

Cooling from the Ground

An Open Source, Low Power Residential Earth to Air Heat Exchanger, with a Las Vegas Design Case, Safety Controls, and a Reproducible Validation Protocol

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Open release statement: The design described here is offered for public benefit. No patent monopoly is asserted in this manuscript. The thermodynamic principle is established prior art, while the contribution of this paper is a transparent residential design architecture, a safety gate, a sizing method, and a field validation protocol that anyone may study and improve. Local law, code, professional review, and safe construction practice still apply.

Abstract

Earth to air heat exchangers, often called earth tubes, move outdoor or return air through buried ducts so that heat flows between the air and the surrounding soil. The concept can reduce cooling and heating energy because a fan requires far less power than a vapor compression system. What this project calls for is a forty foot, eight inch tube buried four feet deep, with a screened intake, an inline fan, a condensate slope, and a material cost below 300 United States dollars as of 2026 in Las Vegas, Nevada. What I am proposing is an appealing idea, but it cannot be applied universally, because soil at four feet is not always 55°F, the seasonal phase delay at that depth is not six months, fan electricity is not zero, drainage does not guarantee permanent freedom from mold, permits may be required, and a single short tube cannot be presumed to meet a whole house cooling load. This paper converts the useful core idea into a technically bounded, open source design. The proposed architecture uses site-measured ground temperature, one or more smooth and sealed parallel tubes, positive pressure operation, accessible condensate collection, filtration, a weather and smoke bypass, differential temperature control, radon testing, and documented commissioning. A first order effectiveness model is presented alongside a Las Vegas example. Using an illustrative overall heat transfer coefficient of 10 W per square meter kelvin, 105°F inlet air, and 77°F ground, one forty foot, eight inch tube is predicted to deliver approximately 2,208 to 3,298 Btu per hour across 100 to 300 cubic feet per minute, with outlet air from about 84°F to 94°F. Three parallel one hundred foot tubes at 100 cubic feet per minute each are predicted to approach 8,472 Btu per hour under the same ground condition. These values are design estimates, not measured prototype results. The proposed system is therefore best described as a low power air temperer, ventilation preconditioner, or hybrid cooling stage. Whole house standalone cooling is possible only when measured capacity equals the building load under site specific conditions. A complete installation, instrumentation, commissioning, maintenance, risk, and publication protocol is provided so that future claims can rest on reproducible evidence rather than slogans.

Keywords: earth to air heat exchanger, earth tube, passive cooling, geothermal air tempering, residential ventilation, open source hardware, low power cooling, indoor air quality.

Summary

The idea in everyday words: A backyard is not a freezer, but the ground is a giant thermal buffer. In summer it is usually cooler than the afternoon air, and in winter it is usually warmer than the coldest air. A sealed buried tube lets moving air borrow that stability. The exciting part is that a small fan can move a useful amount of cool air for only a few dollars of electricity per month. The honest part is equally important: the result depends on local soil temperature, pipe length, depth, airflow, humidity, and the cooling load of the space. How much you save depends on where you live and how large an area you are trying to cool. In a favorable climate, tempering a single room or a small, well insulated home can cut cooling cost dramatically, while a large house in a hot, humid place asks far more of the system. The purpose of this paper is to make the system useful, safe, measurable, and free for people to improve.

1. Introduction

Residential cooling has become a major question of comfort, health, affordability, and grid resilience. A conventional air conditioner moves heat from indoors to outdoors by means of a compressor, heat exchangers, refrigerant, and fans. An earth to air heat exchanger uses a different resource. It passes air through a buried duct and lets the soil absorb or release heat. There is no compressor in the earth tube itself. The only continuously powered component may be a fan and a small control system. This difference can produce a high ratio of delivered thermal effect to fan electricity, even when the delivered air is not cold enough to replace a conventional air conditioner.

The principle is not new. Underground air paths have historical precedents, and modern engineering studies have analyzed their thermal and hydraulic behavior for decades. De Paepe and Janssens (2003) linked heat exchanger effectiveness to pressure drop, Pfaffert (2003) proposed a standardized energy evaluation method, Al Ajmi et al. (2006) modeled domestic use in a desert climate, Lee and Strand (2008) modeled multiple climates, and Vaz et al. (2011) compared experimental observations with numerical analysis. Reviews by Peretti et al. (2013) and Mihalakakou et al. (2022) show that length, depth, soil properties, climate, airflow, geometry, moisture, and control strategy all matter. In other words, the technology is real, but no single depth, length, temperature, or price applies everywhere.

The immediate design prompt was one I improvised while working through alternative energy ideas. I will describe a forty foot run of eight inch smooth bore pipe at four feet of depth, a screened intake, an inline duct fan, a drain trap, a slope of one inch per ten feet, and a direct connection to a return duct. I estimate less than 250 dollars in parts, approximately 120 dollars for a trencher, and a weekend of labor. A naive version of the idea assumes a constant 55°F ground temperature, a six month delay, no electricity bill, no mold, no permit, and whole house cooling. The physical concept is worth using and sharing. Those universal promises are not.

This manuscript therefore does not present the earth tube as a perpetual motion machine, a source of free energy, or a guaranteed replacement for mechanical cooling. Energy is conserved. Heat removed from air enters the soil, the soil warms locally during sustained operation, and the fan consumes electricity. The value proposition is simpler and stronger: the ground can provide a renewable seasonal heat sink, and a carefully sized air path can deliver useful cooling with low operating power. A direct photovoltaic panel may offset that fan power during sunny periods, but the panel, fan, controls, and maintenance remain real costs.

2. Design Origin, Prior Art, and Scope

2.1 Claim audit

Peer review requires a clean separation between an inspiring design story and a demonstrated engineering result. Table 1 sets out the main claims about this kind of system in language suitable for a journal paper. The purpose is not to diminish the idea. It is to protect it. A design that survives correction is more useful than a dramatic promise that fails in the first hot week.

Table 1. Engineering audit of the source claims

Source claim	Evidence based restatement	Required proof
Four feet below any American yard is nearly constant at 55°F.	Ground temperature approaches the local annual mean and becomes more stable with depth. Four feet remains seasonally variable, and Las Vegas has a 1991 to 2020 annual mean air temperature of 70.1°F.	Local depth profile measured through the cooling season, or a validated ground model with local inputs.
The ground provides a six month delay at four feet.	Seasonal temperature waves are attenuated and delayed with depth. Under an illustrative diffusivity of 0.07 square meters per day, four feet produces about 25 days of lag, not six months.	Measured soil phase lag and thermal diffusivity.
A forty foot tube holds a house at 55°F.	A tube can move outlet air toward the surrounding ground temperature. It cannot normally reach ground temperature at useful whole house airflow, and capacity must be compared with a Manual J or equivalent building load.	Airflow, inlet and outlet temperature, humidity, fan power, and building load data.
No electricity bill.	The compressor may be eliminated or used less, but the fan and controls consume power. Direct solar drive can reduce grid energy during sunshine.	True wattage and cumulative kilowatt hours.
No pooled water means no mold, ever.	Drainage materially reduces risk, but filters, dust, leaks, biological material, and inaccessible wet surfaces can still create contamination. Inspection and maintenance remain necessary.	Drain test, borescope inspection, moisture records, odor records, and microbial testing when indicated.
No permit is required.	Permit and inspection rules depend on jurisdiction. Clark County states that adding or relocating residential mechanical ductwork requires a permit and inspection.	Written determination from the authority having jurisdiction.
The fan lasts fifteen years and the system improves with age.	Service life is product and environment dependent. Soil around a continuously loaded tube can warm, which can reduce cooling until the ground recovers.	Manufacturer data and long term monitored performance.

Technical restatements are supported by Kusuda and Achenbach (1965), Goswami and Biseli (1993), Chardome and Feldheim (2019), NOAA climate normals, and the regulatory sources cited in the text.

2.2 What is actually new here

Because earth tubes are prior art, novelty cannot honestly be claimed for burying a pipe and moving air through it. The proposed contribution is an integrated open source residential protocol with five features that are often separated in popular descriptions: location specific ground modeling, modular thermal sizing, positive pressure contamination control, an accessible moisture and maintenance path, and a measurement package that defines what counts as success. This is an implementation, invention, and validation framework, not the discovery of a new law of nature.

- A minimum demonstrator that preserves the low cost spirit of the idea while making no whole house promise, since homes and rooms vary enormously in size.
- A scalable array in which additional parallel tubes add airflow and heat transfer area without forcing high velocity through one tube.
- A safety gate that stops a project before excavation if utilities, contaminated soil, groundwater, radon, flood risk, code, or drainage cannot be resolved.
- A control gate that bypasses the earth tube whenever outdoor air is already better, smoke is present, water is detected, radon is elevated, or the delivered air would worsen indoor conditions.
- A reproducible test method using calibrated temperature, relative humidity, airflow, static pressure, radon, condensate, and electricity measurements.

2.3 Intended and excluded uses

The intended use is residential ventilation air tempering, sensible cooling assistance, night and shoulder season ventilation, preconditioning upstream of a heat recovery ventilator or energy recovery ventilator, or load reduction upstream of conventional HVAC. The baseline concept is most attractive in climates with a useful summer difference between outdoor air and the ground, low to manageable humidity, sufficient land, stable soil, and safe drainage.

The system is not presented as life safety cooling during extreme heat, a replacement for code required ventilation, a substitute for humidity control in a humid climate, or a reason to remove a functioning air conditioner before performance has been verified. It is not suitable for contaminated properties, sites with unresolved soil gas intrusion, flood prone trenches, high groundwater without engineered drainage, or any location where the buried duct cannot be inspected and maintained.

3. Design Requirements and Performance Language

A credible design begins with requirements. The system must move air, exchange useful heat, resist collapse and leakage, drain any condensate, protect indoor air quality, allow cleaning, and fail safely. It must also use language that matches the evidence. The term air conditioner is reserved here for a system that can maintain specified indoor temperature and humidity under a defined design load. Until a field test proves that capability, the device is called an earth to air heat exchanger, earth tube, or air tempering system.

Table 2. Proposed performance requirements

Requirement	Design intent	Verification
Thermal usefulness	Delivered air shall be cooler than the selected comparison air by a measurable margin when cooling is requested.	Continuous inlet and outlet temperature, with airflow and uncertainty reported.
Load relevance	Rated delivered cooling shall be compared with the building's sensible and latent load, not with outdoor temperature alone.	Manual J or equivalent load calculation and monitored indoor response.
Low operating power	Fan and control energy shall be measured, not described as zero.	True power meter and cumulative kilowatt hour meter.
Moisture control	The duct shall drain to an accessible point and shall not retain standing water.	Pre burial slope survey, water test, drain inspection, and condensate log.
Air quality	The system shall not create an unacceptable increase in radon, odor, particles, or biological contamination.	Baseline and operating radon tests, filter inspection, visual and odor inspection, and targeted laboratory testing when indicated.
Serviceability	Filters, fan, dampers, drain, sensors, and the interior air path shall be accessible.	Commissioning inspection and annual maintenance record.
Code compliance	The final design shall be approved where required and shall not bypass required ventilation, fire, structural, electrical, or mechanical provisions.	Permit record, inspection, and authority having jurisdiction signoff.
Fail safe operation	Loss of power, sensor fault, smoke, flood, or drain alarm shall close or bypass the outdoor path as appropriate.	Functional alarm and shutdown tests.

Plain language: Do not ask whether the pipe feels cool. Ask how many Btu per hour it delivers, how many watts the fan uses, how much water forms, what the radon level does, and whether the indoor room actually becomes safer and more comfortable.

