when using a compressible fluid like "air". If the system is not balanced, the majority of the flow may go thru only a few of the parallel runs, rendering the rest useless. I have seen a number of layouts where the pipe used throughout the system was all the same diameter, which constraints the flow rate of the whole system. Of course there are some benefits. This type of system is often easier to layout using straight sections of rigid pipe and if one of the pipes is crushed or clogged, at least the other pipes can continue to work. Often, this system is chosen by people using straight PVC pipe or who have a very limited area to run the earth tubes.

Radiant flooring used to be done this way also, but with smaller diameter PVC pipe. While water is famous for taking the path of least resistance, It is possible (but still difficult) to "balance" the flow of a relatively "in-compressible" fluid like water, compressible air flow is much more difficult. Modern radiant flooring tube layouts are typically done with a single PEX or HDPE tube "snaked" across the floor. In addition to increased performance, this is easier and cheaper than the old branched PVC approach.

Earth tubes can also be snaked using U connections or flexible pipe. Of course, if more land is available, fewer bends and larger radius curves can be used.   Larger radius curves cause less resistance to the flow, but a straight pipe is actually ideal (if you have the land for it). However you lay it out, There are many advantages to this serial configuration, including flow uniformity and the ability to clean the pipe if necessary.   (I plan to use a blast of air pressure to fire a bleach soaked Nerf ball thru mine if I ever need to clean it out.)

Another good option is running a number of pipes that are separate for their full length and only come together at the entrance to the home. Particular configurations can be used that make it easy to connect with a rectangular duct inside the home. This spreads the tubes out in the earth for maximum heat transfer and storage, but brings it all together for maximum flow volume thru a single opening into the home.

Since I have several acres around my home site, I plan to keep the earth tubes as straight as I can. I plan to use HDPE pipe that is flexible enough to allow for some bending without any special/expensive connections. The basic rule of thumb is that you can bend straight HDPE SDR 11 pipe around a radius no less than 50 times the diameter. Thinner pipe is more flexible, but there is always a chance of kinking if you try to bend it too tightly. PVC pipe is much less flexible.

Earth Tube Depth

Earth tubes work better when they are deeper. However, after a certain depth, the cost of burying them increases greater than the improvement in performance. Many "failed" earth tubes are buried less than 3 ft deep. At that depth, it is probably not worth doing.   Many small excavators have trouble digging below the 8ft depth. 10 ft would be better, but I can understand someone limiting their earth tubes to the depth that their excavator can handle. Stepping up to the next size excavator could considerably increase the cost.

Working with deeper trenches can be more dangerous, particularly with certain types of soil that tend to cave in. In that case you would need to dig an even wider trench at further increased costs.

I have seen cases where earth tubes were laid at relatively shallow depths, such as 5ft, but then 1 inch of rigid insulation board was placed 2 ft above the tubes to further separate them from the air temperatures. This may be a good compromise if the costs of going deeper are prohibitive.

The choice of when to lay pipe is also important.   I know of at least one project where the earth tubes were laid along with the earth cover over the home, which then settled (there is always settling) and damaged most of the PVC earth tubes.   Laying the tubes earlier, along with the foundations, trenched into undisturbed soil, would get them deeper and with much less risk of settling.

Camels Nose Heat Exchanger?

Authors such as John Hait recommend putting these tubes close together so that the remaining heat from the exiting air can be transferred to the incoming tube. His book calls this earth tube design feature a "camels nose" after the well known biological advantage of camels. I found this excerpt

The Biology of Human Survival.

