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Review

Potential and Future Prospects of Geothermal Energy in Space Conditioning of Buildings: India and Worldwide Review

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Abstract: This paper presents modern trends in geothermal energy utilization, mainly focusing on ground source heat (GSH) pumps for space conditioning in buildings. This paper focuses on India along with a general review of studies around the world. Space conditioning of a building contributes to about 40–50% of the total energy consumed in buildings and has an adverse impact on the environment and human health. The India Cooling Action Plan (ICAP) estimates that the demand for electricity for heating and cooling of buildings will increase by over 700% in India at current levels by 2047 with an additional 800 GW of power generation capacity needed just to meet heating and cooling needs by 2050, of which about 70% is required for the residential sector only. It further intensifies as the demand for peak electric load sharply increases in summer because of the extensive use of building air conditioning systems. Researchers across the globe have tried different cooling systems and found that some systems can offer a certain amount of energy-efficient performance, and also occupant comfort. Therefore, this article examines the geothermal potential in buildings for space conditioning by critically reviewing experimental and numerical studies along with the future prospects of GSH pumps.

Keywords: geothermal; space conditioning; heating; cooling; renewable energy; buildings; pumps

1. Introduction

Buildings constitute roughly 40% of the world's total energy requirements and 30% of carbon dioxide emissions [1–5]. Currently, most of the space-conditioning systems consume high-grade energy generated from fossil fuels that lead to an increase in greenhouse gas emissions, resulting in global warming issues and climate change around the world. Choi et al. [6] reviewed various sectors of energy and found that major sources of emission are the building, transport, and industry sector. Cook et al. [7], Anderegg et al. [8], and Oreskes [9] have reported consensus amongst the scientific community about human activities for heating the Earth's surface and human beings are accountable for global warming. Dino and Akgül [10] investigated various residential buildings having a large share of CO_2 emissions and projected that by 2060 the annual mean temperature is expected to rise by

3–3.5 °C and the ambient temperature is likely to increase by 1.8–3.2 °C. Gonseth et al. [11] analyzed the energy need for space conditioning and effect on climate change, inferring that in the future there will be a huge thermal discomfort for the people living in buildings without space conditioning. This alarming situation around the world has forced researchers to study and develop systems based on renewable energy sources. Kuczyński and Staszczuk [12] investigated how cooling demand gets affected by the wall thickness of residential buildings, and noticed that it can be reduced up to 67% at constant temperature conditions by increasing the thickness of the walls. Space conditioning in extremely cold weather regions and warm/hot weather conditions is always critical for researchers, and thus requires prerequisite treatment using building physics principles, materials, etc.

To overcome these challenges, an effective system design is essential for such types of complex problems. Various researchers addressed the problem seriously looking into the future of extreme cold and warm regions and also keeping in mind depleting conventional sources of energy. Dhepe and Krishna [13] reviewed geothermal systems for space conditioning as a potential alternative to conventional systems. They have reported that about 30% of the total electricity is consumed by the commercial and residential sector out of which about 64% of the electricity is utilized by heating, ventilation, and air conditioning (HVAC) systems. For addressing these issues, Singh et al. [14] analyzed the geothermal potential resources of India; as India is growing rapidly among the developing countries in terms of both energy production and energy demands. Figure 1 shows the geothermal potential map of India and investigated geothermal sites. Based on tectonic elements of India and the heat flow gradient, seven geothermal provinces of India are identified as Himalayan, Sohana, West-Coast, Gujarat-Rajasthan, Godavari, Mahanadi, and Sonata geothermal provinces [14], as shown in Figure 1.