4. Proposed System Architecture

4.1 Air path

The preferred open loop architecture moves outdoor air through a protected intake, a serviceable filter, a low power electronically commutated fan, a sealed supply header, one or more buried tubes, a sealed collection header, an accessible moisture separator or drain point, and a delivery plenum (Figure 1). A motorized bypass permits direct outdoor air or system isolation. A backdraft damper prevents uncontrolled reverse flow. The fan is preferably located upstream of the buried section so the tube remains slightly positive relative to the surrounding soil. If a buried joint leaks, positive pressure tends to push air outward rather than draw soil gas inward. This does not eliminate the need for sealed joints or radon testing.

Proposed earth-to-air heat exchanger: system architecture and air path

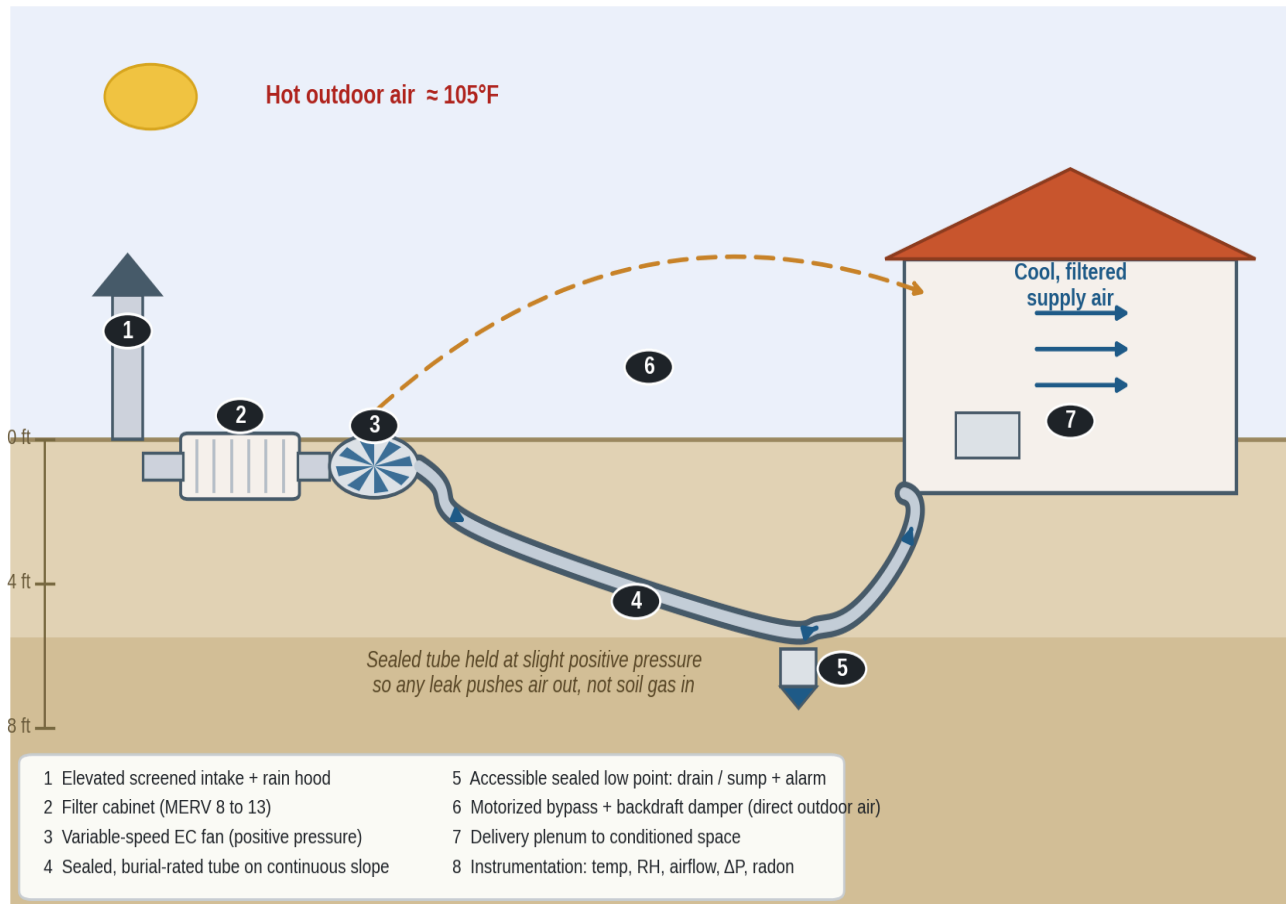


Figure 1. Proposed system architecture and air path for a residential earth to air heat exchanger. Outdoor air is screened and filtered, moved by a variable speed fan under slight positive pressure, tempered in one or more sealed buried tubes, drained at an accessible low point, and delivered to the conditioned space, with a motorized bypass for direct outdoor air. Numbered items correspond to the component specification in Table 3.

The delivery point depends on the building. The safest general description is connection to a designed ventilation or air handling path reviewed by an HVAC professional. Direct connection to a central return can alter building pressure, filter loading, blower operation, combustion appliance draft, and condensation behavior. It must not be improvised. A dedicated supply register may be simpler, but it still requires a relief or exhaust path so the home does not become excessively pressurized.

4.2 Component specification

Table 3. Functional component specification

Component	Minimum functional requirement	Reason
Outdoor intake	Elevated above local splash, snow, pest, and flood exposure, screened against animals, located away from exhausts, vehicles, standing water, chemicals, and wildfire ash accumulation.	Prevents direct entry of water, pests, and concentrated pollutants.
Prefilter and final filter	Washable coarse screen followed by a replaceable filter selected for the available fan pressure. MERV 8 is a practical starting point, while MERV 13 may be used when the fan and housing are designed for its pressure drop.	Reduces dust and biological loading. Higher efficiency filtration is useful during smoke only if the outdoor intake remains safe to operate.

Component	Minimum functional requirement	Reason
Fan	Variable speed, electronically commutated, rated at the required airflow after the measured static pressure of tube, fittings, filter, and dampers.	A free air rating alone does not prove delivered airflow.
Buried tube	Smooth interior, structurally rated for burial and live loads, corrosion resistant, low emission, joint system approved for underground air conveyance, and accessible at both ends.	Supports drainage, cleaning, durability, and air quality.
Headers	Symmetrical geometry for parallel tubes, balancing dampers or measured orifices, sealed cleanout ports.	Prevents one easy tube from taking most of the airflow.
Condensate path	Continuous slope to a visible and serviceable low point, minimum slope not less than the locally adopted code requirement, accessible trap or sealed sump, overflow alarm, and backflow protection.	Standing water cannot be accepted inside an air supply path.
Sensors	Outdoor, inlet, outlet, ground, and indoor temperature; inlet, outlet, and indoor relative humidity; airflow; static pressure; condensate status; fan energy; indoor radon.	Turns a concept into a measurable system.
Controls	Differential temperature logic, dew point logic, smoke and outdoor air quality override, drain alarm, radon alarm, freeze protection, and manual bypass.	The tube should run only when it improves conditions.
Delivery and relief	Code compliant supply path with a defined return, transfer, relief, or exhaust route.	Prevents uncontrolled building pressure and combustion hazards.

4.3 Three implementation levels

Table 4. Scalable implementation levels

Level	Representative geometry	Appropriate claim
A, instrumented demonstrator	One eight inch tube, approximately forty feet long, depth selected from site data, 75 to 150 cubic feet per minute.	Tests local feasibility and can temper a small ventilation stream. No whole house claim.
B, practical residential preconditioner	Two to four parallel tubes, commonly eight to ten inches each, approximately eighty to one hundred twenty feet per tube, with balanced headers and variable airflow.	Preconditions meaningful ventilation or makeup air and may offset part of the sensible cooling load.
C, engineered cooling array	Multiple long parallel tubes or a large thermal labyrinth, deeper installation, building load integration, humidity equipment where needed, professional controls, and full instrumentation.	May provide substantial or standalone cooling only after load matching and field validation.

5. Governing Physics

5.1 Seasonal ground temperature

The ground does not switch immediately when outdoor weather changes. A periodic temperature wave decays and lags as it travels downward. Kusuda and Achenbach (1965) analyzed earth temperature and thermal diffusivity at stations across the United States. A commonly used single harmonic form is shown in Equation 1.

$$T_g(z,t) = \bar{T}_s - A_s \exp[-z \sqrt{(\pi \div \alpha P)}] \cos\{(2\pi \div P)[t - t_{\min} - (z \div 2) \sqrt{(P \div \pi \alpha)}]\} \quad (1)$$

In Equation 1, T_g is undisturbed ground temperature at depth z and time t , $\bar{T}_s$ is annual mean surface temperature, A_s is surface temperature amplitude, α is soil thermal diffusivity, P is the annual period, and t_{min} is the date of minimum surface temperature. The amplitude ratio is $\exp[-z \sqrt{(\pi \div \alpha P)}]$, and the phase lag is $(z \div 2) \sqrt{(P \div \pi \alpha)}$. The equation is useful for screening, but a real site may differ because of irrigation, shade, pavement, soil moisture, groundwater, buildings, snow, and urban heat island effects (Figure 2).

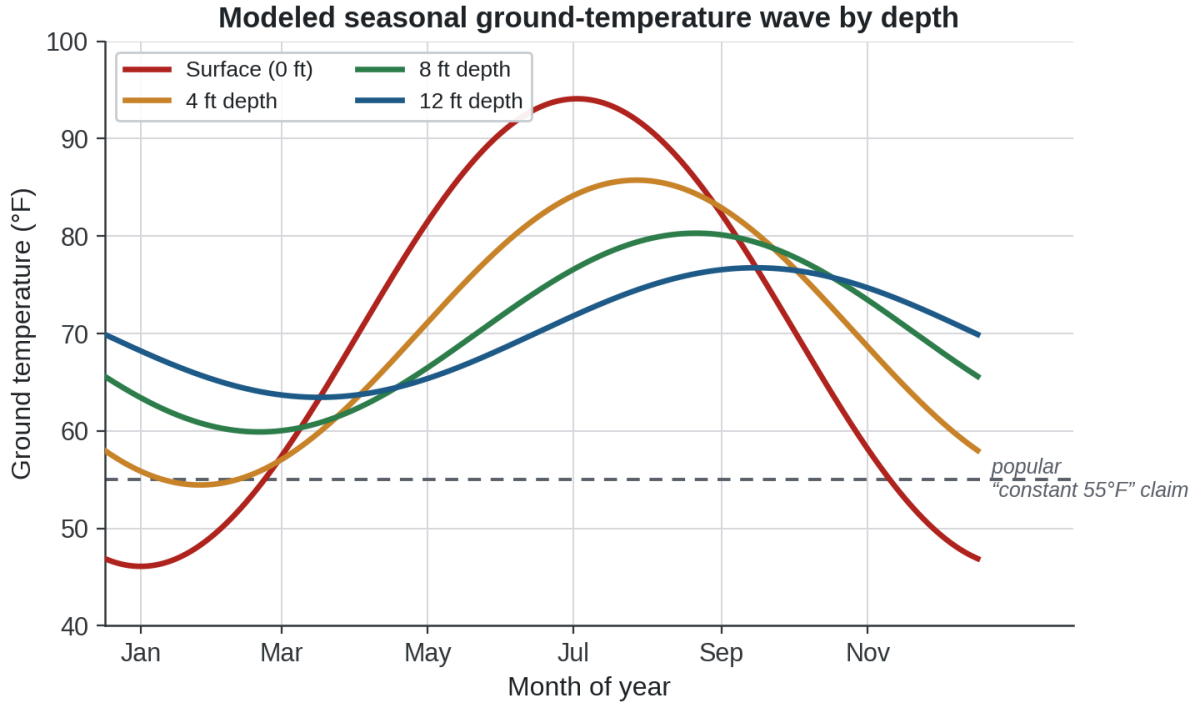


Figure 2. Modeled seasonal ground temperature wave by depth, from Equation 1 with the illustrative Las Vegas screening assumptions in Table 10 (annual mean 70.1°F, surface amplitude 24°F, diffusivity 0.07 square meters per day). Even at four feet the ground is far from a constant 55°F, swinging by roughly 30°F across the year. After Kusuda and Achenbach (1965).

