Geothermal Energy System for Passive Design in Buildings: Applications and Comparative Analysis

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Abstract: The use of renewable energy is essential for sustainable development, and buildings are responsible for a significant part of energy consumption. Therefore, this study is focused on geothermal energy and its application to buildings and its potential significance for energy savings and minimizing the carbon footprint. In this study, geothermal systems like earth air tunnel systems, geothermal exchange systems, earth sheltering systems have been studied and classified, based on their efficiency in different building typologies and climate, and factors affecting these systems are discussed, and systems selection for different needs and method of installation have been analyzed. Four case studies based on different geothermal systems in different regions and of different building typologies have also been compared to assess the performance and evolution in the field. Sustainable development is not the idea but the need for the future and minimizing the carbon footprint of the building is a step towards it, the use of renewable energy supports that step. Geothermal energy alone can be used for different purposes like electricity generation, passive and active heating, and cooling, also other renewable energies like solar for lighting load, use of biofuels for consumption purposes, will lead to an environment where the carbon footprint of the building can be minimized to zero.

Keywords: geothermal system, earth air tunnel, geothermal exchange, earth sheltering, passive cooling, sustainable development

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Introduction

The Geothermal energy existence is from the heat within the earth. The word geothermal comes from the Greek word geo, meaning “earth” and therme meaning “heat”. The earth has three layers core, mantle, crust and the center of the earth’s core lies almost 4,000 miles beneath the earth’s surface (Dickson & Fanelli, n.d.). Surrounding the earth’s core is the mantle, and the outermost layer of the earth, the insulating crust, is not continuous but broken pieces called plates. When these slabs of ocean and continent floor drift apart and came in contact with each other at the rate of about one inch per year in a process then it is known as continental drift (Bates et al., 2014). On the contrary, when magma may come close to the surface where the crust has been thinned, faulted, or fractured by plate tectonics, then this near-surface heat is transferred to water which in turn creates a usable form of geothermal energy. The first use of geothermal energy occurred more than 10,000 years ago from hot springs for cooking, bathing, and cleaning. The first industrial use of geothermal energy began in the late 18th century and the first geothermal power plant in which steam was used to generate the power is in 1904 (Rosen & Koohi, 2017). In the present scenario, the worldwide use of geothermal energy amounts to 49 TWh/a of electricity and 53TWh/a for direct use (UNECE Expert Group on Resource Classification & United Nations. Economic Commission for Europe, n.d.). Electricity is produced with geothermal steam in 21 countries spread on all continents. Geothermal is proving itself as one of the clean sources of renewable energy around the world with time (Lund et al., 2011). Geothermal energy is used in different areas like space heating, greenhouse, covered ground heating, aquaculture pond, raceway heating, bathing and swimming, agricultural crop drying, industrial process heat, snow melting, and space cooling.

1. Types of geothermal energy systems

The geothermal energy system is further divided into two direct and indirect systems. The direct system is basically in which the energy of the earth is used directly into built form needs an indirect system is a system in which the third element like air, water, or any other is used for using the earth's energy.

1.1 Direct system

The temperature below the earth changes very little over the year. A few meters below the surface, the temperature of the ground is in the range of 10-21oC, with this temperature difference it is possible to use the below earth’s top layer or sub-

