Earth-Air Heat Exchangers (Geothermal Heat Pumps)

John A. Paravantis
Professor
Department of International & European Studies
UNIVERSITY OF PIRAEUS

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Earth-air heat exchangers (EAHEs) are a type of energy-efficient <u>heating</u> and <u>cooling</u> system.

They harness the (relatively) stable temperature of the ground to regulate the temperature of buildings.

Abstract

The building sector is responsible for 40% of primary energy consumption

- Heating/cooling covers the most significant portion.

Passive heating/cooling applications have gained significant ground during the last three decades

- Much research on the subject.

Among passive cooling/heating applications, ground cooling (especially earth-to-air heat exchangers) has been highlighted as a remarkably attractive technological research subject because of

- Significant contribution to the reduction of heating/cooling energy loads;
- Improvement of indoor thermal comfort conditions;
- Amelioration of the urban environment
  - Small positive effects on the Urban Heat Island.

Paper that has been assigned for reading is a holistic review of state-of-the-art research, methodologies, and technologies of earth-to-air heat exchangers that help conserve energy and achieve thermal comfort in buildings. It covers

Thermal performance of earth-to-air heat exchanger systems;

Experimental studies and applications;

Parametric studies for investigating the impact of their main characteristics on thermal efficiency;

Recent advances and trends including hybrid technologies and systems.

Models describing the thermal performance of earth-to-air heat exchangers systems may be classified in numerical, analytical, and data-driven, based on theoretical principles and occasionally subject to experimental validation.

System parameters may be grouped into three categories: system design, soil types, and soil surface coverage.

> System design parameters, especially (pipe) length and burial depth, bore the most important influence on the thermal efficiency of the system.

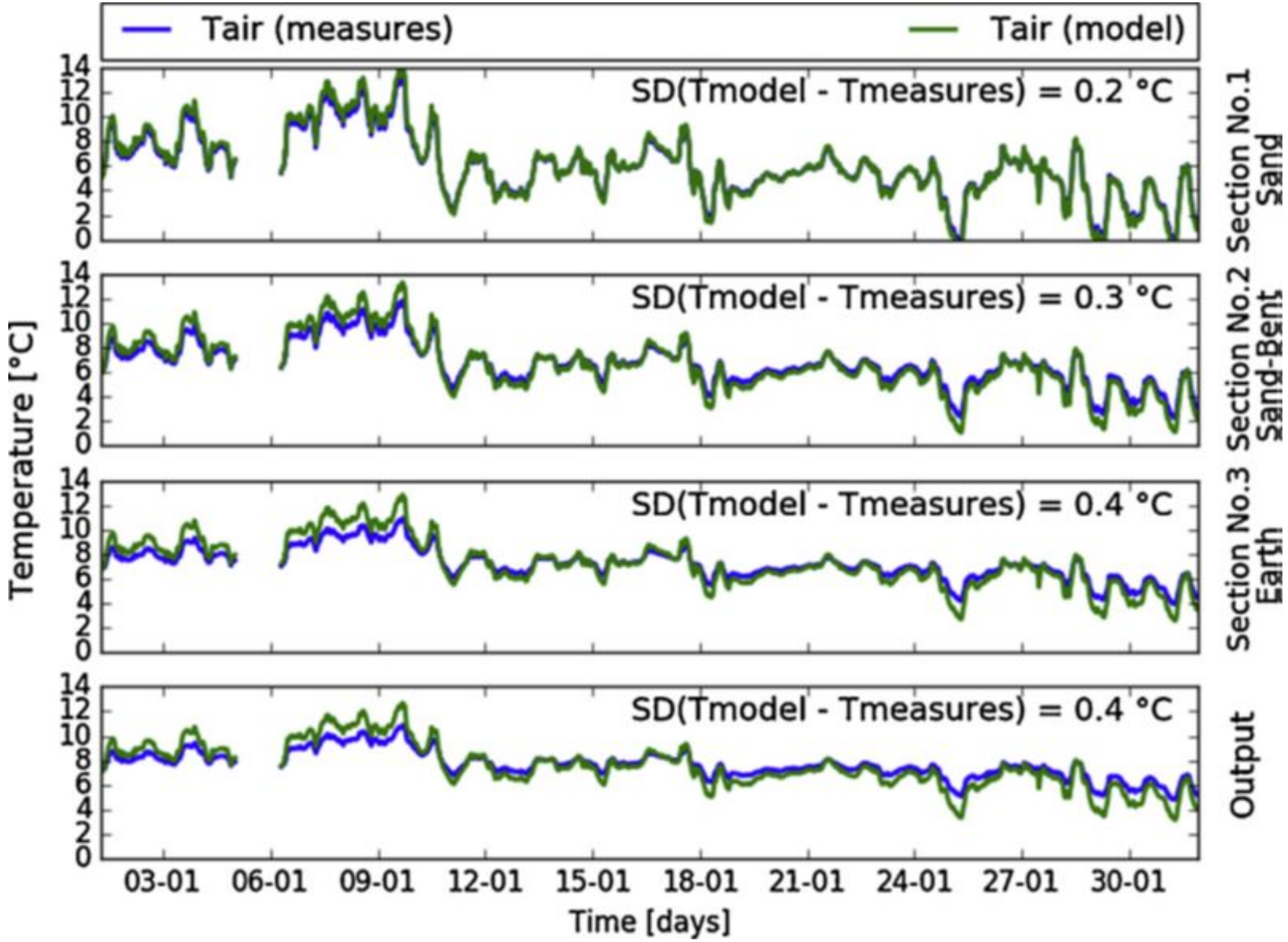
The paper also includes an economic assessment of system application.

Conclusions highlighted the need for more experimental work (including laboratory simulators).