> *The camel's nose conserves water by lowering exhaled air temperature and removing water from it. During heat exchange inside the nose, the nasal passages are alternately cooled by inhaled air and warmed by exhaled air. The loss of heat from exhaled air to the nasal passages condenses water much as one's breath condenses on a cold day, and this moisture is retained in the nose. In addition, the vascular anatomy of the camel's nose and head provides a counter-current heat exchanger that protects the brain from overheating. A camel's brain may remain more than 2°C cooler than its body. ~~~~Claude A. Piantadosi; The Biology of Human Survival, 2003*

While this design improves the heat retention efficiency of the system, it may be less desirable from a flow efficiency perspective. The camel drives the airflow thru his system with a large diaphragm and lungs; but the passive earth tube equivalent is driven by low ΔT based buoyancy.   The theory is that the cold air entering the inlet tube is warmed by the earth, expands and rises due to buoyancy where it enters the home at floor level. At some point the relatively warm, but used up, air exits home thru the return tubes. It is cooled by the surrounding earth and is drawn down the tubes by gravity acting on its increasing density. This is a very low force way to drive the flow and seems to always require fans (augmented passive solar?) to overcome the wall friction of the tubes and actually produce the required fresh-air flow volume thru the home.

The most famous earth sheltered home builders of the natural world are the prairie dogs. These rodents carefully engineer their tunnels (they live in earth tubes) to provide natural air-conditioning, fresh air, etc. They passively drive their earth tube system by separating the inlet and outlet by some distance that creates a pressure differential. Basically, they put the outlet at the top of the hill where the wind-speed is fastest and the air-pressure is lowest. This low pressure exit creates a suction that actually draws the air up into the earth tubes and thru the system.

> This article touches on how prarie dogs use the Bernoulli principle to increase airflow thru their tunnels. I have read others about how they carefully balance the forks in their tunnels for even distribution and how even their beds of dry grass are kept mold free underground; I will connect back if I stumble upon articles like that again…

Termites and other creatures start with the Bernoulli principle, but take it a step further by actually constructing solar chimneys. These use solar energy to heat up the air in the exit pipe which creates expansion and much greater buoyancy than the small temperature difference applied in the Camel-tow method.

> This article is about a mall in Zimbabwe modeled on the principles of a termite mound. This clever approach of copying (mimicking) natures master builders is sometimes referred to as bio-mimicry.

When applied to home construction, many PassivHaus experts suggest that your earth tubes should enter habitable space like living rooms and bedrooms to provide fresh air. This air can move thru the house and then exit from kitchens or bathrooms which require this sort of exhaust vent thru the roof by code anyway. The idea of venting moisture laden air from these rooms into cool underground pipes is probably not a great one anyway.

So, I do not recommend a Camels Nose arrangement for fresh air earth tubes, but I do think it would be a good idea for my by-passive solar heating earth tubes that must start and stop at the same point anyway. I plan to run the inlet and outlet tube as near each other as possible for as far as possible so that as much of the exit air heat is transferred to the intake air as possible. I may also insulate around these when they are outside of the umbrella so that more of the heat is exchanged and not wasted.

Air Intake:

The air intake is an important component of the design.

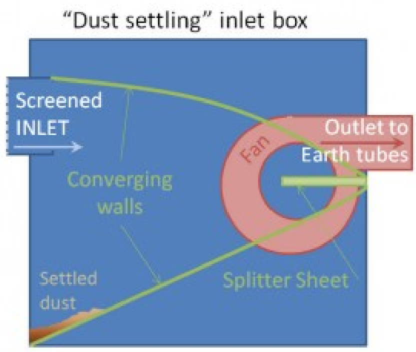
Your earth tube needs to be secure to prevent insects and animals from using it as a subway into your home. In addition to unwanted pests, the tube could bring in odors or germs. These unwanted guests could also build nests that would inhibit or block the flow of air thru the tubes.
I recommend two levels of screening. Thicker screen is needed to keep the larger (stronger) animals out. A second layer of thinner/finer mesh would be used to keep insects out of the tube.   Of course, the ends of the pipe are only a small percentage of the surface and sealing them is not very effective against smaller insects if there are many other holes and joints along the way.   Here again is where HDPE pipe can be a superior option.