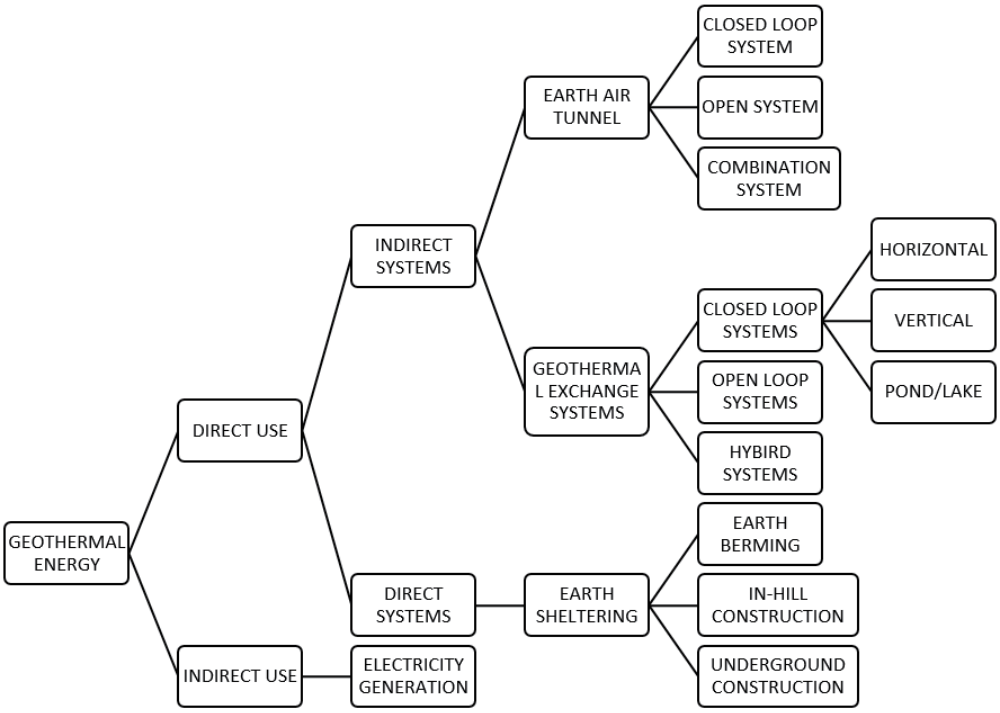

Figure 1. Types of Geothermal Energy use (Source: Authors)

soil layer's temperature for cooling or heating the built form without the use of any equipment (CESEN S.P.A. et al., 1999).

1.1.1 Earth sheltering systems

Earth-sheltered buildings consist of one or more of three types: earth-covered, earth-bunded, and subterranean. An earth-covered building is one where the thermally effective element is placed solely on the roof but is more usually a continuation of the earth-bunding at the unexposed elevations of the building (Routsolias, n.d.). An earth-bunded building is one where the thermally significant element insulates one or more of the sheltered elevations of the building. The bunding can be partial or total. A subterranean building is one where the thermally significant element insulates all elevations of the building, leaving only the roof exposed; or, if the building is built into an incline, it may be that the roof is covered and only one elevation is left exposed.

1.2 Indirect system

1.2.1 Earth air tunnel systems

A ground heat exchanger is an underground heat exchanger that can trap heat and / or dissipate heat to the ground. They use subterranean temperatures to heat or cool air or other liquids in residential, agricultural, or industrial areas. When the building air is blown through a heat exchanger to allow cool air to enter, they are called earth tubes (also known as earth cooling tubes or earth warming tubes) (Murthal, n.d.). These systems are known by a number of other names, including air-to-ground heat exchangers, ground channels, underground channels, underground tunnels, underground heating tubes, hypocausters, underground heaters, thermal labyrinths, underground air ducts, and so on. The earth-air heat exchangers has been used in agricultural areas (animal shelters) and farmland (seedling storage areas) in the United States for the past few decades and has been used in conjunction with solar radiators in dry tropical areas for thousands of years, almost from the beginning. in the Persian Empire. The implementation of these programs in Austria, Denmark, Germany, and India has been a hot topic since the mid-1990s and is gradually gaining ground in North America. Based on the width and depth there are three configurations, a closed loop design, an open 'fresh air' system, or a combination:

a) Closed-Loop system

The air from the inside of the house or building is blown with a U-shaped loop usually 30 to 150m of the tube where it is measured to be close to the temperature before returning to be piped throughout the home or building. A closed loop system can work better (during overheating) than an open system as it cools and re-cools the same air.