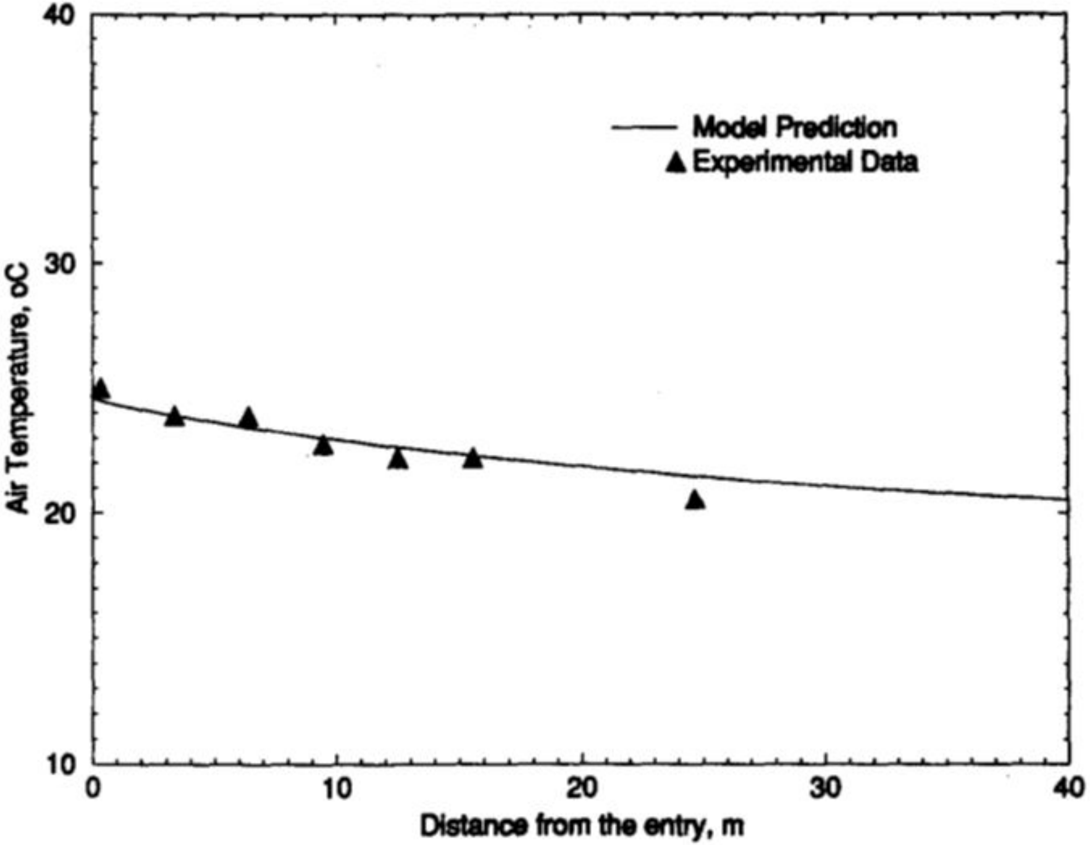
Introduction

From the economic section of the paper:

> *The earth to air heat exchanger (EAHE) is a passive technique that is based on the usage of the underground soil temperature … It consists of one or more pipes, made from metal, plastic or concrete, which are laid underground horizontally … EAHE systems do not require high maintenance and have a high potential for energy saving … They are suitable for the heating or cooling of small and medium spaces, and have low initial and operational costs …*



Measured and calculated exit air temperature values for January 2014 (SD stands for standard deviation)