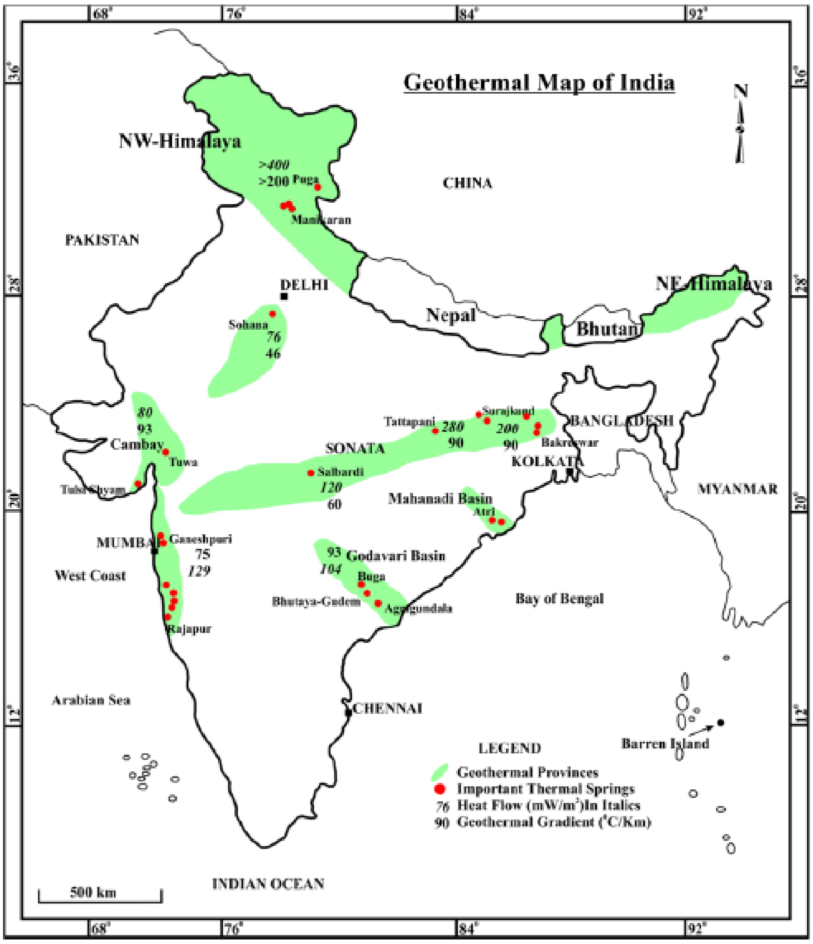

Figure 1. Geothermal map of India [15].

Therefore, a systematic methodology is followed in this article to explore the potential of geothermal energy for space conditioning in buildings in India and around the world. Figure 2 shows the research articles, technical reports, and review articles published in English and available on the Internet that are related to numerical and experimental studies on ground source heat pump and boreholes techniques during the last fifteen years (2005–2020) worldwide. It indicates how the research has evolved over the last two decades in the field of geothermal energy. Data for the analysis has been taken from various scientific journals, which include scientific papers, review papers, and technical reports.

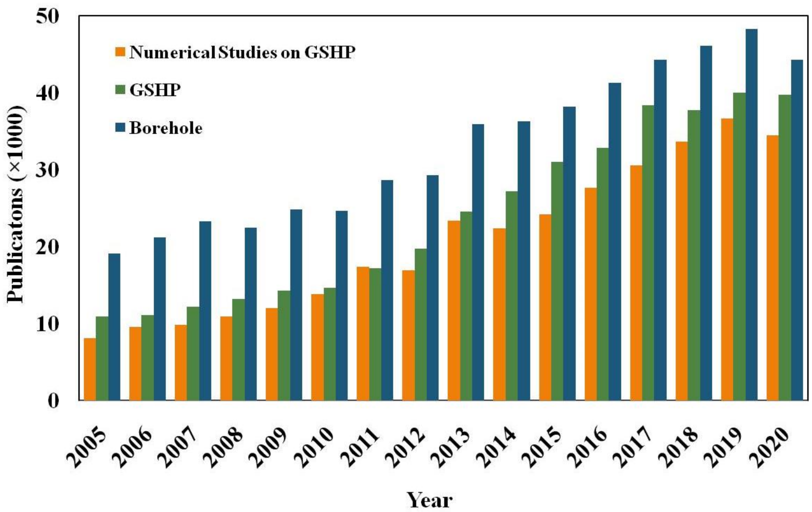

Figure 2. Evolution of research publications during the last fifteen years related to numerical studies on ground source heat pump (GSHP), experimental studies on GSHP, and borehole exchangers worldwide.

Figure 3 shows the market deployment and development of the various renewable energy technologies in the market, as well as the current situation of the various technologies around the world. Data for the analysis has been taken from the International Energy Agency Report 2007-Energy Policy [16]. From Figure 3, it can be inferred that some of the renewable energy technologies are still in the early market phase, therefore, there is a need to analyze the potential of other renewable energy sources.