Plain language: Every extra foot of soil smooths the weather wave and moves it later in the year. Four feet helps, but it does not normally create a perfectly constant temperature or reverse the seasons by six months. Deep, shaded, moist soil behaves very differently from shallow desert soil under sun baked gravel.

5.2 Tube heat transfer

For a first design pass, the buried tube can be treated as a heat exchanger with an approximately constant surrounding ground temperature. The outlet temperature is estimated by the number of transfer units method in Equations 2 and 3.

$$NTU = UA \div (\dot{m} cp) \quad (2)$$

$$T_{out} = T_g + (T_{in} - T_g) \exp(-NTU) \quad (3)$$

$$Q_{sensible} = \dot{m} cp (T_{in} - T_{out}) \quad (4)$$

Here, U is the overall heat transfer coefficient, A is the internal tube surface area, $\dot{m}$ is dry air mass flow, c_p is air specific heat, T_{in} and T_{out} are inlet and outlet temperature, and $\dot{Q}_{sensible}$ is sensible cooling rate. Effectiveness is $\varepsilon = 1 - \exp(-NTU)$. A longer tube, larger wetted area, stronger thermal contact, and lower airflow per tube move the outlet closer to the ground temperature. Higher airflow usually increases total cooling capacity but produces warmer outlet air. This tradeoff is why parallel tubes are valuable: they increase total area and airflow without forcing extreme velocity through one tube (Figure 3).

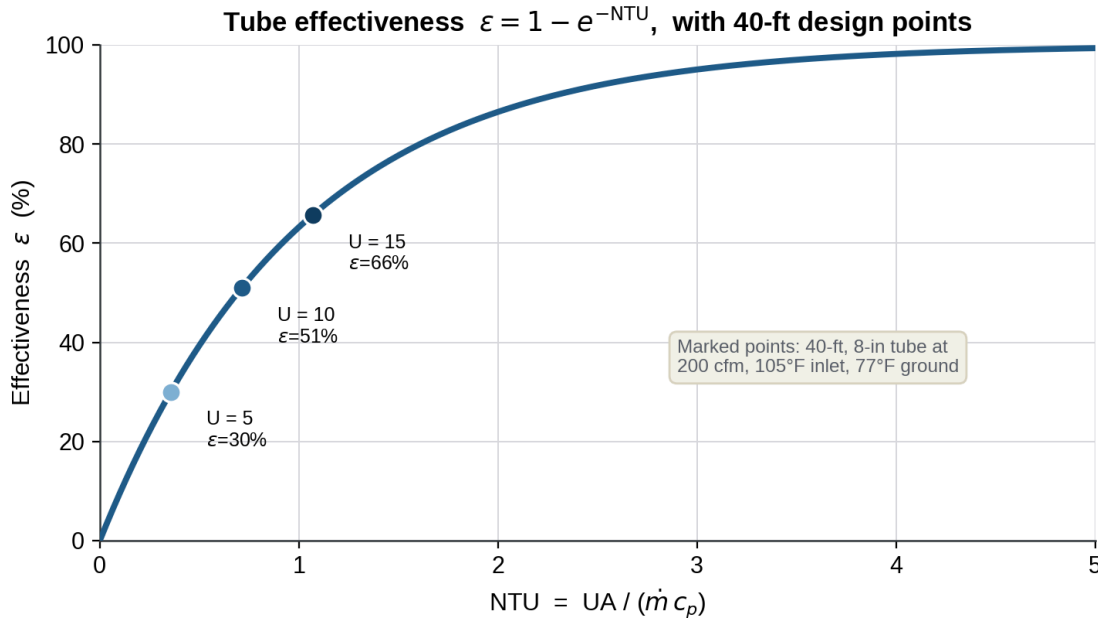


Figure 3. Heat exchanger effectiveness, $\varepsilon = 1 - \exp(-NTU)$, from Equations 2 and 3. Marked points show a 40 foot, 8 inch tube at 200 cubic feet per minute for overall heat transfer coefficients of 5, 10, and 15 watts per square meter kelvin, reproducing the values in Table 13. Effectiveness rises steeply at low NTU and then flattens, which is why added length and contact quality show diminishing returns.

The constant ground approximation is optimistic during long continuous operation. Heat rejected into the soil raises the temperature near the tube, especially when tubes are close together, soil is dry, or the system never rests. Transient simulation or seasonal field data are necessary for final sizing. The first order model is a screening calculation, not a certification.

5.3 Pressure drop and fan power

$$\Delta P = f (L \div D) (\rho v^2 \div 2) + \Sigma K (\rho v^2 \div 2) + \Delta P_{filter} \quad (5)$$

$$P_{fan,electric} = Q_v \Delta P \div \eta_{fan} \quad (6)$$

Equation 5 combines straight tube friction, fitting losses, intake and damper losses, and filter pressure drop. In Equation 6, Q_v is volumetric airflow and η_{fan} is combined fan and motor efficiency. A fan must be selected from its pressure versus airflow curve at the dirty filter condition. The retail fan label and free air airflow are not sufficient. At low velocity the straight section of a smooth eight inch tube may contribute only a modest pressure drop, while a dense filter, insect screen, small cap, sharp elbow, or undersized damper can dominate the system.

Plain language: The fan does not push against pipe length alone. It pushes against every screen, filter, bend, damper, reducer, and dirty surface. Measure the pressure after the system is built, then verify the airflow. Quiet air is not proof of useful air.

5.4 Condensation and latent load

Condensation begins when the tube wall or air temperature falls below the inlet air dew point. The condensate rate can be estimated from the humidity ratio change in Equation 7.

$$\dot{m}_{\text{water}} = \dot{m}_{\text{dry air}} (\omega_{\text{in}} - \omega_{\text{out}}) \quad (7)$$

In a dry Las Vegas afternoon, dew point may be well below the shallow ground temperature, so little or no condensation may occur. During humid weather or in another climate, condensation can be substantial. For illustration, an airflow of 200 cubic feet per minute with 0.0033 kilograms of water removed per kilogram of dry air can produce approximately 1.3 liters of water per hour. The drain must therefore be designed as a real plumbing and air sealing component, not as a symbolic hole. Chardome and Feldheim (2019) modeled heat transfer and condensation because stagnant condensate can create conditions favorable to molds and bacteria.

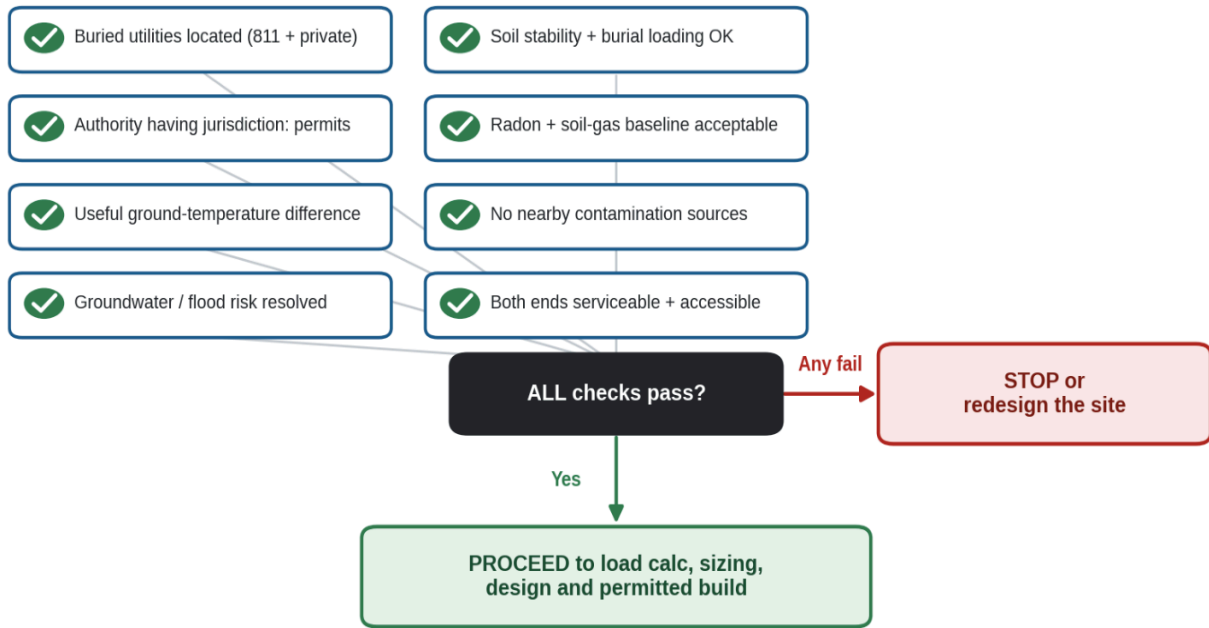
5.5 What unlimited can and cannot mean

The ground is enormous compared with a residential tube, but the immediately surrounding soil is finite. Continuous heat rejection creates a warm plume. Natural conduction, seasonal reversal, rainfall, irrigation, and rest periods recharge the local ground. Unlimited therefore cannot mean infinite instantaneous capacity or unchanged performance forever. In responsible engineering language it can mean that the heat sink is naturally renewed over seasons and does not depend on purchased refrigerant or fuel. The delivered capacity at any moment remains limited by temperature difference, tube area, soil conductivity, airflow, moisture, and recovery time.

6. Site Qualification Before Design

The lowest cost way to avoid an unsafe earth tube is to reject a bad site before digging. Site qualification should be completed before ordering pipe. A minimum program includes utility location, permit inquiry, soil and groundwater review, radon baseline, surface contamination review, drainage plan, climate data, and a trial ground temperature profile (Figure 4).

Site qualification gate



Complete this gate before ordering pipe. The cheapest way to avoid an unsafe earth tube is to reject a bad site before digging.

Figure 4. Site qualification gate. Every check must pass before the pipe is ordered; any unresolved item stops the project or forces a redesign. This is the visual form of Table 5 and the discussion in Section 6.

Table 5. Site qualification gate

Question	Proceed when	Stop or redesign when
Buried utilities	811 and private utility locating are complete, markings are current, and a safe corridor exists.	Any utility is unresolved or required clearance cannot be maintained.
Authority having jurisdiction	Permit, inspection, mechanical, electrical, structural, property line, easement, and drainage requirements are documented.	The project relies on an assumption that no permit is needed.
Ground temperature	Measured or validated modeled temperature at candidate depth provides a useful seasonal difference.	Peak season ground temperature is too close to the required indoor supply condition.
Groundwater and flooding	The tube remains above seasonal high groundwater, the drain has a safe destination, and surface water cannot enter the intake.	The tube can flood, the drain can backflow, or the water table is unresolved.
Soil stability and loading	A geotechnically suitable trench and burial rated pipe can be installed without unsafe entry or collapse.	Caliche, boulders, unstable soil, expansive soil, traffic loads, or trench geometry exceed the proposed design.
Radon and soil gas	Baseline indoor radon is measured, soil gas risk is reviewed, joints can be sealed, and post installation testing is planned.	Elevated radon or vapor intrusion is unresolved.
Contamination	The intake and trench are distant from septic systems, fuel, pesticides, landfills, contaminated fill, vehicle exhaust, and exhaust outlets.	Known or suspected contamination is present.
Maintenance access	Both ends, filters, headers, drain, fan, dampers, and inspection ports remain accessible.	The design buries all service points or creates an uncleanable trap.