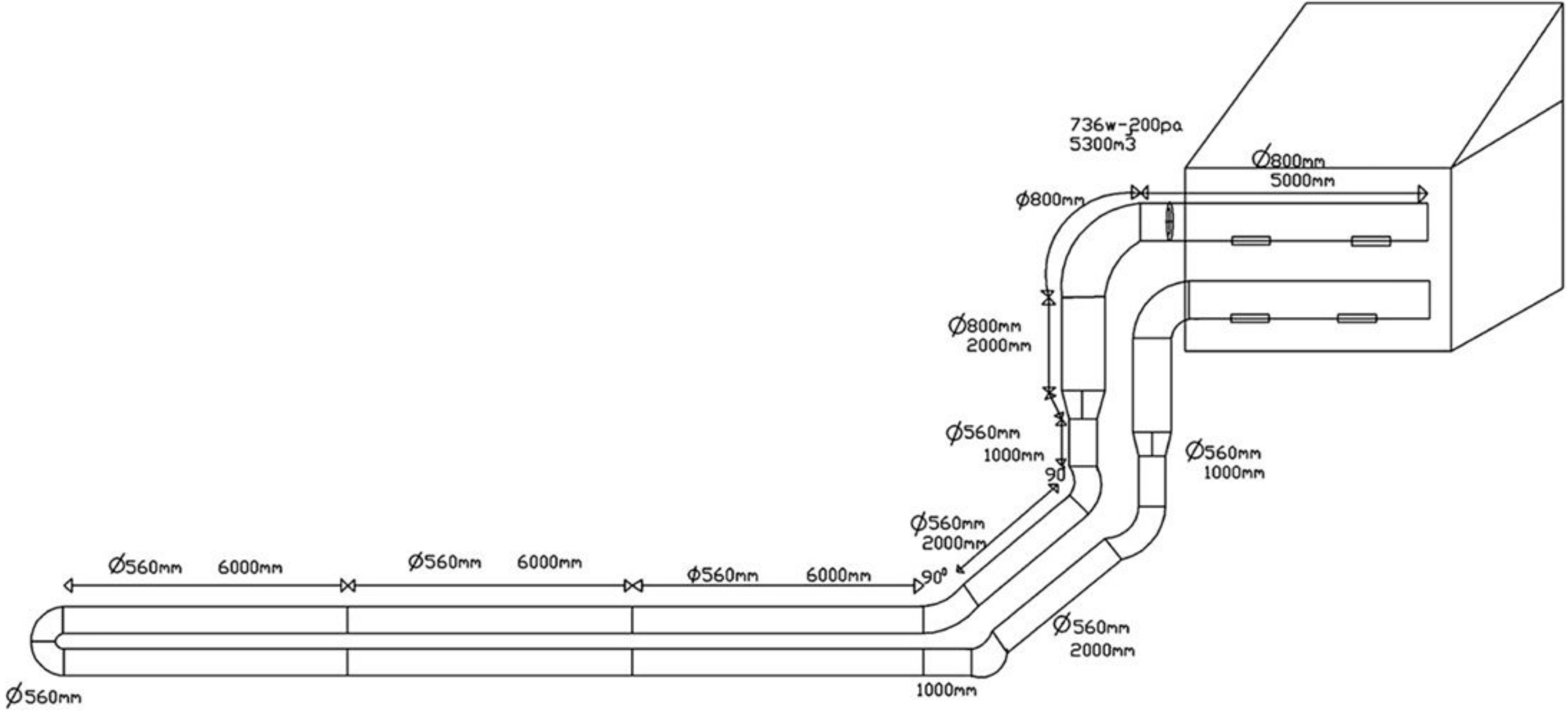
Experimental validation

Transient vs steady state models

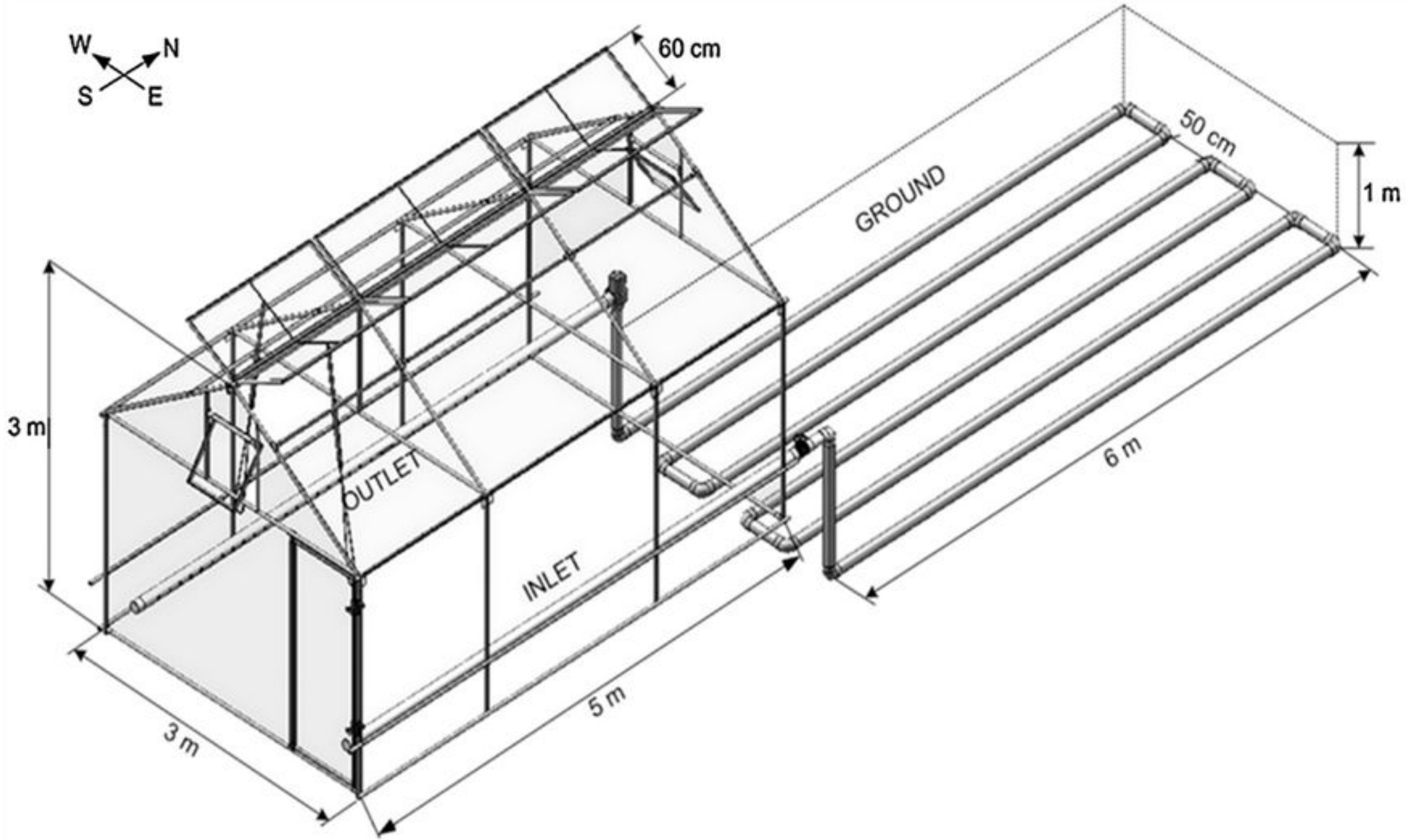
Data driven models are computing systems based on historical data (instead of the mathematical and physical formulations and equations of the deterministic models).

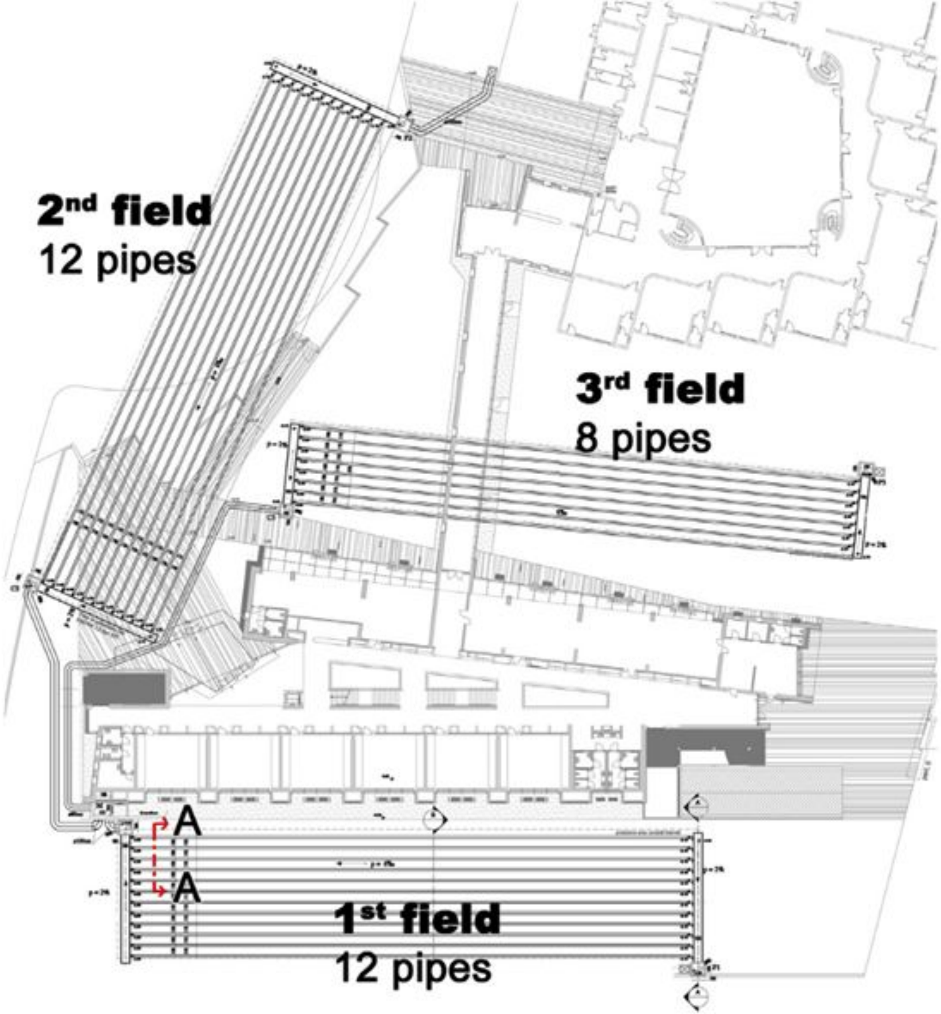
Artificial Neural Networks (ANNs) models and fuzzy logic models belong to this category.