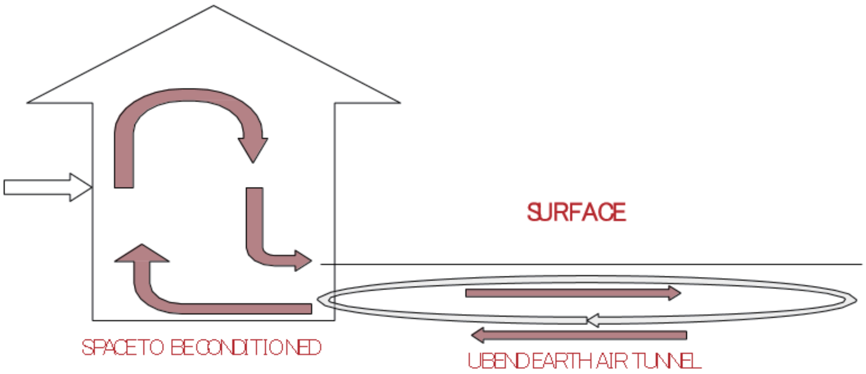

Figure 2. The closed loop system (Source: Authors)

b) Open system

The outdoor air is drawn from filtered air intake (Minimum Reporting Effectiveness MERV 8+ air filter recommended). Cooling tubes are usually 30 m long straight tubes entering the home. An open system combined with exhaust ventilation may work well (80-95%) as a closed loop and ensure that fresh air is filtered and conditioned.

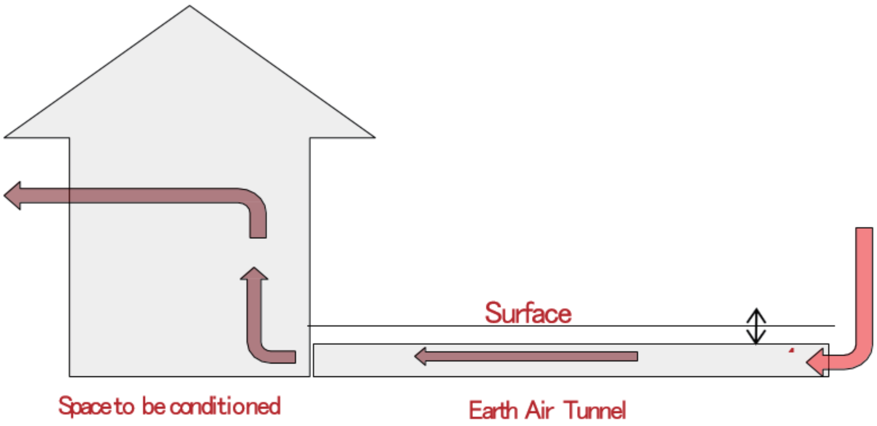

Figure 3. The open system (Source: Authors)

c) Combination system

This can be built with dampers that allow for closed or open operation, depending on the requirements for fresh air intake. Such a design, even in closed loop mode, can absorb the amount of fresh air if the air pressure is reduced through a solar chimney, a dryer, a fireplace, a kitchen, or vent ducts in the toilet. It is better to draw filtered cooling air tube than outside air conditioning.

The single-pass global air temperature sensors provide enhanced indoor air quality enhancement over conventional systems by providing increased outdoor air supply. In some single-pass systems, continuous external air supply is provided. This type of system will usually install one or more units for air temperature detection. (therefore, they do not easily absorb moisture and mold), hard or soft plastic, plastic-lined steel pipes, or plastic pipes covered with antimicrobial layers, buried 1.5 to 3 m below ground level The ambient temperature is usually 10 to 23 °C year-round in temperate and densely populated areas (Bano & Sehgal, 2018). Low temperatures become increasingly stable. Smaller tubes require more energy to move air and have less contact with the ground. Larger tubes allow for slower airflow, which also releases more efficient energy transfer and allows for higher values to be transferred, allowing for more air exchange in a shorter period of time, when, for example, you want to remove bad odor or smoke from a building but suffer. from the transfer of poor heat from the pipe wall to the air due to the increasing distances.