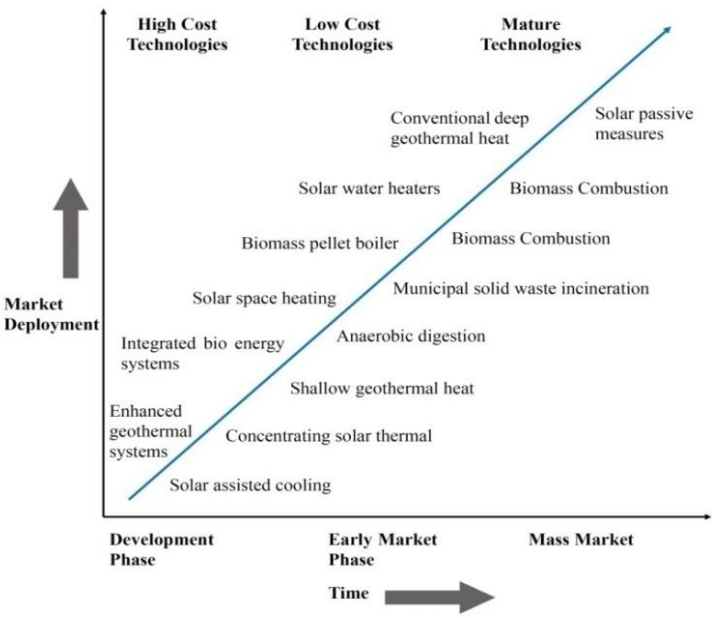

Figure 3. Representation of various renewable energy technologies available in the market [16].

2. Potential of Renewable Energy

Seyboth et al. [16] have reported space conditioning applications in the different building sectors and its benefits from renewable energy are very broad. Although their cost also varies from place to place, almost all renewable technologies are very much competitive with conventional systems, on their operational cost and direct benefits to the environment. According to the International Energy Agency (IEA) [17], in 2009, heat or thermal energy accounted for 47% of the total energy used worldwide and challenges are still there to employ the renewable energy sources. For overcoming these types of barriers, more attention is to be made on policy design. Moreover, investment in renewable heat and energy efficiency affects when it comes to the end-user although investors are the same in both cases most of the time, energy efficiency plays a very important role in attracting investments. The role of governments is highlighted to make economic incentives and subsidies on various renewable technologies. Therefore, more and more people will get attracted to the resource and development will take a long jump when demands get boosted.

Laine et al. [18] have published that during the 21st century the global cooling demand will increase significantly due to many factors and will contribute to the advancement of global warming. The residential cooling sector will be the major driving factor for the increase in demand. Sachs et al. [19] inferred that cooling demand is mainly influenced by climatic conditions, geography, population density, and the selection of cooling systems are influenced by available energy distribution systems. Aghniaey and Lawrence [20] investigated how cooling demand affects the thermal comfort of the occupant. The studies showed how cooling needs will lead to the development of new technologies. The 17 sustainable development goals (SDGs) designed by the United Nations Environment Programme (UNEP) [21] emphasize sustainable cooling to the markets in a cost-effective manner. Therefore, sustainable cooling is targeted for the 21st century. India is the first country that launched the India Cooling Action Plan (ICAP) in 2019 for a long-term vision, seeing the importance of cooling in the economic growth and productivity [22]. ICAP focuses on steps to be taken for reducing cooling demand in the country. Furthermore, the focus will be on reducing cooling demand by 25 and 30% reduction in refrigerant demand over the next 20 years. This is in line with global climate change initiatives for reducing global warming. The SDGs are in line with ICAP and include nationwide productivity, reducing cooling energy requirements in the next 20 years, reducing stress on power systems, reducing leakage of refrigerants, and making safer working places. All these goals can only be achieved by using a 100% potential of renewable energy sources available on Earth. To achieve these goals, the geothermal energy resource is to be reviewed for space conditioning in buildings, as this is the most important driving factor for an increase in energy demand.