Experimental studies



736w-200pa
5300m3
Ø800mm
5000mm
Ø800mm
Ø800mm
2000mm
Ø560mm
1000mm
90
Ø560mm
1000mm
Ø560mm
2000mm
90°
Ø560mm
6000mm
Ø560mm
6000mm
Ø560mm
6000mm
Ø560mm
2000mm
1000mm
Ø560mm


W
N
S
E
60 cm
50 cm
GROUND
1 m
3 m
OUTLET
INLET
6 m
5 m
3 m


2nd field
12 pipes
3rd field
8 pipes
A
A
1st field
12 pipes

Sites of reviewed experimental studies:

- Residential building in the south of France
- Office building in Germany
- School building in Imola, Italy
- Experimental solar greenhouse at Izmir (Turkey)
- Double floor guest house in India
- Agricultural greenhouse in Delhi (India)
- Residential building in Brazil
- Research Laboratory, University of Nottingham, Ningbo, China
- Agricultural greenhouse in Thailand (tropical climate)

Sites of reviewed experimental studies (continued):

- Energy Resources Engineering Department Laboratory, University of Science and Technology, Egypt
- Residential building in Marrakesh (Morocco)

Application for hot, dry, and arid climates

- Implementation in tropical climates
- Experiment carried out in Changsha (China), a city of subtropical climate (hot summers and cold winters)
- City in south-west China characterized by hot and humid climate

Parametric studies

The thermal behavior of an EAHE is strongly affected by many parameters of different type and quality:

(a) buried pipes system design parameters

(b) soil types described by the thermophysical characteristics of the ground

(c) environmental parameters, mostly influencing the ground surface temperature distribution

Parameters studied:

- Air flow rate & air velocity (inside the tubes)
- Ventilation flow rate in the pipe & burial depth
- Reynolds number (inertial/viscous forces~messy/turbulent flow)
- Form factor
- Ground surface cover
- Pipe diameter, pipe length & pipe material
- Space between pipes
- Soil types

Sensitivity analysis is an important part of the process.

Four main system design parameters (pipe length, pipe radius, air velocity inside the pipe, and burial depth) have been regarded as key-variables for extensive sensitivity analyses …

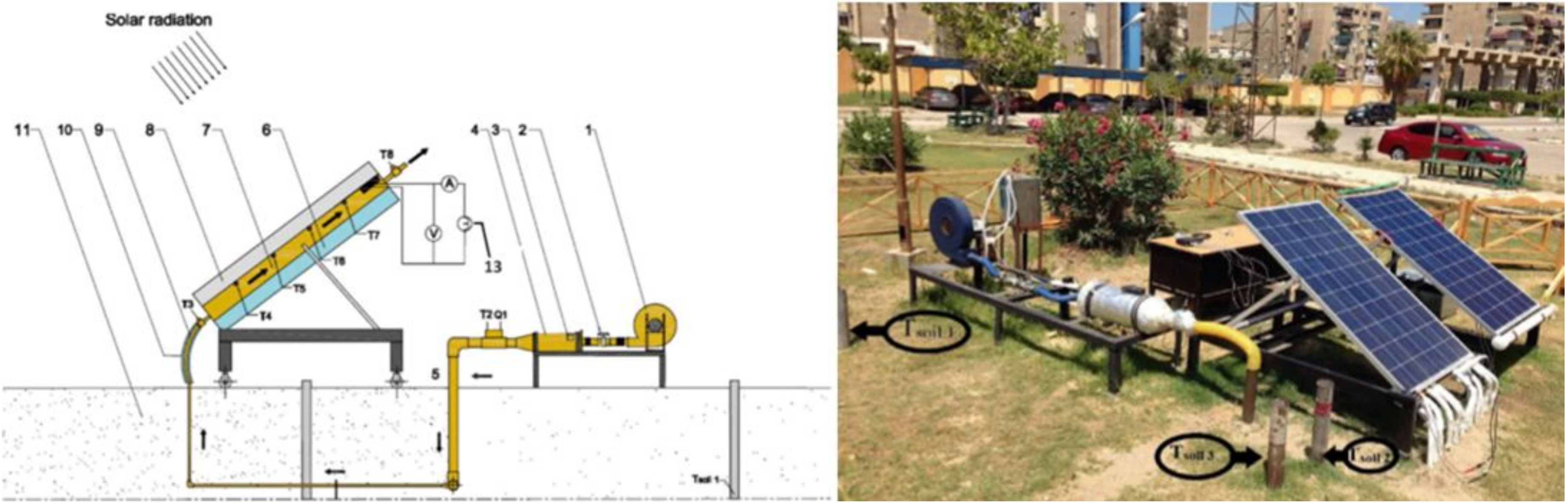
… different ground surface boundary conditions were considered: (a) bare soil, and (b) short-grass soil

Increased system efficiency was often achieved.

