Studies on geothermal energy utilization: a review

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Abstract. Sustainable development requires the use of sustainable energy systems. Energy use will increase worldwide, and geothermal energy consumption for both electricity generation and heating will also increase significantly. Sustainable use of geothermal energy means that it is produced and used outdoors, which is compatible with the well-being of future generations and the environment. This paper provides a review of the links between the development of geothermal energy used in HVAC systems and sustainable development, as well as a review of the sustainability assessment frameworks currently available.

1. Introduction
Accelerated population growth as well as dependence on modern technology lead to a higher demand for energy consumption. Currently 40% of total energy consumption and 36% of CO2 emissions are attributed to the use of buildings in optimal comfort conditions. Nowadays, there is a growing emphasis on creating a sustainable environment, which requires the careful use of energy sources. In this regard, there are two effective solutions to address these concerns, namely, the use of renewable energy resources and increasing the efficiency of current technologies.

The European Commission has developed several strategies in the field of energy, with a view to a safer, more sustainable and low-carbon economy. In addition to combating climate change by reducing greenhouse gas emissions, the use of renewable energy sources is likely to result in a more secure energy supply, greater diversity in energy supply, reduced air pollution, and the possibility of job creation in the environmental and renewable energy sectors.

In January 2014, the European Commission set several energy and climate targets for 2030, with the aim of encouraging private investment in low-carbon infrastructure and technologies. One of the key targets proposed is for the share of renewable energy to reach at least 27% by 2030. These targets are seen as a step forward in achieving the 2050 greenhouse gas emission targets proposed in the Green Sheet.

Becoming the world's first climate-neutral continent by 2050 is the greatest challenge and opportunity of our times. To achieve this goal, on 11 December 2019, the European Commission presented the European Green Pact the most ambitious package of measures that should enable European citizens and businesses to benefit from the transition to green and sustainable economy.

Renewable energy sources (RES) help to diversify existing energy sources and will most likely replace energy sources based on declining fossil fuels (coal, natural gas, crude oil). The use of RES instead of fossil fuels can substantially reduce greenhouse gases, in particular emissions of CO2 and other pollutants.

The use of energy from renewable sources has many potential benefits, including a reduction in greenhouse gas emissions, diversification of energy supply and reduction of dependence on fossil fuel
markets (especially the oil and gas market). The development of renewable energy sources can also boost employment in the EU, by creating jobs in the new ‘green’ technology sector.

The problem of energy consumption in buildings is a growing global concern due to rising living standards and rapid urbanization [1,2]. Due to the important roles of HVAC systems in ensuring thermal comfort, energy demand for air conditioning systems in buildings will continue to increase in the future. The development of energy efficient HVAC systems that are not based on the use of fossil fuels will play a key role in energy saving [3]. More than 50% of the EU’s final energy demand is used for heating and cooling, with 65% of it being supplied by fossil fuels.

Recent studies aimed at long-term global energy consumption estimate that by 2040 total energy consumption will increase by 25% compared to 2014 [4], or even by 48% compared to the values recorded for the year 2012 [5]. In addition, these estimates are anticipated in the context of an increase in energy efficiency for all major energy consuming sectors (construction, transport and industry). Also, an analysis of global climate change shows that a new record of global average temperature growth has been reached based on the values recorded for 2016. In addition, it takes place after other extremely high temperatures recently recorded on the planet ours, the previous maximums being in the years 2005, 2010, 2014 and 2015 [6].

There are several actions in the European Union (EU), among which we can list the document ‘2030 Framework for Climate and Energy’, approved by the European Council in 2014, which proposes to reach the following figures by 2030: reducing greenhouse gas emissions by at least 40% compared to 1990 levels, increasing the share of renewable energy sources to 27% of total EU energy needs and improving energy efficiency by at least 27% [7]. These ambitious goals further raise the bar already set by the EU for 2020, known as the ‘European 20-20-20 Targets’ (20% reduction in greenhouse gas emissions compared to 1990, 20% increase in energy consumption from renewable energy sources and 20% improvement in energy efficiency) [8].