There is a conception that it is better to blow air through a long tube than to push it through a fan. A solar chimney can use natural convection (warm air permeability) to create a relaxing atmosphere to draw air from a cooling tube filtered by cooling tubes of the largest size. Natural convection may be slower than using a strong solar storm. Sharp 90-degree angles should be avoided in the construction of the tube - two 45-degree curves produce less, more efficient air flow. Although tubes with a smooth wall are very good at moving air, they are not very good at transmitting energy.

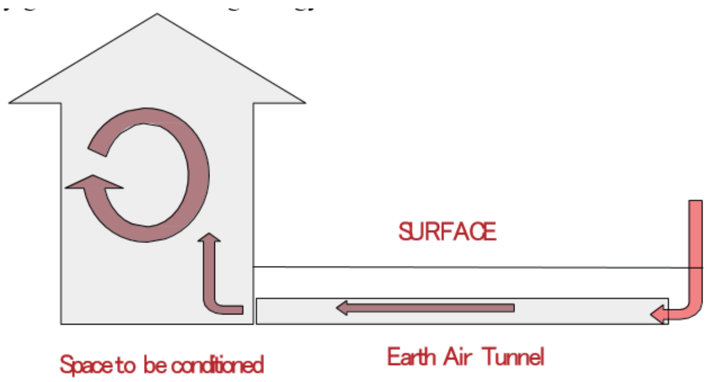

Figure 4. The combination system (Source: Authors)

1.2.2 Geothermal exchange system

Geothermal Heating and Cooling Systems provide space conditioning- heating, cooling, and humidity control. They may also provide water heating - either to supplement or replace conventional water heaters. Geothermal Heating and Cooling Systems work by moving heat, rather than by converting chemical energy to heat like in a furnace. Every Geothermal Heating and Cooling System has three major subsystems or parts: a geothermal heat pump to move heat between the building and the fluid in the earth connection, an earth connection for transferring heat between its fluid and the earth, and a distribution subsystem for delivering heating or cooling to the building. Each system may also have a desuperheater to supplement the building's water heater, or a full-demand water heater to meet all the building's hot water needs.

a) Geothermal heat pump

The geothermal heat pump is packed in a single cabinet and incorporates a heat switch from the loop-to-refrigerant, and controls. The heat transfer systems using a ventilator and consist of an air holder, a duct fan, a filter, a heat exchanger from the refrigerator to the air, and an air-conditioned condensate removal system. In home installation, a geothermal heat pump cabinet is usually found in the basement, ceiling, or closet (Self et al., 2013). In commercial installations, it can be hung over a suspended ceiling or installed as an independent console.

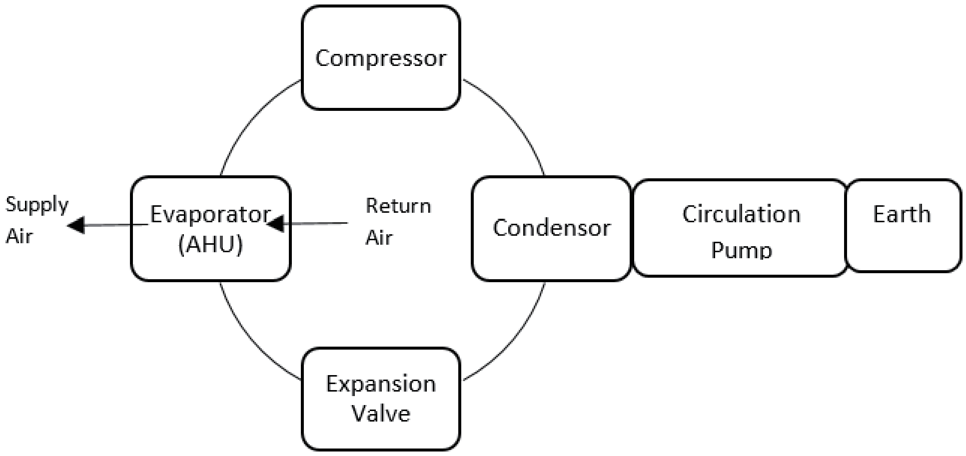

Figure 5. The geothermal heat pump (Source: Authors)