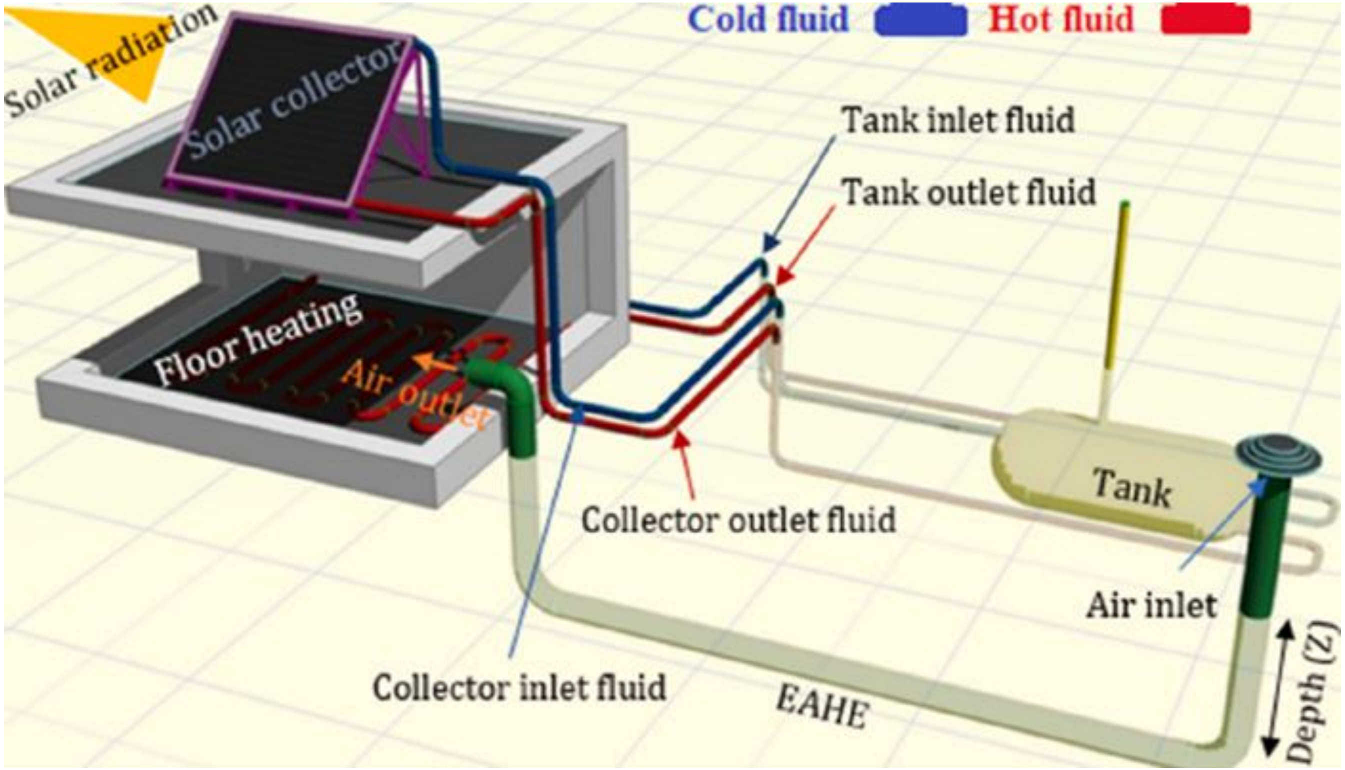
Hybrid EAHE-renewable systems

In all EAHE systems, a small amount of electricity is necessary to transfer both thermal and cooling load to specific locations within buildings and structures

A multi-objective optimization of a seasonal solar thermal energy storage system combined with an EAHE exchanger and a solar collector field was researched in the work of Benzaana et al. …



Schematic diagram and experimental setup of hybrid EAHE coupled with PVT collector



EAHE system coupled with underground tank and solar collector for heating

Economic assessment of earth to air heat exchangers

… residential energy consumption has a significant share in global energy consumption

… the ground source heat pump system is an alternative solution that can help reduce residential energy consumption

The performance of a system in a New Delhi (India) building was assessed with a life cycle cost analysis [assessment], concluding that the integration of earth to air heat exchangers has significant potential for energy saving, estimated at 10,321k Wh/year, compared to 4,946 kWh/year that was the energy saving potential before the integration

The annual cash inflow was estimated at $448/year and the annual cash outflow (operation and maintenance) at $240.9/year

A technoeconomic evaluation for an earth to air heat exchanger, coupled with a hybrid energy system including wind energy, solar energy, and hydrogen, found that effectiveness rose by 8% and energy supply was around 31.55 MJ per month

- If geothermal energy was added to the hybrid system, the renewable fraction could be improved by approximately 5.5%, while emissions and diesel consumption were reduced by approximately 48%

The performance of an EAHE system was assessed in the hot and dry conditions of Bhopal (India)

- The embodied energy of the system was estimated at 1,663.88 kWh, while its maximum heating and cooling potential were found to be 191.06 kWh in January and 247.25 kWh in May
- The energy payback period was calculated to be 1.29 years
- In its 50 years lifespan, the earned carbon credit equaled $2,837.6, while the CO_2 emission mitigation potential was estimated at 101.3 tons.

The evaluation of a passive system that coupled EAHE with a solar chimney showed that such a system could provide up to 2,582 W of cooling capacity, covering the cooling load of the building and maintaining thermal comfort.

An EAHE system preheating fresh air in cold climates could lead to a temperature increase that could reach 12.4°C … meaning that that system was effective and economic.

The study of the efficiency of an EAHE system in both hot and cold climates in Iran indicated that it could be used for

294 days per year to provide energy savings of 50.1 to 63.6% in hot climates

225 days per year, providing energy savings of 24.5 to 47.9% in cold climates.