There are also strategies in Romania regarding the energy efficiency of buildings, these being developed even in the period of pre-accession to the EU [9]. Also, national energy policies were adopted in Romania after EU integration on January 1, 2007: ‘Romania’s Energy Strategy for 2007-2020’ [10], ‘National Strategy for Sustainable Development, Horizons 2013-2020-2030’ [11], ‘National Action Plan for Energy Efficiency (PNAEE III)’ approved by the Government in 2015 [12], a document developed based on the requirements of Directive 2012/27 / EU [13]. EU Directives on the energy performance of buildings have also been transposed into national law: Directive 2002/91 / EC [14] has been taken over in full at national level by Law no. 372/2005 [15] (entered into force on 01.01.2007).

2. Solutions for using geothermal energy

Geothermal energy has a significant potential to reduce fossil fuel consumption and environmental impact. In order to improve the energy conversion efficiency of geothermal energy systems, numerous system projects have been proposed and sought to optimize them [16]. Because polygeneration systems produce various energy products (electricity, heat and / or cooling), it can play key roles in maximizing the use of geothermal energy. In particular, binary technology polygeneration systems, which can efficiently produce electricity from geothermal resources at moderate temperatures, have significant potential for improving overall performance [16].

The transition from fossil fuel-based energy systems to renewable energy systems is becoming increasingly important for environmental protection and sustainable energy development, due to increasing global primary energy demand and the need to reduce carbon emissions [17].

The known equipment in the use of geothermal energy that have been used and studied are heat pumps. Depending on the depth at which the geothermal source is located, these systems can be: surface, called ‘shallow geothermal’ in which energy can be exploited with both closed systems (vertical, helical or mixed drilling) and open systems (vertical drilling) and deep boreholes referred to in the literature as ‘deep geothermal’ where energy can only be exploited using open systems.
The use of geothermal energy in a closed system has the following advantages:

- Operational safety;
- Minimum maintenance costs;
- It does not have a negative impact on the environment;
- Possibility of BTES energy storage and management.

![Borehole thermal energy storage (BTES)](image1)

Figure 1. - Schematic of the BTES system [17]

As an inconvenience for the use of this heating/cooling system we can highlight the fact that a large area of land is needed for the execution of the geothermal sensor.

Regarding the use of geothermal energy in open system, these systems have the following advantages:

- High efficiency heat pumps;
- They have large installation capacities that are limited by the nature of the aquifer;
- It presents the possibility of energy storage and management - ATES.

![Aquifer thermal energy storage (ATES)](image2)

Figure 2. - Schematic of the ATES system [17]

3. Numerical and experimental approach for determining the performance of geothermal systems

We further present in this section a review of the works dedicated to experimental and numerical analyses, mainly related to the use of geothermal energy in buildings.

Geothermal energy pylons, the application of which has become popular in recent years, have a similar operating principle as vertical trenches [18,19]. In fact, to reduce the additional costs of drilling and installing heat exchangers with conventional drilling and to take advantage of the fact that piles are needed to support the superstructures, the heat exchanger pipes are installed directly inside the
foundation. According to Lee et al. [20], due to the relatively high drilling costs of the ground heat exchanger (GHE) of conventional GSHP systems, merging GHE with batteries that support the structural load of a building can reduce installation costs by 83.7%.

Saaly et al [21] investigated the performance of a proposed geothermal energy storage system for the energy demand of an institutional building located on the Fort-Garry campus of the University of Manitoba in Canada. They used the foundations of the building for geothermal pylons, the use of foundations as heat exchangers with the ground is a relatively new technology. The consistency of the clay deposit changes from very soft to very rigid with depth. Moreover, the moisture content of the clay deposit varies from 27% to 61% over the entire profile [22].

HVAC systems, which consisted of fans, underfloor radiant heating and cooling systems, a dedicated outdoor air system with a heat recovery fan and several air handling units, were modeled in detail.

Figure 3 General view of the model geometry [21]

The variation of soil temperature closer to the geothermal pillars is more intense, as shown in figure 4. Excessive heat extraction from the ground leads to soil freezing at the interface with piles of concrete. This can temporarily increase the load-bearing capacity of the pilots. However, thawing in the spring drastically decreases the load-bearing capacity of these systems.