Many earth tube designs feature a dust settling box at the inlet. This is a box that allows dust, pollen and other small particles to settle in a dry well before the air is drawn into the earth tube intake and into the house.   Keeping the dust out also keeps the earth tubes cleaner and less habitable to insects.   The key to this design concept is to let the air in thru a small inlet (about the same area as the earth tubes connected to the box, but then expand the volume rapidly so the air slows down and the particles can settle out of it.   This is most simply done with a hole (covered with screen) in a box in front of the earth tube entrance. For maximum effect, don't line up the box inlet and the earth tube inlet. For reduced pressure loss, create a gradual scoop to transition between the box and your inlet. If you have a centrifugal fan in your intake box, adding a splitter sheet can help balance the airflow and improve efficiency. Some keep their tubes even cleaner with the addition of standard furnace filters. Some have used "electronic air filters" that electrostaticly remove particles from the air without physically getting in the way.

Always keep an eye on system pressure losses. Intake screens, air filters, even the sudden change in area between the box and the inlet, can cause significant dynamic system losses.

The box can be further enhanced with a wind-scoop to catch air. This would increase the pressure in the box and help overcome more of the frictional resistance in the pipe. Of course, this scoop feature should be oriented to catch prevailing winds.

The earth tube intake "box" could be built any number of ways (I plan to build several and experiment with cord-wood, masonry, etc.), but should be sealed against insects and other critters. They should also have a lid or small door so you can access the earth tube inlet, filter or other features. I am also considering using some glass block elements to let UV light in for various health reasons.



Schematic design for a dust settling inlet box for an earth tube intake

Ventilation Requirements:

This section about ventilation requirements was broken out into a separate page.

Response to **Earth Tube Design**

September 20, 2012 at 6:21 am
Atul Bhalla says:

Am trying to get enough information to design a simple earth-air tube system to make the temperatures inside a green-house relatively constant throughout the year. Sitea are in India (in the Himalayas), one in a hill region, the second in the plains near Delhi.
I find your approach rational – but obviously we need to look at local costs for all materials and labour.
Would appreciate being on your mailing list for updates.
Thank you.

September 20, 2012 at 8:30 am
Simon says:

Hello, This is still a work in progress as I slowly translate my notes and calculations to the website. Soon, I was going to explain how to use D'Arcy's equation to calculate losses based on length and hydrolic mean diameter…
To get on the "mailing list", you can just put your email address in at the bottom of most pages…
I am interested in your project too. If you have some pictures and explanation, you could send them to "simon@homeintheearth.com".

Pingback: Rekuperace « Martin Bělehrádek

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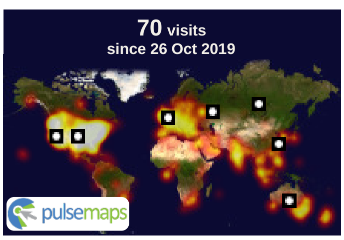

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Archives

- January 2018
- October 2017
- September 2017
- August 2017
- July 2017
- May 2017
- April 2017
- March 2017
- January 2017
- December 2016
- November 2016
- October 2016
- August 2016
- July 2016
- May 2016
- April 2016
- March 2016
- January 2016
- December 2015
- October 2015
- September 2015
- August 2015
- July 2015
- June 2015
- May 2015
- April 2015
- March 2015
- February 2015
- January 2015
- November 2014
- October 2014
- September 2014
- August 2014
- July 2014
- June 2014
- May 2014
- April 2014
- March 2014
- February 2014
- January 2014
- December 2013
- November 2013
- October 2013
- August 2013
- June 2013
- May 2013
- April 2013
- March 2013
- January 2013
- December 2012
- November 2012
- October 2012
- September 2012
- August 2012
- July 2012
- June 2012

Categories

3DModeling (4)
Benefits (6)
Contrast (3)
Design (9)
FYI (102)
Sourcing (20)
Timelapse (66)
Uncategorized (30)