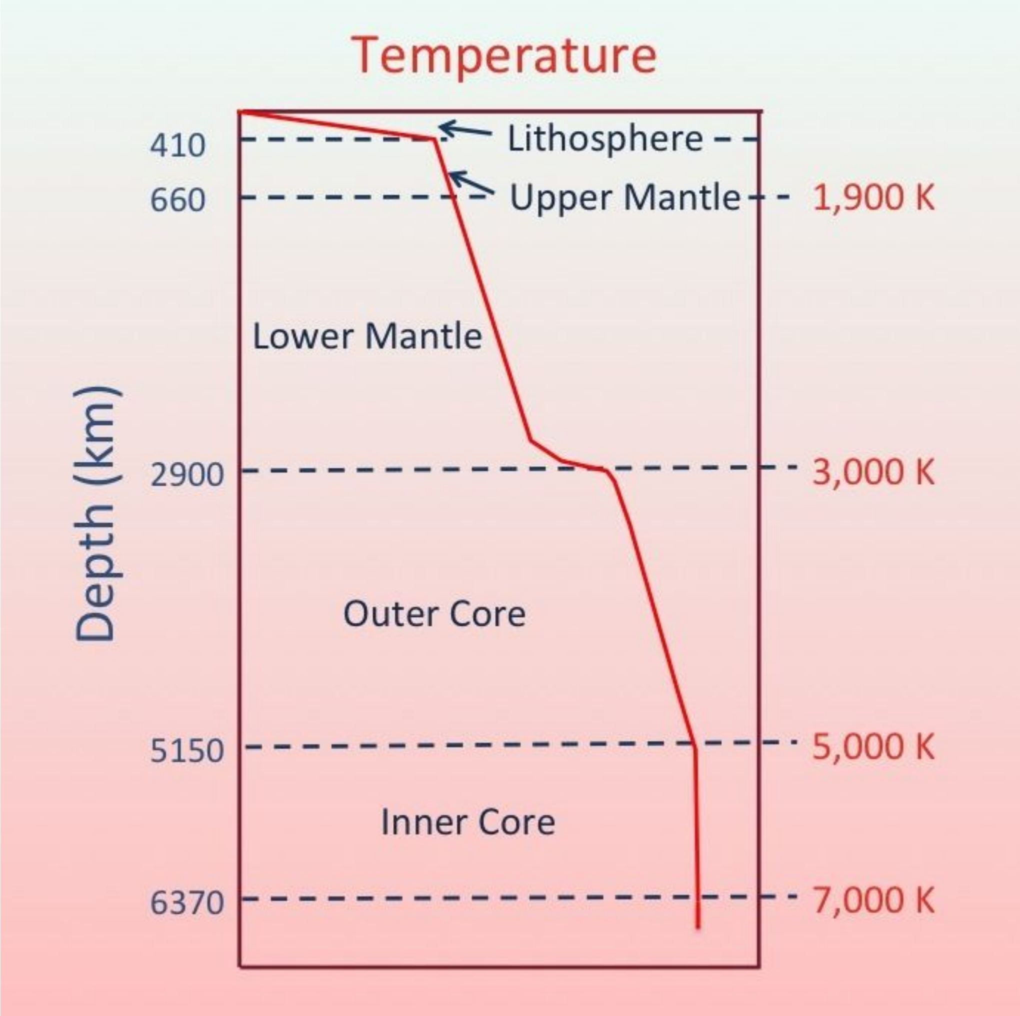
An EAHE in Mexico worked as a cooler in the morning and as a heater at night, coupled with an air conditioning system.

Its payback period was between 1 and 2 years, with the EAHE cost being $132.2 and the percentages of energy savings being 20 to 21% for most months.

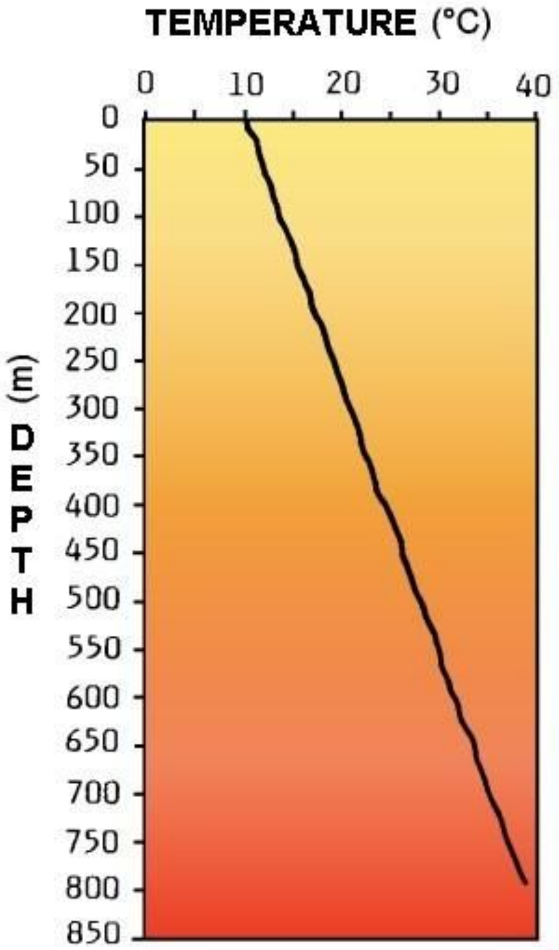
An evaluation of the performance of a hybrid cooling system that combined an earth to air heat exchanger with an indirect evaporative cooler, concluded that the payback time was between 5.5 and 6.4 years.

The evaluation of the performance of a hybrid cooling system, including an EAHE and a water spray channel, in Tehran (Iran), suggested that its effectiveness exceeded 100%, with operation cost saving being up to 71%, and a payback period of 286 days.