Figure 4 Temperature distribution profile at the end of the cooling and heating season [21]

Changing the operation strategy of geothermal pillars can effectively mitigate the thermal imbalance of the soil, especially for the depths less affected by the heat dissipation of the subsoil. Increasing the length of geothermal pillars is an effective approach for increasing the length of the heat exchanger pipe and further increasing the energy supply by geothermal pillars.
Kazemi et al. [23] analyzed numerically the performance of an improved geothermal system in the sedimentary basin of western Canada. They used two coupled models: a thermo-hydraulic (TH) model and a hydromechanical (HM) model. Chen et al. [24] established an integrated model comprising the fractured tank and the double-flash geothermal power plant to compare the heat extraction and electricity generation of EGS under ‘recharge’ and ‘no flow’ limitation conditions based on the geothermal characteristics of the pool in China. A series of numerical studies, aimed at investigating the relationship between injection strategies and the extent of the stimulation area, have been conducted for the California Geysers Geothermal Field [25 - 28]. The results showed the differences in heat extraction and electricity production of EGS in the Gonghe basin, in the conditions of ‘recharging’ and ‘adiabatic’, respectively; the heat extraction potential around the periphery of the tank is overlooked in ‘no flow’ limit conditions.

Ma et al. [29] conducted a study that proposed an improved multi-pillar geothermal system for extracting heat in HDR (hot dry rock) in fracture mode. The results of previous research have shown that the arrangement of the well is a key factor affecting the heat extraction performance of HDR mining [30].

Yang [31] developed a mathematical model to describe the process of extracting heat from the HDR tank in a multiwell production system; the results show that the distance between the wells, the radius of the well, the thickness of the tank and the pumped flow have a significant effect on the efficiency of heat extraction in a multi-well system. Lei [32] created an EGS model with three horizontal probes in the Qiaobuaqia geothermal field, and the results indicated that distances of 300, 400 or 500 m in Qiaobuaqia HDR formation are an appropriate stimulation strategy. Song [33] and Shi [34] proposed a new multilateral probe EGS and found that the thermal output power, production temperature, heat extraction ratio and cumulative thermal energy of the multilateral probe EGS are higher than those of EGS with conventional vertical double shafts. Xia [35] established a model of thermal-hydraulic coupling with injection well and parallel production well and gave the proposed design parameters for industrial supply, based on the new model. Zhang [36] discussed the heat extraction performance of multi-well models and the double-well model; the results indicate that the multi-well model leads to widespread use and a reasonable arrangement of the well can avoid thermal exposure.

Ma et al. [29] proposed a multi-well injection EGS consists of three injection wells and a production well. The triangular elements were produced on the fracture surface and then the meshes were made in the vertical direction towards the opposite upper and lower surface to form hexahedral elements.

They found that as the operating time increases, the tank temperature gradually decreases, the heat transfer phenomenon is gradually weakened; the cooling zone starts from the injection wells and is collected in the production well; the conduction process is more inefficient than the convection process, convective heat transfer is the key to heat extraction in HDR fracture mode.

Figure 5. Mesh placement scheme [29]
The following table summarizes the articles that were considered in this study. Also, in these tables appear observations related to the studied articles, the discoveries that were made, but also the conclusions reached after the study. The studies presented in this table include most of the geothermal systems used in systems that use geothermal energy for heating and cooling buildings.