b) Distribution subsystem

Many residential systems use conventional geothermal ductwork to distribute hot or cold air and provide moisture control. (A few systems use water-to-water heat pumps with one or more fan coil units, base board radiators, or underground circulation pipes) (Saibi et al, 2013). Proper, well-built and well-closed channels are essential to maintain system efficiency. The trenches should be tightly closed and, whenever possible, inside the hot envelope of the building (a designated area). Heating and cooling systems for large commercial buildings, such as schools and offices, often use a different system. Multiple heat pumps (perhaps one for each class or office) are attached to the same global connection with a loop inside the building. In this way, each area of the structure can be controlled individually (Zoet et al., 2011). Heat pumps on the sunny side of the building may provide cooling while those on the shady side provide heat. This system is very economical, as heat is transferred from one building to another, through a ground connection that serves as a heat source or heat sink only because of the difference between the heating and cooling requirements of the building.

2. Type of systems

There are four basic types of ground loop systems. Three of these — horizontal, vertical, and pond/lake — are closed-loop systems. The fourth type of system is the open-loop option. Which one of these is best depends on the climate, soil conditions, available land, and local installation costs at the site. All of these approaches can be used for residential and commercial building applications.

2.1 Closed-loop system

Most closed-loop geothermal heat pumps circulate an antifreeze solution through a closed-loop usually made of plastic tubing that is buried in the ground or submerged in water. A heat exchanger transfers heat between the refrigerant in the heat pump and the antifreeze solution in the closed loop. The loop can be in a horizontal, vertical, or pond/lake configuration. One variant of this approach, called direct exchange, does not use a heat exchanger, and instead pumps the refrigerant through copper tubing that is buried in the ground in a horizontal or vertical configuration. Direct exchange systems require a larger compressor and work best in moist soils (sometimes requiring additional irrigation to keep the soil moist), but you should avoid installing in soils corrosive to the copper tubing. Because these systems circulate refrigerant through the ground, local environmental regulations may prohibit their use in some locations.

2.1.1 Horizontal

This type of installation can usually save a lot of living space installation, especially new construction when adequate space is available. It needs ditches at least four feet deep. The most common structures use two pipes, one six feet deep, and the other four feet, or two pipes laid side by side five feet on the ground in trenches two feet wide. The Slinky method piping system allows for additional piping in the shortcut, which reduces installation costs and makes horizontal installation possible in areas where there will be no standard horizontal applications (Dickson & Fanelli, 2013).

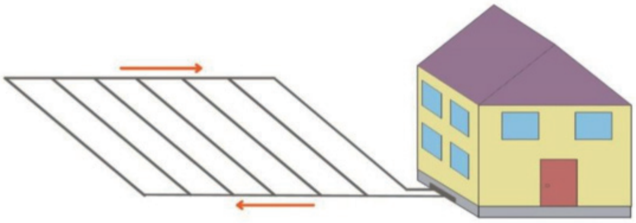

Figure 6. The horizontal loop system (Source: Authors)

2.1.2 Vertical

The large commercial buildings and schools often use straightforward systems because the land area required for horizontal loops can prevent them. The straight loops are also used where the soil is less shallow, and they minimize disturbances to existing land preparation. In a straight line, holes (about four inches in diameter) are drilled about 20 feet apart and 100 to 400 feet deep. These holes enter two pipes connected by a U-bend to form a loop. Straight loops are connected by a horizontal pipe (i.e., a repeater), placed in trenches, and connected to a heat pump in the building (Dickson & Fanelli, 2013).