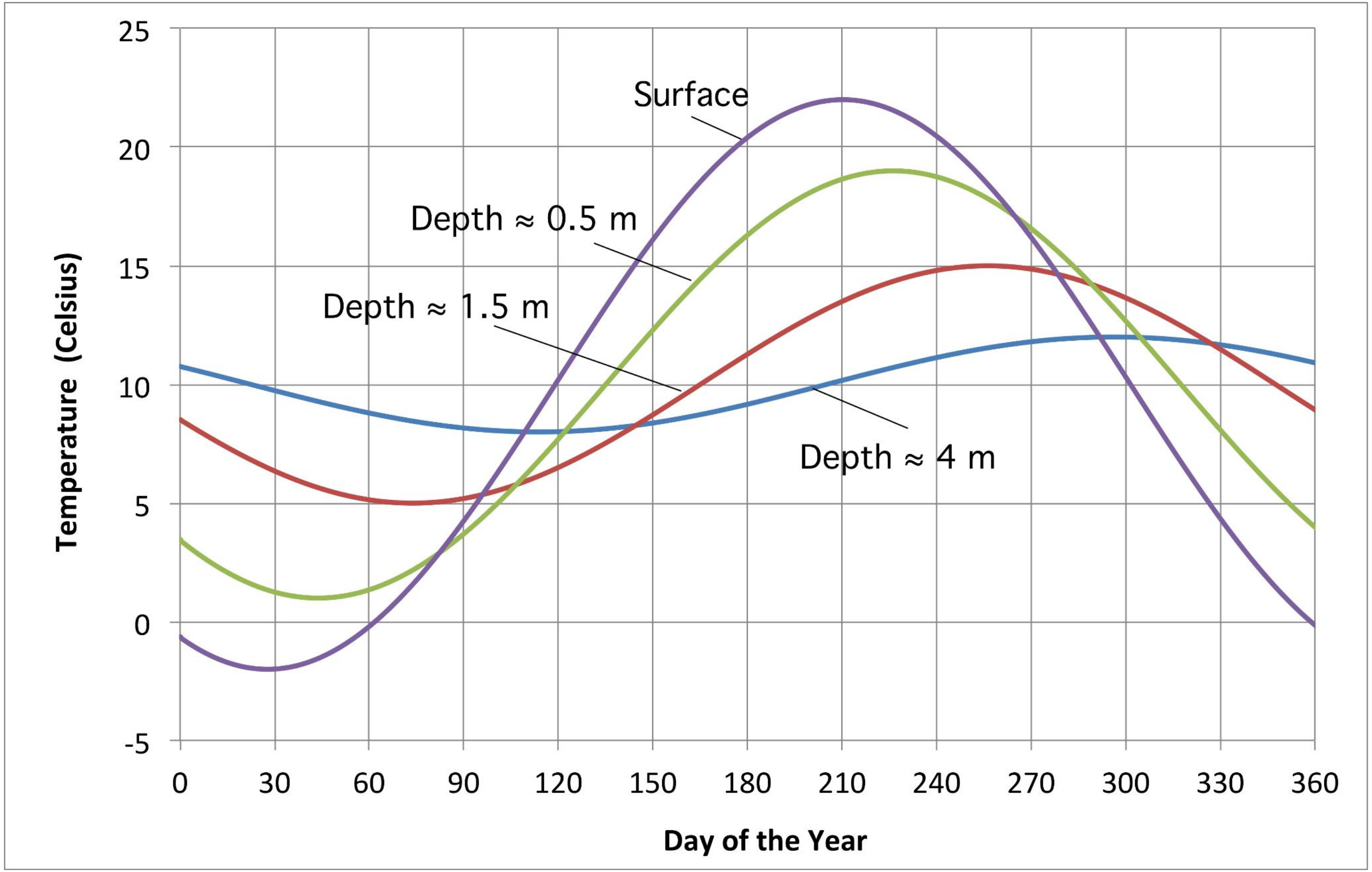
HIGHLIGHTS FROM THE LITERATURE



Ground temperature profile



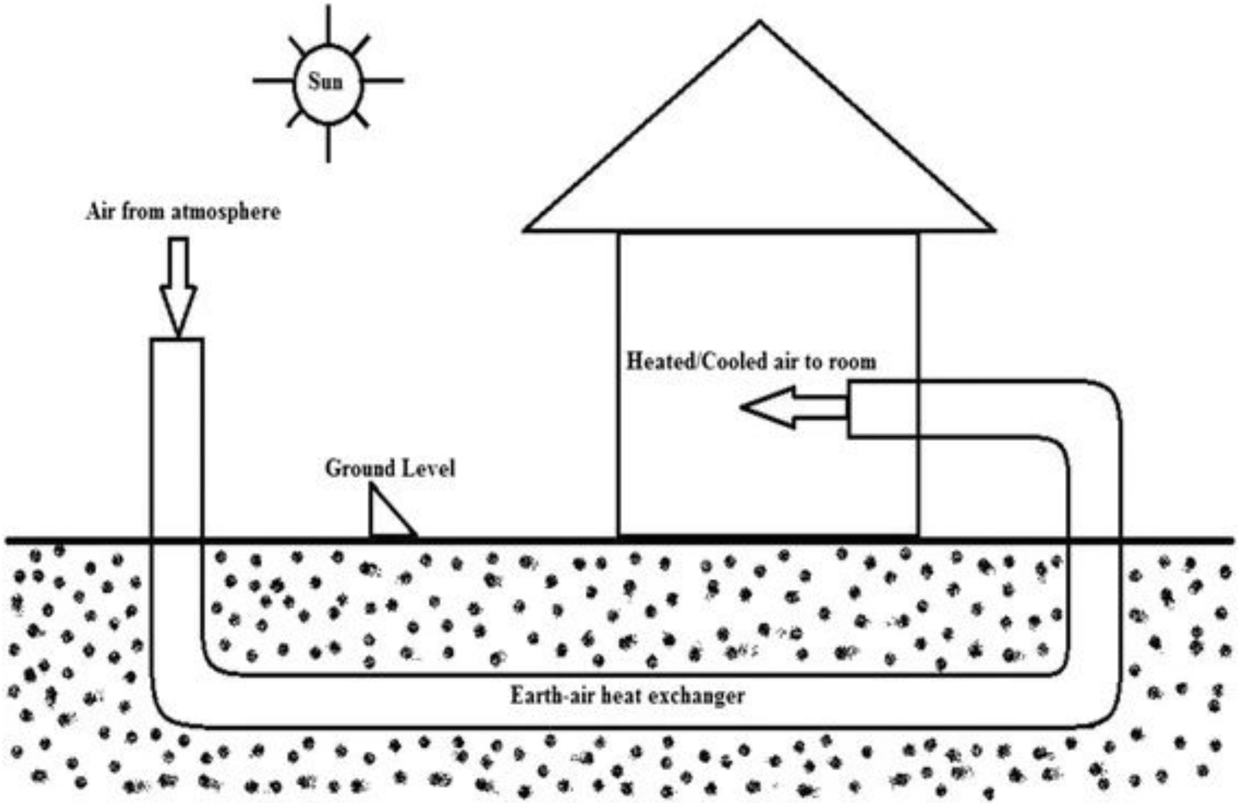
"The geothermal gradient (i.e. the increase in temperature with an increase in depth in the Earth) is not equal all over the world. On average, the temperature increases 2°- 3°C per 100 m in depth, however the increase can range from 1° to 5°C/100 m." (https://www.eniscuola.net/en/mediateca/temperature-and-depth/)


Surface
Depth ≈ 0.5 m
Depth ≈ 1.5 m
Depth ≈ 4 m
25
20
15
10
5
0
-5
0
30
60
90
120
150
180
210
240
270
300
330
360
Temperature (Celsius)
Day of the Year

“The earth–air heat exchanger (EAHE) is a promising technique which can effectively be used to reduce the heating/cooling load of a building by preheating the air in winter and vice versa in summer. In the last two decades, a lot of research has been done to develop analytical and numerical models for the analysis of EAHE systems. Many researchers have developed sophisticated equations and procedures but they cannot be easily recast into design equations and must be used by trial-and-error” (https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-015-0036-2)

Bosch Geo 101 - How Geothermal Heat Pump Systems Work (https://youtu.be/q9DP6v0IW1k)