6.1 Ground temperature survey

The preferred survey installs calibrated probes at candidate depths, for example four, six, eight, and ten feet, plus a shaded outdoor air sensor. Hourly recording through the hottest months is the minimum useful cooling survey. A full year is better because it reveals mean temperature, amplitude, phase lag, and the effect of irrigation or surface cover. Probe placement should avoid foundations, buried utilities, irrigation lines, and local heat sources unless the final tube will occupy that same condition.

If a one year survey is not possible, use NOAA climate normals, site specific soil parameters, and the Kusuda and Achenbach model for preliminary screening, then verify temperature during excavation before committing the entire array. The model input should not use a national 55°F assumption. NOAA reports a 1991 to 2020 annual mean air temperature of 70.1°F for Las Vegas, which immediately shows why 55°F cannot be treated as the deep annual mean there (National Weather Service Las Vegas, 2021).

6.2 Air quality and radon

A buried outdoor air duct can become a pathway for soil gas if it leaks under negative pressure. The United States Environmental Protection Agency explains that radon originates in soil and rock and can enter buildings through openings.

EPA recommends mitigation when the indoor level is 4 pCi/L or greater and consideration of mitigation between 2 and 4 pCi/L because no exposure level is known to be risk free (U.S. Environmental Protection Agency, 2025). Baseline testing should precede construction. Follow up testing should occur during operation, after major soil moisture changes, after repairs, and at least as often as recommended by local radon guidance.

Positive pressure, sealed joints, an above ground intake, and a visible drain reduce risk but do not prove safety. A condensate drain that opens directly to soil can itself become an air path. The drainage assembly therefore needs an air seal, service access, and a design that cannot dry into an unsealed soil connection. If soil vapor risk is significant, an indirect ground loop using liquid and an above ground air coil may be more appropriate than direct underground air conveyance.

7. Detailed Engineering Design

7.1 Load first, pipe second

The building cooling load is the first sizing input. A qualified designer should calculate sensible and latent load under local design conditions using ACCA Manual J or an accepted equivalent (Air Conditioning Contractors of America, 2016). The earth tube is then assigned a fraction of that load. A system intended only for ventilation may be sized to the required outdoor airflow. A system advertised for whole house cooling must demonstrate that its delivered sensible and latent capacity equals or exceeds the design load while maintaining acceptable indoor temperature, humidity, and air quality. Temperature drop alone is not a capacity rating.

1. Define the operating goal: ventilation tempering, partial cooling, or verified standalone cooling.
2. Calculate building sensible and latent load and required outdoor airflow.
3. Measure or model ground temperature at feasible depths during the design period.
4. Choose a preliminary tube diameter, length, count, and airflow per tube.
5. Calculate effectiveness, outlet temperature, sensible capacity, pressure drop, fan power, dew point, and condensate rate.
6. Check thermal interference, land area, trench safety, burial loading, service access, and code.
7. Iterate the number of parallel tubes until capacity and fan energy meet the design objective.
8. Commission the built system and publish measured performance with uncertainty.

7.2 Depth

Depth is selected by benefit versus risk and cost, not by folklore. Greater depth usually reduces seasonal amplitude and increases phase lag, but excavation becomes more expensive and dangerous. At depths of four feet or more, OSHA requires a safe means of egress for employees in trench excavations, with no more than twenty five feet of lateral travel. Protective systems are generally required unless an excavation is less than five feet and a competent person finds no cave in indication, or the excavation is entirely stable rock (Occupational Safety and Health Administration, n.d.a, n.d.b). Homeowner status does not make caves in physics disappear. The design should minimize human entry, assemble pipe above ground where possible, and use a competent excavation contractor.

7.3 Tube diameter, length, and spacing

The source concept uses one eight inch tube forty feet long. That is suitable as a test article, but it offers only about 7.8 square meters of internal surface. Larger diameter lowers velocity and pressure drop for a given airflow, but it also reduces internal convective heat transfer and increases cost. Longer tubes increase area and residence time, but the additional benefit diminishes as air approaches the tube wall temperature. Multiple parallel tubes generally provide the best path to residential airflow because each tube can remain at moderate velocity.

Tube spacing must prevent thermal interference. There is no universal spacing because the affected soil radius changes with operating schedule, conductivity, moisture, and season. Preliminary residential layouts should leave generous separation, commonly at least one to two meters center to center when land permits, then confirm with transient modeling. Parallel tubes placed tightly in one small trench may behave thermally like one larger source and exhaust the local cool reservoir faster.

7.4 Slope and drainage

I propose a one inch drop per ten feet, equivalent to 0.10 inch per foot. A commonly published International Mechanical Code provision for underground ducts requires at least one eighth inch per foot to an accessible drainage point, subject to local adoption and amendment. Over forty feet, one eighth inch per foot produces five inches of fall. The local authority must confirm the applicable value. Surveyed continuous fall is more important than an average slope because a single low pocket can retain water.

The drain should terminate at a serviceable, observable, and hygienically isolated location. Options include a sealed condensate sump with an alarm and pump, or an accessible trapped drain with a reliable trap seal and code compliant destination. Discharge directly into unknown soil is not acceptable where it can admit radon, pests, groundwater, or contaminated vapor. The low point requires a cleanout large enough for inspection and flushing (Figure 5).

Trench cross-section: burial, bedding, drainage, and safety

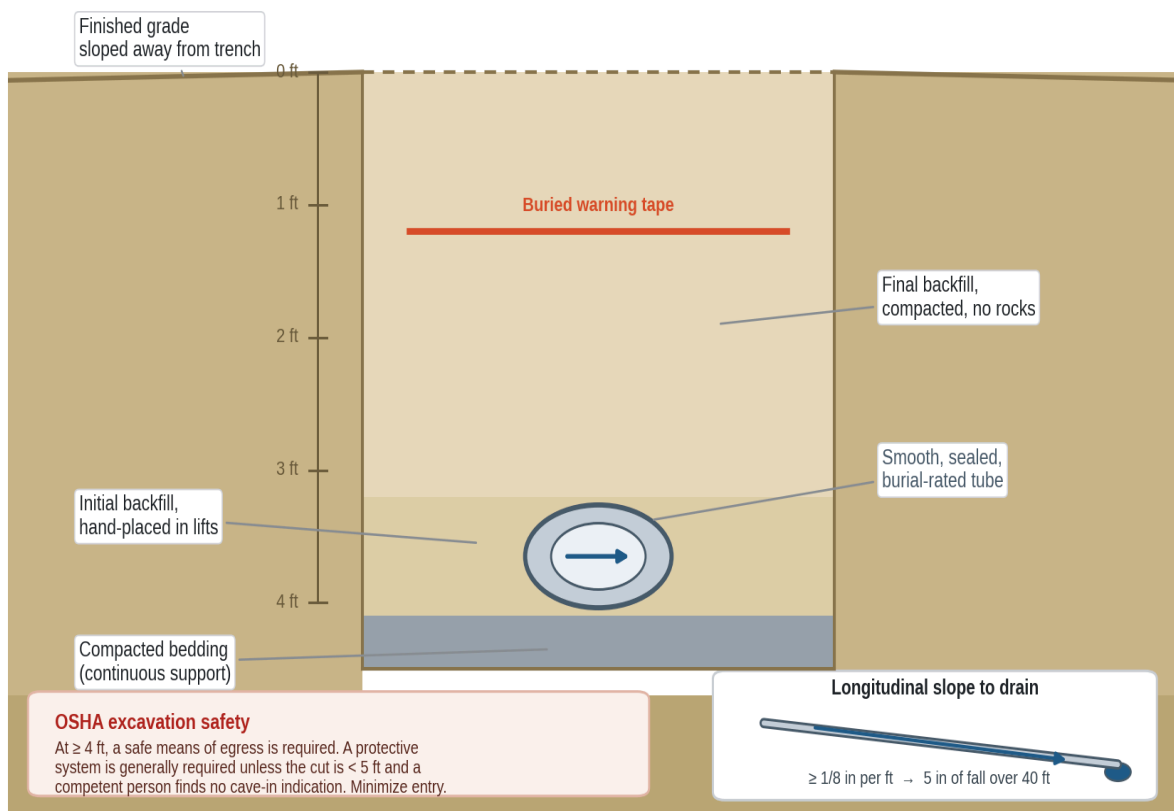


Figure 5. Representative trench cross-section showing burial depth, compacted bedding, hand placed initial backfill, buried warning tape, and finished grade sloped away from the trench. The inset shows the continuous longitudinal fall to the drain, at least one eighth inch per foot, or about five inches over 40 feet. Excavation must follow the OSHA requirements summarized in Section 7.2.

7.5 Intake and filtration

The intake should face away from prevailing dust and be located where vehicles, generators, plumbing vents, dryer exhaust, cooking exhaust, pesticide application, and stagnant water cannot contaminate it. A rain hood and pest screen protect the opening without creating excessive pressure drop. A coarse washable screen catches insects and debris. A sealed filter cabinet downstream catches finer particles and allows the filter to be changed without disturbing the buried tube.

Wildfire smoke requires a bypass or shutdown plan. EPA advises closing fresh air intakes or using recirculation when outdoor smoke is unhealthy, and recommends MERV 13 filtration where the HVAC system can accommodate it (U.S. Environmental Protection Agency, 2026). An earth tube does not remove smoke gases merely because it is underground. Outdoor air quality must override the cooling command.

7.6 Fan and solar option

A variable speed electronically commutated fan permits low airflow for colder outlet air and higher airflow for greater total capacity. The design point must include the final filter pressure, not a clean laboratory condition alone. The fan should be mounted in an accessible, weather protected location with vibration isolation and a straight measurement section where possible. Fan power should be metered continuously.

A direct photovoltaic option can make grid energy nearly zero during sunny operation. The simplest arrangement uses a photovoltaic module, a suitable direct current fan, and a controller that limits voltage and starts reliably under changing sunlight. A small grid supply can provide backup without a battery. If night cooling is a major goal, a battery or grid connection is required. The paper does not call this free electricity because the module, controller, wiring, disconnect, mounting, and maintenance have real cost and must meet electrical code.

7.7 Control sequence

The control logic below is summarized in Table 6 and shown as a decision flow in Figure 6.

Table 6. Proposed control sequence

Condition	Command	Reason
Cooling requested and predicted outlet is at least 3°F cooler than direct outdoor air	Open earth tube path, close direct bypass as appropriate, and modulate fan to target airflow or supply temperature.	Avoids spending fan energy when thermal benefit is trivial.
Outdoor air is cooler than earth tube outlet	Use direct outdoor bypass if outdoor air quality and humidity are acceptable.	The shortest path is best when nature already provides cooler air.
Indoor humidity or predicted supply humidity exceeds limit	Reduce or stop outdoor flow, engage dehumidification or an energy recovery strategy, and inspect condensate system.	Sensible cooling alone can worsen comfort if moisture is uncontrolled.
Drain high level or water sensor alarm	Stop fan, close earth tube damper, announce alarm, and require inspection before restart.	Prevents aerosolization and concealed water accumulation.
Indoor radon rises above the project action threshold	Isolate tube, confirm measurement, test joints and pressure, and engage a qualified radon professional.	Treats air quality as a hard safety limit.
Wildfire smoke or hazardous outdoor air	Close outdoor intake and use indoor recirculation or alternative safe cooling.	Prevents importing polluted air.
Freeze or ice risk at drain or intake	Use frost control, bypass, heat trace only if approved, or suspend operation.	Prevents blocked drainage and structural damage.
Sensor failure or communication loss	Move dampers to the predetermined safe position and flag a fault.	Unknown conditions are not permission to continue.