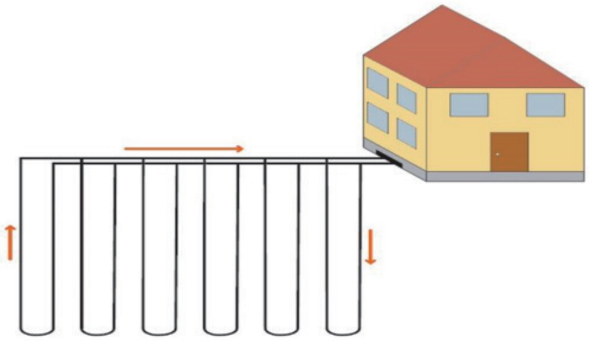

Figure 7. The vertical loop system (Source: Authors)

2.1.3 Pond/Lake

If the site has a sufficient water source, this may be a very low cost option. The pipeline line is carried underground from the building to the water and rolled in a circle at least eight feet below the surface to prevent freezing. Coils should only be placed in a water source that meets a minimum amount of volume, depth, and quality process.

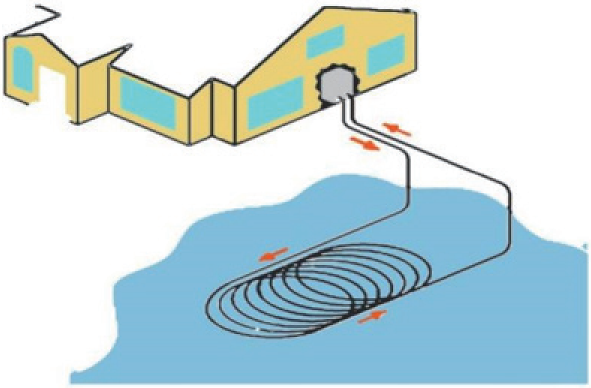

Figure 8. The pond/lake close loop system (Source: Authors)

2.2 Open-loop system

This type of system makes good use of or surface water as a heat exchange fluid that circulates directly into the GHP system. Once it circulates in the system, the water returns to the ground through a well, a full reservoir, or overflow (Dickson & Fanelli, 2013). This option only works if there is sufficient fresh water, and all local codes and regulations regarding groundwater discharge are met.

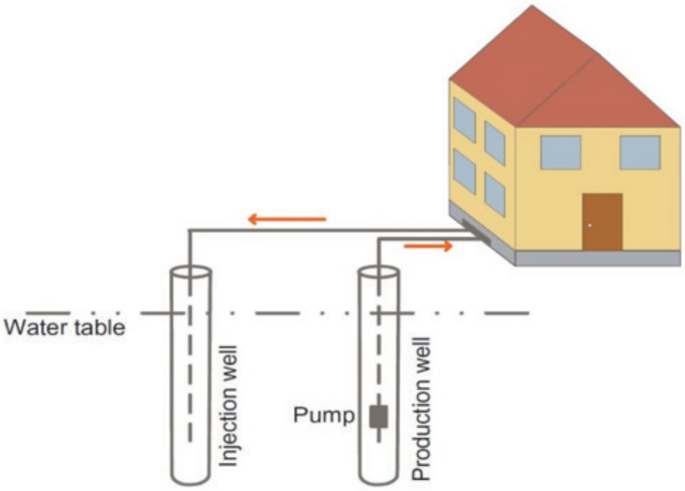

Figure 9. The open-loop system (Source: Authors)

2.3 Hybrid systems

The hybrid systems use several different geothermal resources, or a combination of an external geothermal device (i.e., a cooling tower), another technical option. Mixed methods work best when cooling requirements are much greater than heating requirements. When geology permits, a "well-shaped column" is another option. In this variation of the open loop system, one or more deep direct springs are drilled. Water is collected at the bottom of a standing column and then returned to the top. During periods of high temperatures and cooling, the system is able to bleed a portion of the returning water rather than return it all, resulting in the flow of water in a column from the surrounding aquifer. The bleeding cycle cools the column during heat dissipation, heats it during heat removal, and reduces the depth of the required drill.