3. Geothermal Energy

3.1. Role of Geothermal Energy in Space Conditioning

Molavi and McDaniel [23] reviewed the benefit of replacing the conventional HVAC systems with the geothermal central HVAC systems. Challenges reported by the authors in using geothermal energy with a central HVAC are expensive machinery, extensive soil and environment testing, and difficulties in the designing stage. Vibhute et al. [24] have discussed the geothermal HVAC system and found that a conventional air conditioning unit utilizes much more energy than the geothermal space conditioning system and is up to 50% energy efficient. The geothermal space conditioning system is reliable and durable up to the life of 50 years for the underground piping and heat pump up to 20 years of life. Yu et al. [25] concluded that geothermal cooling systems are feasible with zero external energy consumption. Fathizadeh and Seim [26] have done a comparison between conventional HVAC and geothermal systems along with estimating, designing, and calculating geothermal heating and air conditioning of residential houses or small businesses in Indiana, USA and concluded that geothermal systems are more efficient in larger installation areas.

3.2. Worldwide Scenario

Developed countries have been giving grants to the residential sector to use geothermal HVAC so that their national grid needs do not increase at an alarming rate. D'Agostino and Mazzarella [27] analyzed the targets of Europe to reduce greenhouse emissions from buildings by 80% by 2050. According to the analyses, the UK has committed 100% of their buildings to be nearly zero energy buildings by 2050 and 70% by 2030. This would have control over energy use and emission. Similarly, Germany and the UN recommending the same, geothermal exchange coupled with building physics is the shortest route to achieve nearly zero energy buildings (nZEBs). As per the World Geothermal Congress 2015 (WGC2015), the globally installed capacity of geothermal is 592,638TJ which is an increase of 39.8% as compared to the World Geothermal Congress 2010 [28]. The major utilization capacity is contributed by five countries; China (174,352 TJ/year), USA (75,862 TJ/year), Sweden (51,920 TJ/year), Turkey (45,892 TJ/year), and Iceland (26,717 TJ/year) accounting for about 65.8% of the world capacity. Gong and Werner [29] reported an analysis in which they showed the gradual shifting of researchers from nuclear energy to geothermal and solar energy.

Indonesia [30] possesses the world's foremost geothermal potential at 40% of the world's geothermal energy but only 4.5% is being utilized for generating electricity. The study concludes that there is a huge potential at geothermal sites in Indonesia to explore and extract energy from the ground for different applications. Table 1 shows the installed capacity of geothermal along with key results reported in the literature around the world with specified locations.

Table 1. Studies carried out in different parts of the world and their key findings.

Investigators	Location	Key Results
Seyboth et al. [16]	Germany	Installed capacity of geothermal found to be 25–30 GW. Moreover, the growing demand should be recognized in the field of renewable and new policies must be designed.
Gong and Werner [29]	China	One third of all the international scientific journals on district heating came from China during 2010–2013.
Soltani et al. [31]	Iran and Canada	Total geothermal installed around the world was 8771 MW in 2004. Moreover, CO_2 production is reduced to 200 ton/yr from 28,000 ton/yr by replacing fossil fuels with geothermal energy.
Beerepoot and Marmion [32]	France	New policies are required for renewable heat production as this is expected to increase in the future.
Demirbaş [33]	Turkey	Installed geothermal capacity is found to be 8200 MW. Moreover, 14% of the total world energy demand is supplied by renewable energy sources.
Lund et al. [34]	USA and New Zealand	Capacity of geothermal is found to be 28,268 MW and countries are using geothermal fluids for direct use, but their development is very slow as compared to other sources of energy.
Melikoglu [35]	Turkey	Turkey's target for 2023 was to achieve 600 MW geothermal installed capacities but they achieved it by 2015 only, then they modified it to 1000 MW by 2023 installed capacity.
Sivasakthivel et al. [36]	India and UK collaborated	COP of 3.92 (for heating and cooling) is observed.
Frick et al. [37]	Indonesia	Installed capacity of geothermal is 2 GW. Indonesia has a lot of potential when it comes to geothermal energy but no GSHP technology advances are taking place here.
Feng et al. [38]	China, USA, and Singapore	Research and case studies found that countries have developed nZEBs, but the policy framework needs to be implemented and focused for removing the barriers in the path of nZEBs.
Shahare and Harinarayana [39]	India	Underground water is maintained at a constant 26 °C at all ambient conditions in the Ahmedabad region using a shallow geothermal up to 3m of depth.