Energy 101: Geothermal Heat Pumps (https://youtu.be/y_ZGBhy48YI)



https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-015-0036-2

“The temperature of earth at a depth of 1.5 to 2 m remains fairly constant throughout the year … This constant temperature is called earth’s undisturbed temperature (EUT). The EUT remains higher than ambient air temperature in winter and lower than ambient air temperature in summer. The concept of earth–air heat exchanger (EAHE) is very simple … The ambient air is drawn through the pipes of the EAHE buried at a particular depth, moderated to EUT, and gets heated in winter and vice versa in summer. In this way, the heating and cooling load of [a] building can be reduced passively … The design of earth–air heat exchanger mainly depends on the heating/cooling load requirement of a building to be conditioned … The diameter of pipe, pipe length, and number of pipes are the main parameters to be determined. With an increase in length of pipe, both pressure drop and thermal performance increase. A longer pipe of smaller diameter buried at a greater depth and having lower air flow velocity results in an increase in performance of the EAHE system.”
(https://geothermal-energy-journal.springeropen.com/articles/10.1186/s40517-015-0036-2)

Successful geothermal policy implementation means more use of geothermal energy, like this geothermal district heating system that keeps sidewalks clear after snowfall in Klamath Falls, Oregon.

https://energypost.eu/eu-heat-pumps-warnings-against-one-size-fits-all-policies/

Heat pumps and tipping points: Weaning the world off Russian energy (https://www.atlanticcouncil.org/blogs/new-atlanticist/heat-pumps-and-tipping-points-weaning-the-world-off-russian-energy/)

A 10-Point Plan to Reduce the European Union’s Reliance on Russian Natural Gas (https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas):

- ➔ No new gas supply contracts with Russia
- ➔ Replace Russian supplies with gas from alternative sources
- ➔ Introduce minimum gas storage obligations to enhance market resilience
- ➔ Accelerate the deployment of new wind and solar projects
- ➔ Maximize generation from existing dispatchable low-emissions sources: bioenergy and nuclear
- ➔ Enact short-term measures to shelter vulnerable electricity consumers from high prices

A 10-Point Plan to Reduce the European Union's Reliance on Russian Natural Gas *(continued)* (https://www.iea.org/reports/a-10-point-plan-to-reduce-the-european-unions-reliance-on-russian-natural-gas):

- ➔ Speed up the replacement of gas boilers with heat pumps
- ➔ Accelerate energy efficiency improvements in buildings and industry
- ➔ Encourage a temporary thermostat adjustment by consumers
- ➔ Step up efforts to diversify and decarbonise sources of power system flexibility

Heat Pumps Are a Weapon in the E.U.'s Energy Face-Off With Russia (https://time.com/6157947/heat-pumps-europe-russia/)

Heat Pumps Will Change Everything—and Not Enough; It's a long-term solution for climate change with plenty of short-term problems (https://foreignpolicy.com/2022/04/28/heat-pumps-climate-change-renewable-energy-renovation-installation-bottlenecks/)

Heat pumps do work in the cold — Americans just don't know it yet; These heating/cooling systems have been called the *"most overlooked climate solution."* Now they can work in temperatures far below freezing (https://grist.org/housing/heat-pumps-do-work-in-the-cold-americans-just-dont-know-it-yet/)

How Does Geothermal Heating Work? A Step-By-Step Guide (https://a1mechanical.com/geothermal-heating-system/)

“The ground loop is a piping system that is buried on the property … either a closed loop or an open loop, which opens into a water source nearby, such as a pond or well.”

“The geothermal heat pump exchanges heat between the air and the ground loop system, extracting heat from the air or the ground loop depending on whether heating or cooling is in use.”

“The distribution system is the method which delivers heated or cooled air throughout the home … The heat pump’s heat exchanger exchanges heat between the fluid in these pipes and the fluid within the ground loop instead of between the air and ground loop fluid.”

“A geothermal system works by exchanging heat between the air and the ground. Because temperatures below ground remain consistent around 55 degrees Fahrenheit [12.8°C] all year, there is always significant energy available to heat your home – and it’s free energy!”

“Fluid within the ground loop absorbs heat from the surrounding earth.”

“This fluid is pumped through the ground loop up to the heat pump, which is housed inside the home.”

“The heat pump’s heat exchanger uses the energy to warm the air that passes through the unit.”

“The heated air circulates through the ductwork into indoor areas throughout the home or building.”

“Ground source heat pumps are great because they also provide indoor cooling! Here’s how a geothermal system works for cooling:”

“The heat pump’s heat exchanger extracts heat from the air circulating through the system.”

“The heat pump transfers this heat to the fluid within the system.”

“The fluid is pumped down through the ground loop, carrying heat.”

“Heat from the fluid is deposited into the earth or water source that serves as the system’s heat sink, or receptacle for heat energy.”

https://www.hannainc.com/wp-content/uploads/2018/03/Global-Geothermal-Heat-Pump-Market.jpg

Policymakers' Guidebook for Geothermal Heating and Cooling (https://www.nrel.gov/docs/fy11osti/49477.pdf)

EAHEs and geopolitics

Overall, the geopolitics of EAHEs are highly dependent on a range of factors, including climate, energy policy, economics, technology, and infrastructure.

The adoption of EAHEs can have significant implications for energy consumption, environmental impact, and the development of sustainable infrastructure, making it an important area for study and consideration.

The successful implementation of EAHEs is subject to a number of geopolitical factors:

Climate: The effectiveness of EAHEs is highly dependent on climate, with regions that experience extreme temperature variations or high humidity potentially experiencing reduced efficiency. Therefore, the geopolitical implications of EAHEs are heavily influenced by the location of the building and the local climate conditions.

Energy Policy: The adoption of EAHEs is influenced by national and local energy policies, which may provide incentives or subsidies for energy-efficient systems. In countries where there is a strong commitment to renewable energy and energy efficiency, there may be a greater uptake of EAHEs.

Economic Factors: The cost of installing and maintaining EAHEs is an important factor in their adoption. The geopolitical implications of EAHEs will therefore depend on the economic climate of the region, including factors such as the availability of financing and the cost of energy.

Technological Innovation: The advancement of technology in the field of EAHEs can lead to greater efficiency and more widespread adoption. The geopolitical implications of EAHEs will depend on the rate of technological innovation, which is influenced by factors such as research funding, intellectual property laws, and international collaboration.

Infrastructure: The implementation of EAHEs requires adequate infrastructure to support them, including the availability of skilled labor and materials. The geopolitical implications of EAHEs will therefore depend on the quality of infrastructure in the region.