Control sequence: run the earth tube only when it improves conditions

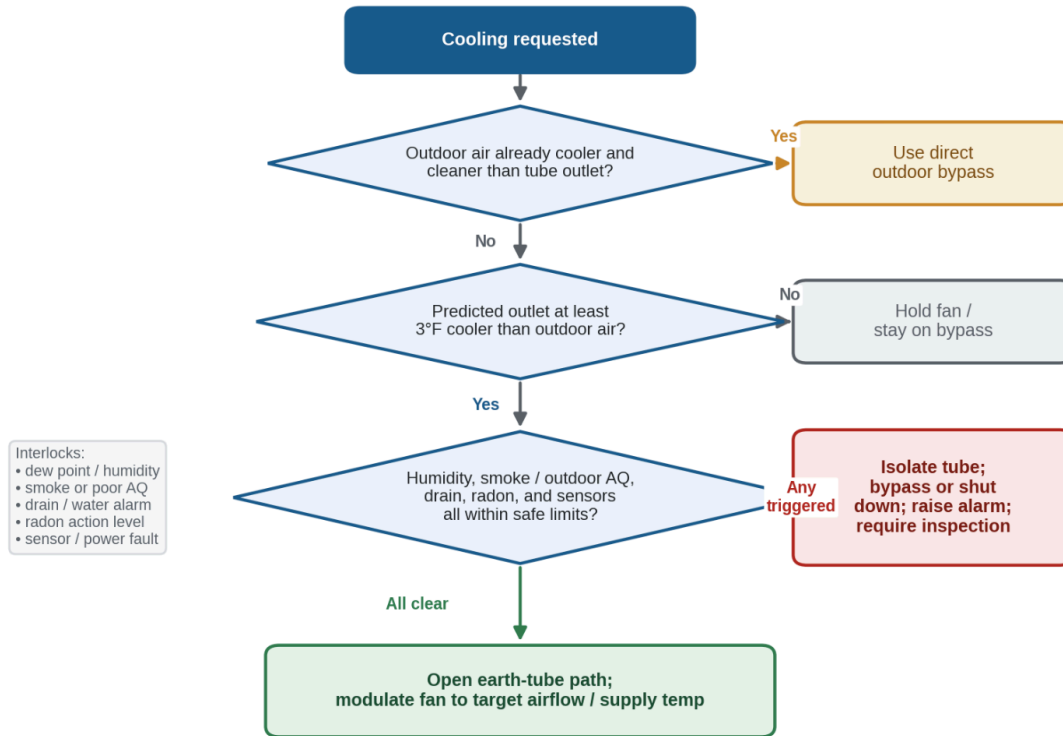


Figure 6. Control sequence for the earth tube. The system runs only when it is predicted to improve indoor conditions, and it is isolated or bypassed whenever humidity, smoke or outdoor air quality, drain water, radon, or a sensor fault is detected. This is the decision logic behind Table 6.

8. Reference Designs

8.1 Level A, instrumented demonstrator

Table 7. Level A reference specification

Parameter	Reference value	Design note
Tube	One smooth, sealed, burial rated tube, nominal inside diameter near eight inches, length near forty feet.	Use only material accepted by the local authority for underground air conveyance.
Depth	Selected from measured ground data, not automatically four feet.	Four feet may be used as a research depth if thermal benefit and excavation safety are acceptable.
Airflow	75 to 150 cubic feet per minute, variable.	Lower flow gives colder outlet air, higher flow gives more total capacity.
Slope	At least the locally adopted minimum to an accessible low point, with five inches of fall over forty feet if one eighth inch per foot applies.	Survey the bottom and the pipe before backfill.
Fan	Variable speed fan selected at measured static pressure, approximately 15 to 75 watts depending on airflow and accessories.	Do not select by price or free air rating alone.
Control	Differential temperature, manual bypass, drain alarm, smoke shutdown, and energy metering.	Minimum controls for honest testing.
Claim	Ventilation air tempering demonstrator.	No whole house or 55°F claim without measured proof.

8.2 Level B, scalable residential preconditioner

Table 8. Level B reference specification

Parameter	Reference value	Design note
Tube array	Three parallel smooth tubes, each near eight inches inside diameter and one hundred feet long.	This is an analytical example, not a universal prescription.
Total airflow	Approximately 300 cubic feet per minute, near 100 through each tube.	Balance each branch and verify with measurement.
Depth	Commonly six to ten feet where safe and feasible, but selected by site measurement and code.	Deeper is not automatically better if mean ground temperature remains too warm.
Spacing	Generous center spacing, preliminarily one to two meters or more, subject to transient analysis.	Limits thermal interference.
Headers	Sealed, symmetrical, accessible, with balancing points and cleanouts.	Allows inspection and equal flow.
Fan and controls	Variable speed, pressure capable fan, differential temperature control, humidity and dew point logic, drain alarm, radon monitoring, smoke override, and bypass.	Designed as building equipment, not an unattended buried pipe.
Integration	Dedicated ventilation supply, or professionally engineered connection upstream of compatible HVAC or energy recovery equipment.	Protects pressure balance and indoor air quality.

8.3 Bill of materials framework

A rough parts estimate is 60 to 90 dollars for forty feet of eight inch pipe, 12 dollars for an intake cap, 40 to 70 dollars for a fan, 8 dollars for a drain trap, and less than 15 dollars for couplings and primer, with parts under 250 dollars and trencher rental near 120 dollars. These figures are rough starting points, not a 2026 procurement estimate, because prices change over time and vary by location. Pipe class, cleanouts, filters, dampers, sensors, safe drainage, permits, electrical work, excavation, and professional review can move installed cost far above 300 dollars.

A useful historical comparison is the University of Florida demonstration. Goswami and Biseli (1993) documented a twelve inch, one hundred foot tunnel buried nine feet deep. Their 1993 retail cost table totaled 1,309 dollars for corrugated plastic and 1,692 dollars for galvanized steel, including equipment and labor. The numbers are historical and not current bids, but they show that a complete instrumented system has never been guaranteed by pipe price alone.

Table 9. Complete bill of materials categories

Category	Included items	Cost treatment
Underground air path	Burial rated smooth tube, couplings, gaskets or approved cement, headers, cleanouts, structural bedding, warning tape.	Obtain local written quotes for exact pipe class and quantity.
Intake	Weather hood, pest screen, coarse screen, filter cabinet, replaceable filters, support, sealed access door.	Include replacement filters in annual operating cost.
Air movement	Variable speed fan, controller, isolation mounts, disconnect, wiring, overcurrent protection, weather enclosure.	Use delivered airflow and pressure, not catalog free air alone.

Category	Included items	Cost treatment
Control and measurement	Temperature and humidity sensors, ground probes, airflow station, pressure ports, fan energy meter, radon monitor, drain sensors, data logger.	Separate minimum control cost from research instrumentation cost.
Moisture	Slope survey, low point access, sealed sump or trapped drain, condensate pump if needed, overflow alarm, backflow protection.	Do not delete this category to preserve a target price.
Building integration	Damper, bypass, backdraft protection, plenum, registers, relief path, HVAC interlock, fire and smoke provisions.	Requires project specific mechanical review.
Civil work	811, private utility locate, permit, excavation, trench protection, bedding, backfill, compaction, surface restoration.	Often the largest variable cost.
Quality assurance	Pressure test, drainage test, airflow balance, radon test, commissioning, professional inspection.	Treat as part of the system, not an optional extra.

9. Illustrative Las Vegas Analysis

9.1 Climate and assumptions

Las Vegas is an important test because it is hot, dry, sunny, and strongly affected by urban heat. NOAA reports a 1991 to 2020 annual mean air temperature of 70.1°F for the Las Vegas station (National Weather Service Las Vegas, 2021). Deep undisturbed ground tends toward a value related to the annual mean surface temperature, not a national 55°F constant. Surface solar gain and dryness can make actual ground behavior different from air based estimates, so the following numbers are illustrative and must not replace measurement.

Table 10. First order Las Vegas screening assumptions

Input	Value	Reason for selection
Annual mean temperature	70.1°F	NOAA 1991 to 2020 Las Vegas normal mean air temperature, used only as a screening proxy for mean surface temperature.
Surface annual amplitude	24°F	Illustrative rounded value chosen for sensitivity, not a measured soil surface amplitude.
Soil thermal diffusivity	0.07 square meters per day	Representative analytical assumption within the broad range of soils. Field measurement is preferred.
Summer inlet temperature	105°F, 40.6°C	Hot afternoon design illustration.
Baseline tube	Eight inch inside diameter, forty feet long	Baseline geometry used in this design.
Overall heat transfer coefficient	10 W per square meter kelvin	Illustrative first order value. A sensitivity range of 5 to 15 is also shown.
Air density and heat capacity	1.15 kilograms per cubic meter and 1,006 joules per kilogram kelvin	Rounded hot air properties for screening.
Electricity price	13.11 cents per kilowatt hour	EIA preliminary Nevada residential average for June 2026.

Climate source: National Weather Service Las Vegas (2021). Electricity source: U.S. Energy Information Administration (2026). All remaining values are explicit analytical assumptions for sensitivity testing.

9.2 Ground wave result

Table 11. Illustrative annual ground wave by depth

Depth	Amplitude retained	Phase lag	Illustrative annual range
4 ft, 1.22 m	65.2 percent	24.8 days	54.4°F to 85.8°F
8 ft, 2.44 m	42.5 percent	49.7 days	59.9°F to 80.3°F
12 ft, 3.66 m	27.7 percent	74.5 days	63.4°F to 76.8°F

Calculated from Equation 1 using the explicit assumptions in Table 10. These are not measured Las Vegas soil temperatures.

Under the same assumptions, a six month phase lag requires approximately 29.4 feet of depth. That value changes with soil diffusivity, but it demonstrates the order of magnitude. The phrase four feet equals a six month weather delay is not physically supported by this model (Figure 7). At four feet, the late summer ground can also be much warmer than 55°F. This matters because the tube cannot cool air below the surrounding wall temperature without another cooling mechanism.

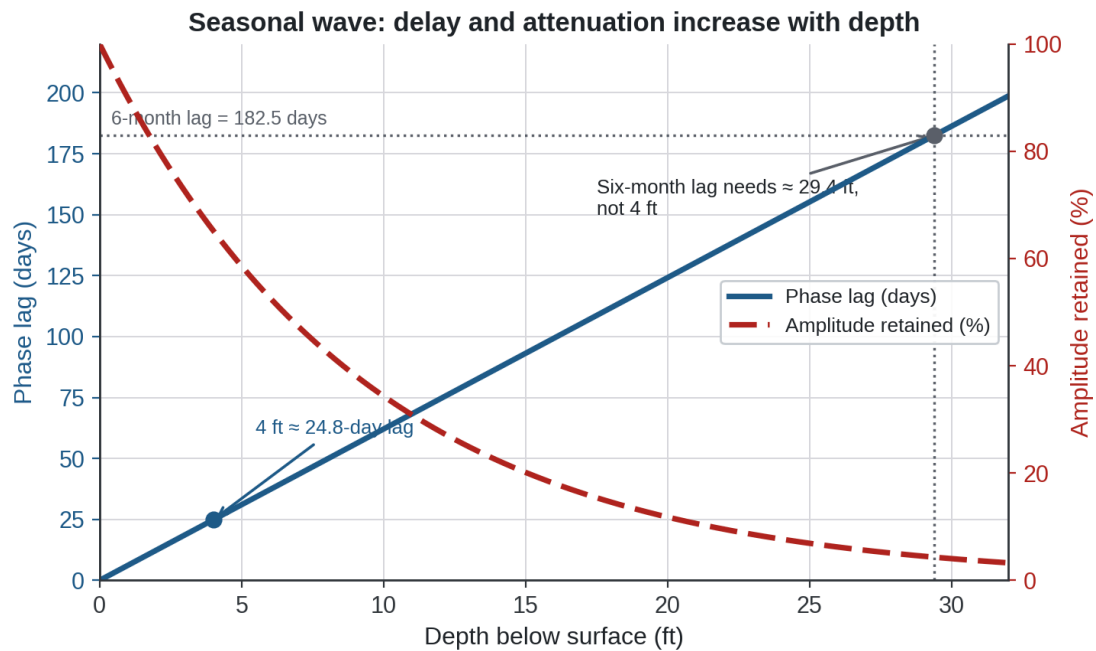


Figure 7. Seasonal phase lag and retained amplitude versus depth for the same screening assumptions. A six month delay requires roughly 29.4 feet of depth, not four feet, where the lag is only about 25 days. This figure directly tests the popular claim of a six month delay at four feet.