Fernández [40] discussed three different countries using geothermal energy as space conditioning in their supermarkets and analyzed the percentage reduction in greenhouse gas (GHG) emissions, as well as in energy consumption: (i) Germany used the shallow geothermal technology supermarket and recorded energy consumption reduction up to 45%, whereas a reduction in carbon dioxide emission was recorded up to 28%; (ii) Portuguese conventional space conditioning systems were replaced by the GSHP system for space conditioning and a 30% reduction of energy consumption and 30% reduction of carbon dioxide emission were possible; (iii) Turkish supermarkets use stored thermal energy in an aquifer and integrated it into heat ventilation and the air conditioning system which recorded a reduction in energy consumption and about 36% reduction in carbon dioxide emission. The study concludes that utilization of geothermal energy will help in reducing carbon emissions.

3.3. Indian Scenario

In India, utilization of geothermal energy is still in an immature stage where only a few authors have tried to explore the geothermal energy potential for space conditioning. Shahare and Harinarayana [39] analyzed geothermal based space conditioning with the heat exchanger by using a shallow process for cooling in summer and solar energy as the major source for space heating during winter, and validated it with computational fluid dynamics (CFD) modeling and proposed a hybrid way to do it with the help of geothermal and solar energy. The tropical climate in India makes it susceptible to a heavy load of energy that ultimately affects the environment which can be mitigated by employing geothermal cooling.

Dhepe and Krishna [13] have done a literature review on geothermal cooling and heating systems and the advancements in this field. The increasing demand for energy leads to more exploration of renewable energy technologies. Geothermal heating and cooling is the new advancement in the field of HVAC. The analysis of geothermal ground source heat pump shows that 51% of electricity can be saved with the help of these pumps. Their longer life and lower maintenance also play an important role in early acceptance of the technology. Badgujar et al. [41] reviewed the work done by various researchers in the field of implementation, application, dynamic simulation, and modeling of the geothermal system and proposed that further research is needed to explore the potential of geothermal energy for a different typology of buildings in various regions in India with different ground temperatures, as well as to develop generic models for different built-up area buildings with quantified performance. Figure 4 shows how geothermal energy storage takes place. In Figure 4a, the borehole thermal energy storage is shown, which is used mostly for closed loop applications with multiple borehole heat exchangers. In Figure 4b, the aquifer thermal energy storage is shown, which operates as wells.

Figure 5 shows the direct utilization of geothermal energy in different ways with heat pumps showing an exchange from different exchange mediums. Shallow geothermal systems extract heat energy from the ground for supplying to the buildings and other purposes. It can be a closed-loop or open-loop system, as shown in Figure 5. In many regions, cooling with the help of a ground source heat pump is gaining more interest [42]. Mostly, closed-loop systems are used in which ground heat is exchanged with the help of fluid flowing through tubes, boreholes, energy piles, etc. Ground source heat (GSH) pump is shown in Figure 5a with a horizontal heat exchanger mainly used for a shallow geothermal (for depth < 5 m). In Figure 5b, the GSH pump with a vertical borehole heat exchanger for depth greater than 10m is shown. In Figure 5c, energy piles are shown with multiple vertical boreholes installed in the foundation of new buildings. In Figure 5d, the open-loop (GWHP) is shown, which utilizes groundwater directly as a heat carrier.