| Authors        | Year | Objectives                                                                 | Study conditions and metrology used | Conclusions                                                                 | Discoveries                                                                 |
|----------------|------|-----------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Saaly et al.   | 2019 | Performance analysis of a proposed geothermal pile system for heating and cooling energy demand for a building in cold regions | University of Manitoba building, geothermal pillars | Despite the heat loss through the basement, the thermal balance of the soil, in the case of the support of the total energy demand of the building by the geothermal pillars, cannot be satisfied | underground temperatures are substantially higher than surrounding rural areas due to heat loss from buildings at ground level |
| Chen et al.    | 2019 | Impacts of boundary conditions on reservoir numerical simulation and performance prediction of enhanced geothermal systems | Integrated model tank and geothermal power plant | The heat extraction potential around the periphery of the tank is neglected in adiabatic boundary conditions | compared to EGS in adiabatic boundary conditions, it was found that under “recharge” it has a lifespan of more than 20% |
| Authors | Year | Objectives | Study conditions and metrology used | Conclusions | Discoveries |
|---------|------|------------|-------------------------------------|-------------|-------------|
| Lee     | 2019 | Thermal performance of a standing column well geothermal heat exchanger system using re-injection of bleeding water | SCW type geothermal heat exchanger | Groundwater inlet and drainage wells can be improved to achieve high thermal performance | the thermal conductivity of the two-well SCW geothermal heat exchanger was 4.0 times higher than that of a well-type SCW geothermal heat exchanger |
| Kazemi et al. | 2019 | Performance Evaluation of an Enhanced Geothermal System in the Western Canada Sedimentary Basin | 2 coupled models: thermohydraulic (double thermal performance) and hydromechanical (deformation of matrix blocks) | The existence of the fault at 60 ° to the main flow direction has a reduced effect on the life of the system | The introduction of a more permeable area (a defect) on the flow path between the wells does not shorten the life of the useful tank |
| Han et al. | 2020 | Numerical study on heat extraction performance of multistage fracturing Enhanced Geothermal System | EGS system with triple horizontal well arrangement | Increasing the number of fracturing steps contributes to the improvement of the cumulative thermal production power, but generally leads to a decrease in the operating time of the EGS. | a more uniform flow in each perforation can lead to better thermal efficiency |
| Shi et al. | 2019 | Numerical study on heat extraction performance of a multilateral-well Enhanced geothermal system considering complex hydraulic and natural fractures | Mechanical hydraulic thermal coupled 3D model; 11 networks of complex fractures | Natural fractures should be considered when estimating EGS performance | The model with flat fracture networks overestimates the production temperature and thermal power of multilateral EGS with wells |
| Song et al. | 2018 | Numerical analysis of heat extraction performance of a deep coaxial borehole heat exchanger geothermal system | CBHE system - finite difference method validated with experimental data | The outlet temperature drops a lot in the initial phase, and remains relatively stable | The thermal conductivity of the cement sheath has a remarkable influence on the thermal process, and the partial cementation with cement with high thermal conductivity is favorable. |
| Authors          | Year | Objectives                                                                                                                                                                                                 | Study conditions and metrology used | Conclusions                                                                                                                                                                                                 | Discoveries                                                                                     |
|------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| Meng et al.      | 2020 | Techno-economic performance comparison of enhanced geothermal system with typical cycle configurations for combined heating and power                                                                       | 4 CHP systems that use geothermal water for heating and electricity | System performance varied with temperature and dryness of the geothermal liquid;                                                                                                                                                  | The combined heating and power system based on the classic double flash cycle had the highest efficiency |
| Ma et al.        | 2020 | Experimental study on flow and heat transfer characteristics of water flowing through a rock fracture induced by hydraulic fracturing for an enhanced geothermal system | Hydraulic model in HDR tank with fractures | Multi-pillar injection system can achieve high heat extraction ratio after 30 years                                                                 | injection temperature and injection mass flow are important parameters that influence heat extraction performance |
| T. Renaud et al. | 2019 | Numerical simulation of a Deep Borehole Heat Exchanger in the Krafla geothermal system                                                                                                                   | CFD Modeling - Ansys Fluent CFD 17.1.0, Darcy Law | DBHE provides more heat, shows an improvement of 2-3% compared to the standard design                                                                                                                                              | The deep geothermal doublets in the open system depend on the site |
| Meng et al.      | 2020 | Synergistic mechanism of fracture properties and system configuration on techno-economic performance of enhanced geothermal system for power generation during life cycle | Fist and second law of thermodynamics, numerical model | The evaporation temperature of the system should be reduced accordingly during the life cycle to maintain the optimal performance of the system.                                                                                              | The increase of fracture spacing has a negative impact on the power generation performance and economic performance of systems |
| Chen et al.      | 2020 | Thermodynamic performance analysis and multi-criteria optimization of a hybrid combined heat and power system coupled with geothermal energy                                                                 | A hospital building in Harbin; hybrid CHP system coupled with geothermal resource | Compared to the CCHP systems with a solar resource, the hybrid CHP system coupled with GSHP has the highest AR, 6.40%.                                                                                                                 | The COP of a CCHP system coupled with PV is higher than that of the other solar assisted CCHP systems, because the electric output has a higher exergy level than solar hot water output. |