9.3 Baseline forty foot tube

Table 12. Predicted baseline performance with 105°F inlet air

Airflow	Air velocity	Outlet at 77°F ground	Cooling at 77°F ground	Outlet at idealized 55°F ground	Cooling at idealized 55°F ground
100 cfm	1.46 m/s	83.8°F	647 W, 2,208 Btu/h	67.0°F	1,154 W, 3,937 Btu/h
200 cfm	2.91 m/s	90.8°F	868 W, 2,963 Btu/h	79.6°F	1,549 W, 5,284 Btu/h
300 cfm	4.37 m/s	94.5°F	966 W, 3,298 Btu/h	86.1°F	1,724 W, 5,881 Btu/h

First order constant ground model, $U = 10$ W per square meter kelvin. Values are calculations, not prototype measurements.

The table exposes the central tradeoff (Figure 8). At 100 cubic feet per minute, the air spends more effective time exchanging heat and leaves much closer to the ground temperature. At 300 cubic feet per minute, total cooling is greater but the outlet is warmer. Even under the idealized 55°F ground assumption, the forty foot tube does not deliver 55°F air at these flows. Under a 77°F ground condition, it delivers useful precooling but not conventional air conditioning supply temperature.

One 40-ft, 8-in tube: the airflow trade-off (105°F inlet, U = 10)

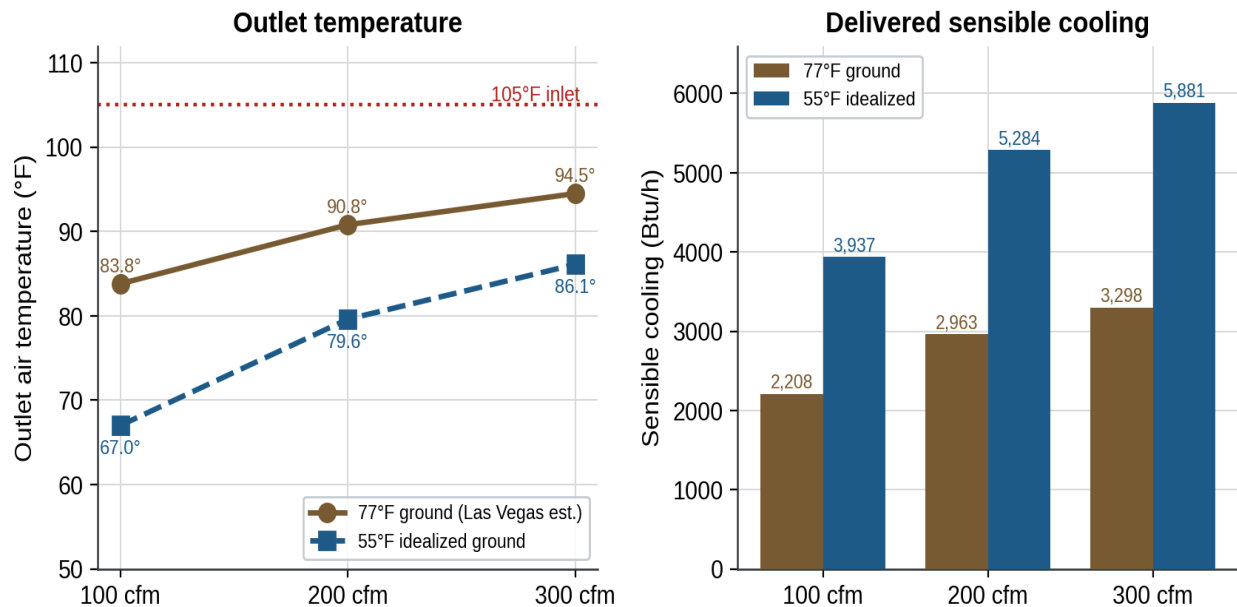


Figure 8. Predicted performance of one 40 foot, 8 inch tube at 105°F inlet air, from the first order model of Section 5.2 (Table 12). Lower airflow gives colder outlet air, while higher airflow gives more total cooling but warmer air. Even under an idealized 55°F ground, this single short tube does not deliver 55°F supply air at these flows.

9.4 Heat transfer sensitivity

Table 13. Sensitivity to overall heat transfer coefficient at 200 cubic feet per minute

U value	Effectiveness	Outlet temperature	Sensible cooling
5 W per square meter kelvin	0.300	96.7°F	511 W, 1,743 Btu/h
10 W per square meter kelvin	0.510	90.8°F	868 W, 2,963 Btu/h
15 W per square meter kelvin	0.657	86.6°F	1,119 W, 3,817 Btu/h

Inlet 105°F, ground 77°F, eight inch inside diameter, forty foot length. The wide result range is why field calibration is required (Figure 9).

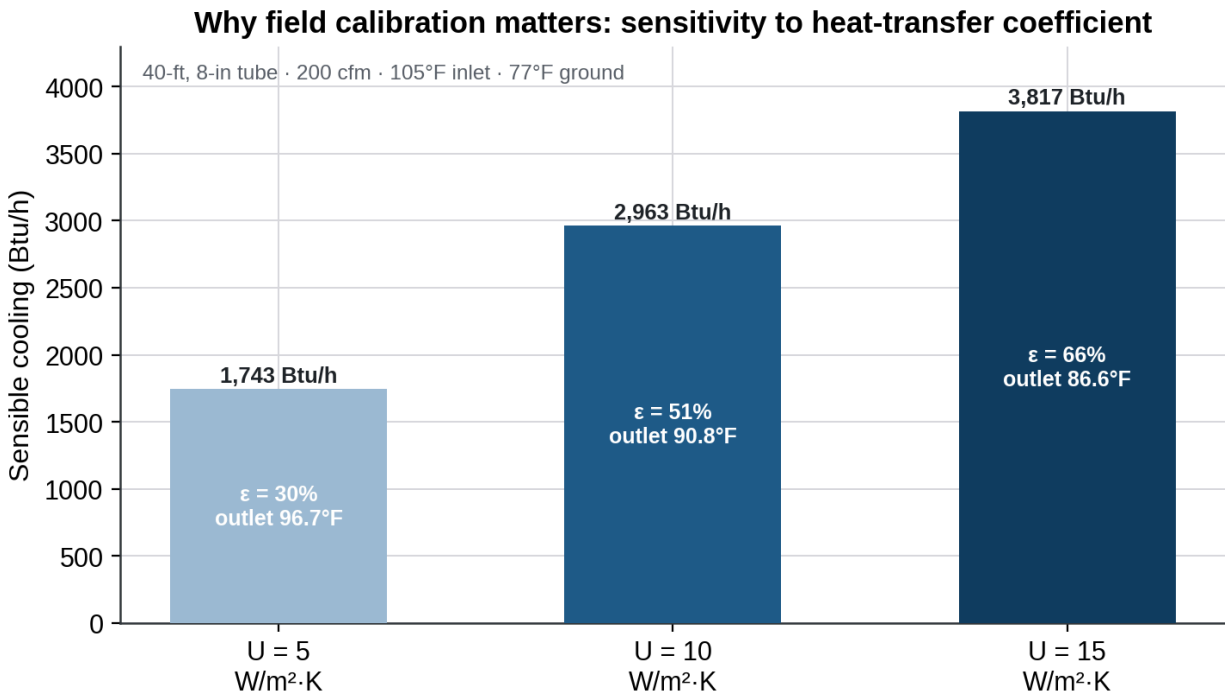


Figure 9. Sensitivity of delivered cooling to the overall heat transfer coefficient at 200 cubic feet per minute (Table 13). The spread, from about 1,743 to 3,817 Btu per hour as U moves from 5 to 15, is why the coefficient must be calibrated in the field rather than assumed.

9.5 Scaled three tube array

Table 14. Predicted performance of three parallel one hundred foot tubes

Ground condition	Total airflow	Predicted outlet	Total sensible cooling
77°F, 25.0°C	300 cfm	77.8°F	2,483 W, 8,472 Btu/h
72°F, 22.2°C	300 cfm	72.9°F	2,925 W, 9,980 Btu/h
68°F, 20.0°C	300 cfm	69.1°F	3,279 W, 11,187 Btu/h

Each tube carries 100 cubic feet per minute. U = 10 W per square meter kelvin. No soil warming penalty is included.

The scaled array approaches one nominal ton of sensible cooling only in the cooler ground cases (Figure 10). One ton is 12,000 Btu per hour. Many Las Vegas houses require multiple tons at design conditions, so even this larger array should be described as a substantial preconditioner unless a specific low load building and measured seasonal data prove otherwise. A very efficient small home may be a different case, but that conclusion must come from its load calculation.

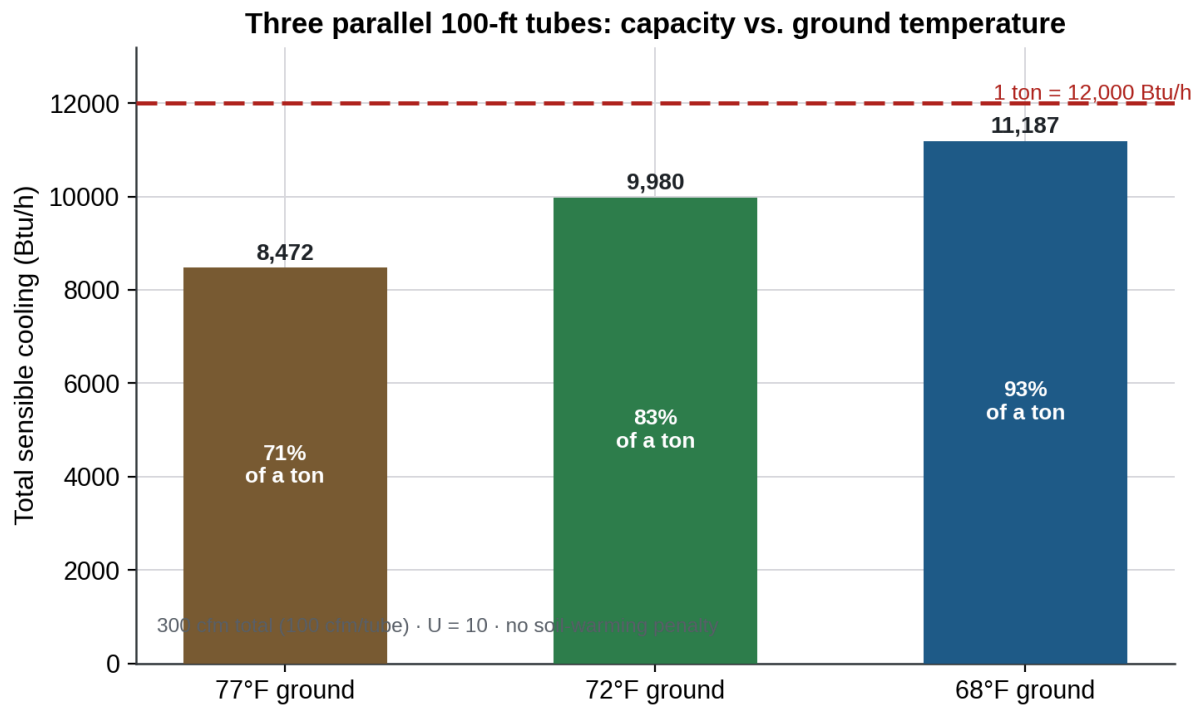


Figure 10. Predicted capacity of three parallel 100 foot tubes at 300 cubic feet per minute against ground temperature (Table 14). The array approaches, but does not reach, one ton of sensible cooling, and only in the cooler ground cases, so it is best described as a substantial preconditioner rather than a whole house air conditioner.