Table 1. Comparison between geothermal systems (Source: Authors)

Type	Source	Advantages	Limitation	Conclusion
Earth Air Tunnel Systems (EAT)	Air passes through tunnel 4m under the earth	100 % Fresh Air without recirculation	Add-ons to achieve effective cooling	A passive method that includes a tunnel to pass the estimated amount of local HVAC air using natural ground temperature, 4 meters below ground.
Geothermal Exchange Systems (GES)	Loops of pipe through which fluid passes under the earth can be in a horizontal, vertical manner. And also, nearby lakes & rivers can be used	Works according to the site conditions. Effective in each climate. Durable. Energy Saver	Not for every accessible area Although one-time investment but the investment is quite high Some system typically requires a large space	Mostly Used type system for active use around the world and this type have different subtypes for the different area like areas which have less space and large space and have water bodies. So, this type functions according to the conditions of the site. Which all over works in favor of geothermal energy.
Earth Sheltering Systems (ESS)	Construction of using earth against building walls	Taking advantage of the earth as a thermal mass. Energy Savings Shelters have low maintenance requirements.	Water Seepage Internal Condensation Poor Indoor Air Quality	Passive solar & Sustainable Technique

3. Case studies

Based on the types of geothermal systems 4 case studies are selected to analyse the application of geothermal energy systems in different building typologies. TERI retreat centre is selected for an in-direct earth air tunnel system; the temperature in the living room is maintained at a comfortable temperature of 20°C to 30°C throughout the year, without the use of an air conditioner. This concept is based on the fact that underground places are naturally cooler in summer and warmer in winter. In ancient India and medieval India, a similar concept was developed in the construction of buildings similar to those seen at Red Fort in Delhi. To achieve air in the living room, each room is fitted with a 'solar chimney', and warm air rises and flows through the chimney creating an air stream. Cool air from underground channels, aided by two sprays in the tunnel, runs into the air instead of warm air. In winter, cold air in the rooms is replaced by warm air from the tunnels.

The NIIT University is selected as an in-direct combined air tunnel system, this system is used for P.G hostels and academic blocks, and with the help of it, tunnels cool outside air from 44/36°C to 28°C, 18 tunnels are used to handle 200,000 CFM. Each Tunnel is 90m long to handle 12000 CFM -18000 CFM and 8 air change/hours in peak summer and 3 air change/hours during Monsoon & Winter and displacement ventilation for proper air circulation (Vinod-Gupta, n.d.).

The Drake landing solar community (DLSC) is selected for a direct hybrid close loop system, DLSC consists of 52 low-rises, detached houses, which are located within a larger subdivision containing 835 houses. The size of typical DLSC houses, based on gross floor area, is 138–151 m^2, each house has an independent garage at the back facing the route and the garages are connected to an airway. The roof structure extends the full length of each of the four lanes. DLSC houses are provided with space heating and hot water using solar thermal heaters mounted on the roof. To simplify the operation of the DLSC power system, TES and regional heating technologies are also used. The DLSC power system thus creates a public power system. About 800 single-panel solar panels are available at DLSC housing garages. There are four rows of garages with two rows of collectors in each garage. Solar collectors have an area of about 2300 m^2. Hot water is generated by a self-contained, separate domestic hot water system that uses solar panels on the roof. This two-component solar energy system is different from the one used to heat space. Natural gas-fired hot water units add to the demand for hot water when solar energy is not available and acts as backups.

The Kumamoto University is selected for thermal energy storage (TES), Kumamoto University and Kyushu Electric Power Co. jointly developed a system for storing electricity obtained inexpensively at night as thermal energy in underground thermal storage, and using it for space conditioning during the day. Soil is the heat storage medium in the underground TES system, which is integrated with the space conditioning system. In the underground TES, 4800 m of flexible 25-mm-diameter plastic water pipe are buried up to 1 m beneath the ground surface. The piping is configured in four layers. The TES system occupies about 200 m^2 (the same area as the building space it is used to heat and cool. This depth is 1.8 m for the present application. Based on research and analysis it is identified that the most important in selecting the system typology depends upon five factors soil type, climate, rock types in earth layers, building typology, and land availability.