| Authors        | Year | Objectives                                                                 | Study conditions and metrology used                                                                 | Conclusions                                                                                                                                                                                                 | Discoveries                                                                                                                                   |
|---------------|------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|
| Wang et al.   | 2020 | Performance investigation of a new geothermal combined cooling, heating and power system | Is proposed a new geothermal combined cooling, heating and power (Geo-CCHP) system, numerical simulation | The thermodynamic parameter analysis results show that an optimal flash pressure about 300 kPa and an optimal generator temperature about 120 °C exist, which could yield the maximal exergy efficiency of system respectively. | the exergy efficiency of Geo-CCHP system could achieve 43.69% under the condition of 170 °C geothermal water.                                                                 |
| Ma et al.     | 2020 | Numerical simulation study on the heat extraction performance of multi-well injection enhanced geothermal system | multi-well injection EGS, numerical simulation, Darcy law                                           | The injection temperature and the injection mass flow rate both are the key parameters affecting the heat extraction performance.                                                                                 | the reservoir temperature gradually decreases, the cooling zone starts from the injection wells and collects into the production well.            |
| Zhou et al.   | 2019 | Analysis of influencing factors of the production performance of an enhanced geothermal system (EGS) with numerical simulation and artificial neural network (ANN) | Numerical simulation, the TOUGH2-EOS1 CODES                                                        | The injection temperature and well spacing have a large impact on production temperature, followed by fracture permeability and injection temperature. | increasing the injection flow rate results in a high production rate.                                                                                                                                  |
| Wang et al.   | 2020 | Production performance of a novel open loop geothermal system in a horizontal well | Numerical simulation, COMSOL                                                                           | The tank temperature directly affects the long-term operating temperature of the production and determines the average thermal power.                                                                            | A longer length of the injection section is beneficial for significantly improving the production temperature and reducing the injection pressure. |
| Hu et al.     | 2020 | Numerical modeling of a coaxial borehole heat exchanger to exploit geothermal energy from abandoned petroleum wells in Hinton, Alberta | Numerical simulation, COMSOL, analytical model - Ramey’s equation                                  | Properties related to the heat transfer of water and rock have a significant influence of the outlet temperature during the production of geothermal energy.                                                | The spatial extension of the tank temperature drop during geothermal production with a coaxial BHE in an abandoned oil well increases with operating time. |
| Authors            | Year  | Objectives                                                                 | Study conditions and metrology used                      | Conclusions                                                                                                                                                                                                 | Discoveries                                                                                                                                                                                                 |
|--------------------|-------|----------------------------------------------------------------------------|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wang et al.        | 2019  | Numerical investigation on heat extraction performance of an open loop geothermal system in a single well | Numerical simulation, Comsol, Darcy law                 | A higher permeability can lead to a significant increase in thermal power and a marked decrease in injection pressure, the permeability of the tank is an extremely important factor to improve the performance of OLGS. | the injection rate around the drill is much higher than in most regions of the reservoir, which can lead to a large increase in injection pressure.                                                                |
| Song et al.        | 2020  | Numerical simulation study on the heat extraction performance of multi-well injection enhanced geothermal system | numerical simulation, Computer programming Matlab, Ramey’s equation | Thermal power and outlet temperature and increase both linearly with increasing length of the horizontal section.                                                                                 | at a certain depth in the ascending section, the working fluid temperature reaches the highest value, which is higher than that of the surrounding formation.                                               |
| Song et al.        | 2019  | Numerical simulation of heat extraction performance in enhanced geothermal system with multilateral wells | Numerical simulation, Comsol, Darcy law                 | Over a 30-year heat extraction period, multilateral pylon EGS had an average production temperature, output heat output, heat extraction ratio, and accumulated heat extracted higher than conventional double-well EGS. | the proposed EGS system model with multilateral pillars has proven to be an efficient and low-cost method to exploit hot dry rock. a high production rate.                                                                   |
| Elghamry et al.    | 2020  | Impact a combination of geothermal and solar energy systems on building ventilation, heating and output power: Experimental study | geothermal system coupled with a photovoltaic system, experimental simulation | The maximum total daily natural heating and ventilated air are achieved in case of solar chimney without PV while their daily minimum values occur in case of solar chimney including PV at inclination angle 30. | the proposed passive renewable energy systems for ventilation and heating of rooms in buildings have proven their ability to heat a room ventilation compared to the forced system, and in addition they produce energy. |