9.6 Comparison with measured precedent

The University of Florida demonstration provides a useful reality check. Its tube was twelve inches in diameter, one hundred feet long, and nine feet deep. At 1,000 cubic feet per minute, measured ambient air near 90°F was reduced to about 83°F. The fan input was 186.5 W and the reported thermal effect was 127 Btu per minute, equivalent to 7,620 Btu per hour, for a reported thermal coefficient of performance near 12 (Goswami & Biseli, 1993). That outcome is excellent for low energy tempering, but the outlet was not equal to deep soil temperature and the researchers recommended the open system particularly where a 7°F to 10°F drop was acceptable. This measured precedent is more credible than a universal promise of 55°F air from forty feet of shallow pipe.

10. Energy Use and Economic Interpretation

10.1 Fan electricity

A 50 W fan operating twelve hours per day for thirty days uses 18 kWh. At 13.11 cents per kWh, the energy cost is approximately 2.36 dollars per month. Continuous operation uses 36 kWh and costs approximately 4.72 dollars per month. These are low values, but they are not zero. A dirty filter, higher pressure, larger fan, or central blower can raise them. A direct solar fan may reduce grid energy, while metering should still report the electrical energy produced and used.

$$\text{Monthly fan cost} = P_{\text{fan,kW}} \times \text{hours per day} \times \text{days} \times \text{electricity price}$$

(8)

10.2 Avoided compressor energy

Thermal delivery is not identical to bill savings. The earth tube saves compressor energy only when its cooling actually displaces an equivalent building load. A simple instantaneous comparison divides delivered cooling in Btu per hour by the conventional system energy efficiency ratio in Btu per watt hour, then subtracts earth tube fan power. Seasonal analysis should use measured schedules and the conventional system performance at corresponding conditions.

$$P_{\text{avoided,net}} = Q_{\text{delivered}} \div \text{EER}_{\text{reference}} - P_{\text{fan}} \quad (9)$$

For example, 3,000 Btu per hour of useful displacement against a reference EER of 12 corresponds to 250 W of avoided air conditioner input before fan energy. A 50 W earth tube fan leaves about 200 W net. If that condition persists twelve hours per day for thirty days, the net is 72 kWh, or about 9.44 dollars at the illustrative Nevada rate. This is a scenario, not a promised monthly saving. If the delivered air causes unwanted humidity, pressurization, or simultaneous conventional cooling, the saving may be smaller or negative.

10.3 Honest cost language

Recommended public description: Use the phrase low operating cost earth cooling or low power ground tempered ventilation. Reserve almost free for a clearly labeled scenario in which fan power is measured, solar input is accounted for, maintenance is included, and the system has already demonstrated useful displacement. Do not use unlimited to imply infinite capacity.

11. Installation and Construction Safety

This section describes the engineering sequence. It is not permission for untrained trench entry, electrical work, structural modification, or HVAC alteration. Before any excavation, contact 811 and wait for all utilities to respond. The national 811 service states that anyone planning to dig should request utility marking a few business days before excavation (Common Ground Alliance, n.d.). Private lines may require separate locating. Obtain the local permit determination in writing. Clark County states that residential duct additions and relocations require permits and inspection (Clark County, Nevada, n.d.).

11.1 Construction sequence

1. Complete survey, load calculation, soil temperature screening, radon baseline, utility locate, permit, drainage plan, and final stamped design where required.
2. Stake the intake, headers, tube centerlines, cleanouts, drain, and building penetration. Confirm slopes and elevations with a laser level.
3. Excavate using the approved trench protective plan. Keep spoil, equipment, and people away from unsafe edges. Avoid human entry whenever placement can be done from the surface.
4. Prepare compacted bedding that supports the full tube barrel and creates continuous fall. Remove sharp rocks and point loads.
5. Assemble the longest practical tube sections above ground. Clean, join, and cure connections according to the approved material system.

6. Lower the assembly without standing under suspended loads. Anchor temporarily so the tube cannot float, bow, or shift.
7. Install headers, cleanouts, drain, inspection ports, intake sleeve, and building penetration. Keep all service points accessible.
8. Perform a low pressure leakage test, slope survey, and water drainage test before backfill. Record results with photographs and measurements.
9. Place compatible initial backfill evenly by hand or approved method around the tube. Compact in lifts without crushing or displacing the pipe.
10. Install warning tape, probes, and location records. Complete backfill and surface drainage so water moves away from the intake and building.
11. Install fan, filters, dampers, controls, electrical protection, delivery path, and relief path. Label all isolation and service points.
12. Commission the system under Section 12 before it is used as occupied space ventilation.

11.2 Before backfill hold point

Table 15. Mandatory inspection before backfill

Item	Acceptance criterion	Record
Alignment and support	The tube is continuously supported, with no point loads, sharp bends, deformation, or reverse slope.	Survey readings and photographs.
Slope	Every segment falls to the designated accessible low point at or above the approved minimum.	Laser level elevation log.
Leakage	Pressure decay or leakage is within the project criterion and all joints remain accessible for correction.	Test pressure, duration, temperature, and result.
Drainage	A known water volume reaches the collection point without retained pockets and the drain remains air sealed.	Input volume, recovered volume, time, and visual inspection.
Structural rating	Pipe class, cover, bedding, compaction, and live load protection match the approved design.	Material certificates and inspector signoff.
Cleanliness	The interior is free of soil, primer residue, water, pests, and construction debris.	Borescope video or direct inspection.
Access	Both ends, drain, cleanouts, headers, and sensors remain reachable after backfill.	As built location plan.

12. Commissioning and Field Validation Protocol

12.1 Research status

The design reported in this manuscript is free for anyone to use, and I have applied it as a general working prototype at my own studio in Las Vegas, installed at the baseline depth or deeper. Its everyday behavior was consistent with the air tempering described here.

I did not log instrumented measurements and, having since moved, retain no photographs or records from that installation, so I report no direct field data, and the studio experience is offered as practical background rather than as evidence. All performance values in Section 9 remain analytical estimates. The next scientific step is a preregistered field study. The following protocol is designed so that a homeowner, journal reviewer, or independent laboratory can reproduce the measurements and distinguish delivered cooling from appearance.

12.2 Research questions and hypotheses

Table 16. Proposed hypotheses

Hypothesis	Primary outcome	Decision rule
H1, thermal benefit	Outlet dry bulb temperature and sensible cooling rate.	During eligible cooling hours, median outlet is at least 3°F cooler than direct outdoor air and positive sensible cooling is measured.
H2, low electrical intensity	Thermal coefficient of performance, delivered sensible watts divided by fan and control watts.	Seasonal median exceeds 8, with uncertainty reported.
H3, building benefit	Indoor operative temperature, conventional HVAC runtime, and electricity.	Matched period analysis shows a statistically and practically meaningful reduction without unacceptable humidity.
H4, moisture safety	Condensate volume, retained water, drain alarms, and interior inspection.	No standing water after drainage interval and no unresolved moisture alarm.
H5, air quality safety	Indoor radon, particulate matter, odor, and inspection findings.	No sustained adverse change relative to baseline and comparison periods.
H6, model validity	Difference between measured and predicted outlet temperature and capacity.	Bias and error remain within a predeclared engineering tolerance, for example mean absolute outlet error below 3°F after calibration.

12.3 Instrumentation

Table 17. Minimum research instrumentation

Variable	Location and method	Suggested accuracy or resolution
Dry bulb temperature	Shaded outdoor, tube inlet, tube outlet, indoor supply, occupied zone, and ground at multiple depths.	$\pm 0.3^{\circ}\text{C}$ after paired calibration.
Relative humidity	Tube inlet, tube outlet, and occupied zone, with calculated dew point and humidity ratio.	± 2 percent RH in the operating range.
Airflow	Straight delivery section or calibrated flow station, plus branch measurements for parallel tubes.	± 5 percent of reading.
Static pressure	Across filter, buried path, fan, and total system.	Resolution near 1 pascal.
Electrical energy	True power for earth tube fan and controls, and separate conventional HVAC energy where possible.	Revenue grade or validated submeter, cumulative kWh.
Condensate	Collection volume or pulse meter, high level alarm, and drain temperature.	0.1 liter resolution for research.
Radon	Occupied zone baseline and operation, using an approved short and long term protocol.	Report pCi/L or Bq per cubic meter and device uncertainty.
Particles and outdoor air quality	Outdoor intake and occupied zone PM _{2.5} , with official regional air quality record.	Calibrated research instrument preferred; consumer sensor identified as screening only.
Weather	Outdoor temperature, humidity, solar radiation if available, wind, precipitation, and smoke events.	Hourly data synchronized to system logger.

12.4 Commissioning stages

1. Sensor calibration: place air temperature and humidity sensors together in a stable environment, calculate offsets, and lock the calibration record before the trial.
2. Air path sanitation: inspect the complete interior, clean using the approved method, install new filters, and document the starting condition.
3. Leakage and pressure: verify tube pressure, building pressure, damper operation, relief path, and combustion safety where applicable.
4. Drain challenge: introduce a known water volume at the high end, confirm transport to the low point, verify alarm, and verify that the air seal remains intact.
5. Airflow balance: measure total and branch airflow at low, medium, and high fan command with clean filters.
6. Control challenge: test outdoor bypass, earth path, smoke shutdown, high humidity response, drain alarm, radon alarm, freeze response, and power failure position.

7. Unoccupied burn in: operate for at least seventy two hours while logging temperature, humidity, radon, pressure, condensate, odor, and power before regular occupied use.
8. Baseline comparison: collect at least two weeks of comparable conventional operation or randomized on and off periods before making savings claims.
9. Seasonal trial: collect the complete cooling season, retaining raw data, calibration records, exclusions, maintenance events, and weather.

12.5 Data reduction

Data should be reduced at a fixed interval, for example one minute raw and fifteen minute reporting. Sensible cooling is calculated from measured airflow and inlet to outlet temperature. Latent removal is calculated from humidity ratio and condensate cross checked against collected water. Fan energy is integrated from true power. Thermal coefficient of performance is delivered total cooling divided by fan and control electricity over the same interval. Report both sensible and total cooling because a dry desert system may be almost entirely sensible while a humid climate may generate a large latent load.

$$\text{COP}_{\text{thermal}} = \int (Q_{\text{sensible}} + Q_{\text{latent}}) dt \div \int P_{\text{fan,controls}} dt \quad (10)$$

For building impact, compare matched outdoor enthalpy, solar, occupancy, and thermostat conditions. A randomized crossover schedule, earth tube on versus bypass, is stronger than comparing one hot day with one mild day. Report mean, median, peak, confidence intervals, sensor uncertainty, missing data, and all exclusion rules. Publish the raw time series in a machine readable repository if the journal permits.