Table 2. Comparison between case studies (Source: Authors)

Case Study	Building Type	Technology Type/ Rational for Study	Conclusion
TERI Retreat centre, India	Institutional & Recreational	In-Direct close loop earth air tunnel system	This concept is based on the fact that underground places are naturally cooler in summer and warmer in winter.
NIIT University, Neemrana, India	Institutional	In-Direct combined earth air tunnel system	Displacement Ventilation for Proper Air Circulation. Special AHUs for re-cooling & Dehumidifying air for each Tunnel.
Drake Landing Solar Community (DLSC), Canada	Residential	Direct hybrid close loop system	To facilitate the operation of the DLSC energy system, TES and district heating technologies are also utilized. The DLSC energy system thus forms a community energy system.
Kumamoto University, Japan	Institutional	Thermal Energy Storage in Ground for Heating and Cooling	Soil is the heat storage medium in the underground TES system, which is integrated with the space conditioning system.

4. Direct use of geothermal energy worldwide

The direct use of geothermal energy is one of the oldest, most flexible, and most common forms of geothermal energy (Dickson and Fanelli, 2003). More than 25 countries around the world have a history of using geothermal over 2,000 years. Currently, direct use of geothermal energy is practiced in more than 80 countries. Based on a study on the direct use of geothermal 2020 energy the global review of John W. Lund and Aniki N. Toth identified China, USA, Sweden, Germany, and Turkey as the five most active countries. the most direct of which includes geothermal heat pumps. Apart from that China, USA, Sweden, Turkey, and Japan, account for 73.4% of land use. In the study, it was also determined that most of the increase was due to the additional installation of underground heat pumps r to better report on bathing and swimming use. Worldwide 107,727 MWt of energy is used for direct use of geothermal energy with a capacity of 0.3. Geothermal energy heat pumps account for 71.6% of the installed capacity and 59.2% of annual energy consumption. Energy savings reach 596 million barrels (81.0 million tons) of the same oil per year, preventing 78.1 million tons of carbon and 252.6 million CO2 tons of emissions (Lund & Toth, 2021).

5. Analysis and discussion

In this study, various active and passive methods of geothermal energy from different research papers and commission reports of the European Union and other countries have been analysed. Based on that analysis it is evident that geothermal is the present and future of renewable energy (Fridleifsson, 2001), research teams of different countries like Norway, Ireland, the United Kingdom, the United States, and many more are engaging in finding the geothermal hotspots on land and even in offshore also. Other than finding geothermal hotspots many research teams are working on finding techniques for long time storage of geothermal energy below and above land. The direct use of geothermal energy is increasing at a compound rate of 11.5% annually worldwide (Lund & Toth, 2021), with the appropriate study of geothermal systems and their application, it is considered the most viable option in replacement of the traditional systems.

6. Conclusions

The geothermal energy is the best possible alternative to traditional energy sources, as this is an environmentally friendly source with almost no greenhouse gases. In the present scenario, it is not fully used due to factors like location, space availability, and high cost but with present research going on, it is going to be an economical source of power generation as well as a resource to cater to direct uses like geothermal heat pumps, bathing and swimming, space heating, greenhouse heating, aquaculture pond, and raceway heating, agricultural drying, snow melting, and cooling, and for many other applications. Systems like earth air tunnel and earth sheltering are considered to be the best passive techniques for space heating and cooling, other than geothermal exchange systems are considered costly because of the installation of geothermal heat pumps but considered good alternatives where there are space and government schemes to support the cost and cause of environmentally friendly energy use. Geothermal exchange systems combined with proper storage needs serve almost every need there is to complete the requirement of minimizing the carbon footprint of a building. In the geothermal exchange systems, hybrid systems are the future of the direct use of geothermal systems as it involves the combination of different renewable resources along with geothermal energy, and each energy can be utilized where it is efficient the most. In residential settings, geothermal heat pumps are the most preferable method for heating and cooling the envelope. With the help of this study, it is possible to learn and identify different geothermal systems based on the requirement and availability of space.

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