| Authors       | Year | Objectives                                                                 | Study conditions and metrology used | Conclusions                                                                                           | Discoveries                                                                 |
|--------------|------|----------------------------------------------------------------------------|--------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Soltany et al. | 2019 | A comprehensive study of geothermal heating and cooling systems            | general study on the use of geothermal energy in heating and cooling systems | Geothermal systems have a high initial cost and a long construction time, but their advantages over other renewable energy sources make geothermal energy more suitable in many, perhaps in the vast majority of applications. | Ground heat exchangers are usually coupled to heat pumps, unlike ambient air temperature, ground temperature is always less seasonally variable. |
| Bu et al.     | 2019 | Performance of geothermal single well for intermittent heating            | Experimental study, Formula Dittus-Boelter | The extracted thermal power can be kept stable if the temperature and the injection speed change and thus the imbalance of the extracted thermal power between different heating seasons can be adjusted. | the most effective way to solve the problem of fog caused by winter heating is to use geothermal energy to heat buildings. |
| Vaccari et al. | 2020 | A rigorous simulation model of geothermal power plants for emission control | UniSim Design (version R440), Process Flow Diagram (PFD) | GTPP's energy performance is mainly affected by environmental conditions, rather than by the effort required to stay within the emission limit values and to achieve environmental performance. | The variation of the air flow, as explained above, depends only on the weather conditions |
| Gong et al.   | 2019 | Evaluation of geothermal energy extraction in Enhanced Geothermal System (EGS) with multiple fracturing horizontal wells (MFHW) | Numerical simulation, Comsol | The MFHW geothermal system increases the conductivity between injection and production, significantly increases the volume of the stimulated tank and the heat exchange area, which has proven to be an efficient method of extracting geothermal energy. | the speed in fractures is 6 orders of magnitude higher than that in the matrix, which shows that fractures are the main channels for heat exchange and fluid flow. |
| Authors            | Year | Objectives                                                                 | Study conditions and metrology used | Conclusions                                                                                                                                                                                                 | Discoveries                                                                                                                                                  |
|--------------------|------|-----------------------------------------------------------------------------|-------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Lyu et al.         | 2020 | Utilizing shallow geothermal energy to develop an energy efficient HVAC system | System built on the platform TRNSYS | The energy saving rate of the integrated system compared to that of the conventional GSHP system is about 29%, and the reduction of CO2 emissions is more than 7 kg per square meter of surface.                   | Available temperature differences between undisturbed soil and building tires, as well as fresh air can often exceed 20°C.                                                                                             |
| Kljajic et al.     | 2019 | Shallow geothermal energy integration in district heating system: An example from Serbia | the geothermal system that belongs to a public company in the city of Pancevo | The proposed GWHP results in a 30% reduction in primary energy from the existing HWCB system, given that SHW consumption is unchanged.                                                                 | The GWHP system can offer more competitive prices for thermal energy compared to the existing HWCB system due to the use of shallow geothermal energy and cheap electricity. |
| Zhu et al.         | 2019 | A review of geothermal energy resources, development, and applications in China: Current status and prospects | review of geothermal energy resources in China | Research and development should focus on the following aspects: technical development of EGS projects, low costs and scale development for geothermal energy generation.                              | Research and development should focus on the use of a hybrid system integrated with geothermal energy and the sustainability of operation and use of geothermal tanks. |
| Song et al.        | 2020 | Numerical simulation of heat extraction performance in enhanced geothermal system with multilateral wells | Numerical simulation, Darcy’s law, Comsol | For 30 years of heat extraction, multilateral pylon EGS had a higher average production temperature, heat output, heat extraction ratio and accumulated heat extracted than conventional double-well EGS. | The low temperature zone in the multilateral EGS tank was funnel-shaped.                                                                                             |
4. Conclusions
Energy consumption due to buildings represents more than 40% of final energy consumption, and carbon dioxide emissions are due to buildings in a proportion of 36%, with a massive growth potential. Given the current situation, which is far from ideal in most countries, renewable energy is the number one substitute for this problem, being a viable solution to reduce the carbon footprint left in the atmosphere. The use of energy from renewable sources has many potential benefits, including a reduction in greenhouse gas emissions, diversification of energy supply and reduction of dependence on fossil fuel markets. Solutions that can help reduce the energy consumption of buildings and reduce greenhouse gas emissions include the use of geothermal energy as a heating agent for cooling / heating systems. Geothermal energy is a largely carbon-free renewable energy source available in almost every location. Geothermal energy has important advantages: it will not be affected by climate change and has the potential to become the lowest source of sustainable thermal fuel in the world. Geothermal energy can also be expected to replace more emissive fossil energy resources with a key role in climate change mitigation strategies. Some of the methods of using geothermal energy have been presented above.

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The 7th Conference of the Sustainable Solutions for Energy and Environment
IOP Conf. Series: Earth and Environmental Science 664 (2021) 012072
doi:10.1088/1755-1315/664/1/012072

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