13. Operation and Maintenance

A buried system is not maintenance free. It is maintenance sensitive because the air path is long and mostly invisible. Service intervals should be shortened during dust, smoke, pollen, construction, pest activity, or heavy condensation. The schedule below is a starting point and must be adapted from measured pressure, filter loading, water, and inspection results.

Table 18. Preventive maintenance schedule

Interval	Action	Shutdown trigger
Continuous	Monitor outlet temperature, relative humidity, drain alarm, fan fault, outdoor air quality, and indoor radon trend.	Any hard alarm, unexplained odor, water, smoke, or radon increase.
Monthly during use	Inspect intake, screen, weather hood, filter pressure, drain visibility, pest evidence, and fan sound.	Blocked intake, wet filter, damaged screen, drain backup, or abnormal vibration.
Every three months	Replace or clean filter based on pressure and manufacturer guidance; test bypass and backdraft damper.	Failure to reach airflow or damper position.

Interval	Action	Shutdown trigger
Before and after cooling season	Flush and challenge the drain, inspect cleanouts, perform borescope survey, verify sensor calibration, and review data.	Standing water, deposits, damaged joints, or biological growth.
Annually	Repeat radon test, airflow balance, pressure test trend, fan energy check, and electrical inspection.	Adverse change from commissioning baseline.
After flood, earthquake, excavation nearby, or major repair	Keep isolated until structural, leakage, drainage, and air quality checks pass.	Any uncertainty about tube integrity.

Cleaning methods must be compatible with tube material and indoor air use. Do not introduce fragrances, pesticides, unapproved biocides, or residues that will later enter occupied space. Physical removal, controlled flushing to the serviceable drain, and complete drying are preferred. If contamination cannot be fully accessed and removed, abandon or line the direct air path under professional design, or convert to an indirect ground exchange approach.

14. Risk Analysis

Table 19. Failure modes and controls

Failure mode	Consequence	Primary prevention	Detection and response
Standing condensate	Odor, microbial growth, corrosion, aerosolization, airflow blockage.	Continuous surveyed slope, smooth interior, accessible sealed drain, overflow path.	Water sensor, condensate log, borescope, shutdown and clean.
Soil gas leakage	Radon or vapor intrusion into supply air.	Positive pressure buried path, sealed joints, safe drain, contaminated site exclusion.	Radon monitoring, pressure test, isolate and investigate.
Tube collapse or deformation	Blocked airflow, trapped water, soil movement, inaccessible failure.	Burial rated pipe, correct bedding and compaction, live load design.	Airflow and pressure change, borescope, ground settlement inspection.
Filter blockage	Low airflow, fan overheating, loss of cooling, noise.	Large accessible filter area and maintenance schedule.	Differential pressure alarm and fan power trend.
Outdoor pollution event	Smoke, ozone, dust, exhaust, or chemicals brought indoors.	Intake siting, air quality input, manual and automatic bypass.	Close intake, recirculate safely, replace filter when appropriate.
Humidity overload	High indoor humidity, discomfort, condensation on building surfaces.	Dew point control, dehumidification or energy recovery integration.	Indoor humidity alarm, reduce outdoor flow, engage backup system.

Failure mode	Consequence	Primary prevention	Detection and response
Thermal saturation	Outlet warms during extended operation and cooling falls.	Adequate tube area and spacing, duty control, night bypass, transient design.	Ground and outlet trend, rotate tube banks or rest system.
Building depressurization or pressurization	Backdrafting, infiltration, door problems, moisture transport.	Balanced air plan and professional HVAC integration.	Building pressure test and combustion safety test.
Power or control failure	Uncontrolled damper position, loss of ventilation or cooling.	Fail safe actuators, manual override, backup cooling plan.	Alarm and safe position test.
Unsafe excavation	Cave in, utility strike, equipment injury, fatality.	811, private locate, permit, competent excavation plan, no unnecessary entry.	Stop work authority and competent person inspection.

15. Regulatory and Standards Context

A residential earth tube crosses several regulatory domains. The locally adopted mechanical code governs underground ducts, materials, slope, sealing, inspection, and building connections. The International Mechanical Code includes dedicated provisions for ducts in or under the earth, but exact section numbering and amendments must be checked in the adopted edition (International Code Council, 2021). ASHRAE Standard 62.2 defines minimum residential ventilation and source control requirements, while ASHRAE Standard 55 provides methods for evaluating thermal environmental conditions and comfort (ASHRAE, 2023, 2025). Compliance with one standard does not prove compliance with the others.

Electrical work, photovoltaic wiring, structural penetrations, fire and smoke dampers, floodplain rules, drainage disposal, property setbacks, easements, and homeowner association rules may also apply. If a central return connection interacts with a gas appliance, combustion safety review is essential. The statement no permit should never appear in installation instructions without a written local determination.

16. Limitations

The calculations use a one dimensional constant ground approximation and an assumed overall heat transfer coefficient. They do not model soil warming, daily temperature waves, moisture dependent soil properties, tube to tube interference, solar surface heating, complex headers, leakage, fan curves, or full building dynamics. The Las Vegas ground values are illustrative. Material costs are prices will differ by region. Long term studies do exist, including recent large diameter field work, but they do not justify universal no mold or whole house claims.

The design also does not guarantee thermal comfort. Comfort depends on air temperature, radiant temperature, humidity, air speed, clothing, and activity. Earth tube air near 80°F may be very useful

when it replaces 105°F ventilation air, yet it may not maintain an occupied room at the desired setpoint. It worked great in my studio where I sat and worked on my computer and filed content. The system must be evaluated as part of the building, not as an isolated outlet thermometer.

17. Open Source Release and Public Benefit

The central ethical commitment of this project is access. A useful household energy design should be understandable, measurable, and improvable by ordinary people, researchers, builders, and communities. Public disclosure may establish prior art and can limit later claims that the disclosed combination is novel. The author does not assert a patent monopoly in this manuscript. Readers may study, build, test, and improve the functional concept, subject to law, safety, and third party rights. This paragraph is a statement of intent, not a legal opinion.

Open source does not mean responsibility free. Anyone publishing a derivative should disclose geometry, site, climate, ground temperature, airflow, humidity, fan power, maintenance, failures, and raw data. Negative results are valuable. A tube that performs poorly in one soil or contaminates in one drainage configuration teaches the community how to design better. The project succeeds when claims become more accurate, systems become safer, and the evidence becomes easier to reproduce.

18. Discussion

The earth tube sits in a productive middle ground between natural ventilation and mechanical refrigeration. Its thermal coefficient of performance can be high because the denominator is mainly fan power. Its absolute capacity can still be modest. This distinction explains why popular demonstrations can feel astonishing while failing to cool an ordinary whole house. High efficiency and high capacity are different achievements.

Measured precedent supports the cautious interpretation. Al Ajmi et al. (2006) predicted a 1,700 W peak load reduction and a 2.8°C indoor temperature reduction for a desert climate case. The University of Florida system reduced 90°F air to roughly 83°F through a much larger and deeper installation. Duarte et al. (2023, 2025) showed that a large diameter system can support standalone office room cooling in a hot and dry setting, but that result came from a purpose designed large system and long monitoring, not a single short residential pipe. The literature supports earth exchange as a serious engineering tool. It does not support one universal backyard recipe.

Las Vegas also clarifies the phrase stored winter cold. At depth, the annual wave is delayed and attenuated, so late summer soil can indeed reflect earlier seasonal conditions. Yet a six month delay at four feet is not a reasonable general model. The deeper ground also tends toward the local annual mean, about 70°F in the NOAA air normal used here, rather than 55°F. In a cooler climate the same concept may deliver colder summer air. In a warmer climate or beneath sun heated pavement, it may deliver less. Site data are the invention's compass.

The strongest practical pathway is therefore a staged one. Build an instrumented Level A demonstrator if the site passes the safety gate. Measure a complete hot period. Calibrate the model. Scale with parallel tubes only when the measured result justifies the land and excavation. Keep existing cooling until the system proves the required indoor outcome. This sequence preserves the charisma of a simple idea and adds the discipline that makes it trustworthy.

19. Conclusion

A buried air path can deliver useful residential cooling and heating assistance with very low operating power. The idea deserves wider testing and open sharing. The most defensible design, however, is not a universal 300 dollar, 55°F, zero bill promise. It is a site specific earth to air heat exchanger sized from ground temperature and building load, built from sealed and serviceable components, drained to an accessible point, operated under positive pressure, filtered, bypassed during unsafe outdoor air, monitored for radon and moisture, and validated with measured airflow, thermal output, and electricity.

For the forty foot, eight inch source geometry, the first order Las Vegas example predicts meaningful precooling but only a fraction of a typical whole house load. A parallel array can deliver much more, and a low load building may obtain major benefits. Those possibilities are exciting precisely because they can be tested. The future claim should be simple: build it safely, measure everything, publish the truth, and let people improve it for the common good.

Declarations

Data availability: No new experimental dataset was generated for this design manuscript. All numerical examples are reported with their assumptions and equations. Future field data should be deposited in a public machine readable repository.

Funding: This manuscript does not report an externally funded experimental program.

Patent and access statement: No patent application or exclusive license is asserted in this manuscript for the disclosed functional design. Installers remain responsible for law, permits, safety, and third party rights.

Conflict statement: The open publication of this concept is intended to permit public use and independent testing. Any additional commercial or personal interests should be disclosed by the named author at submission according to journal policy.

Author responsibility: The named author must review the final manuscript, verify the calculations and biographical details, approve submission, and accept responsibility for the work before the paper is submitted to a journal.

Appendix A. Commissioning Record Template

Table A1. Field commissioning record

Record	Required entry	Result
Project identity	Address or coded site, climate station, authority, permit number, date, responsible installer.	_____
Geometry	Tube material, inside diameter, length, depth profile, spacing, slope, fittings, headers, drain.	_____
Soil	Classification, moisture, thermal conductivity or diffusivity, groundwater, surface cover.	_____
Leakage test	Method, pressure, duration, air temperature, allowable leakage, measured leakage.	Pass / Fail
Drain test	Water introduced, water recovered, drain time, retained water inspection, alarm function.	Pass / Fail
Airflow	Low, medium, high fan setting, total flow, branch flow, clean filter pressure.	_____
Controls	Bypass, smoke, humidity, drain, radon, freeze, power failure, manual override.	Pass / Fail
Air quality	Baseline radon, operating radon, odor, PM2.5, filter condition, interior cleanliness.	_____
Thermal test	Outdoor, inlet, outlet, ground, indoor temperature and humidity, fan watts, calculated capacity.	_____
Approval	Installer, owner, HVAC reviewer, building inspector where applicable.	_____

Appendix B. Owner Operating Checklist

- Confirm the intake area is dry, clean, unobstructed, and free from nearby exhaust or chemical activity.
- Check the outdoor air quality alert. Keep the outdoor intake closed during hazardous smoke or pollution unless a qualified design specifically provides safe filtration.
- Confirm the filter is installed, dry, within pressure limit, and seated without bypass leakage.
- Confirm the drain is clear, air sealed, and not in alarm.
- Review inlet and outlet temperature. Run the earth path only when it is predicted to improve the selected air source.
- Review indoor humidity and radon trend. Isolate the system if either changes adversely.
- Keep a backup cooling plan during extreme heat until the earth tube has demonstrated the required capacity.
- Log maintenance, alarms, unusual odor, water, pests, repairs, filter changes, and operating hours.

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