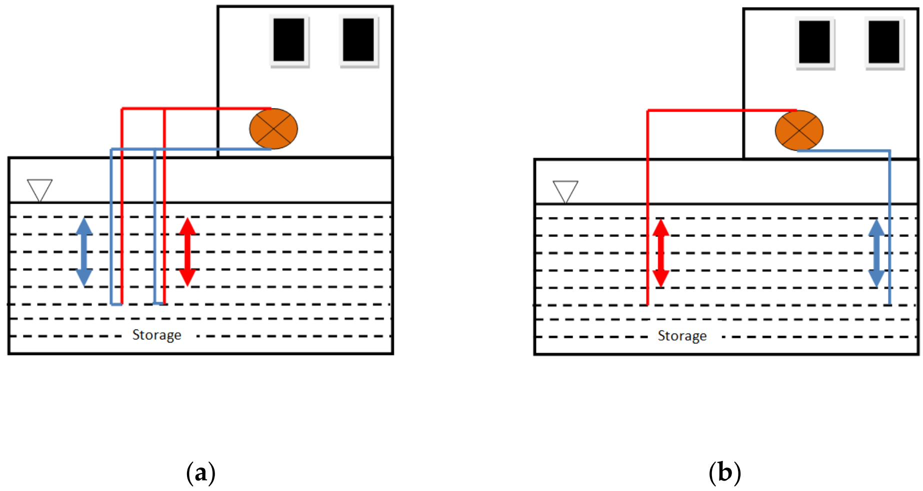

Figure 4. Thermal energy storage: (**a**) Borehole thermal energy storage; (**b**) aquifer thermal energy storage.

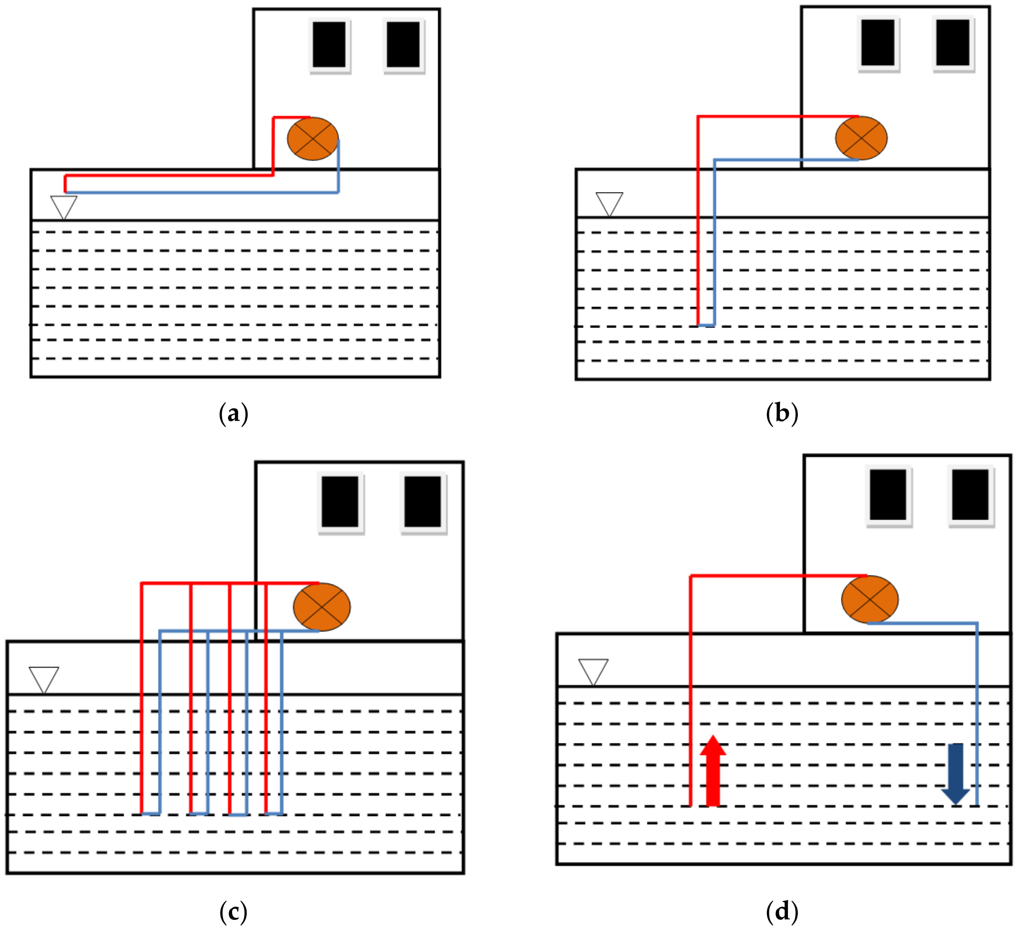

Figure 5. Use of geothermal energy: (**a**) Ground source heat (GSH) pump; (**b**) ground source heat (GSH) pump with borehole heat exchanger (BHE); (**c**) energy piles; (**d**) ground water heat pump (GWHP).

3.3.1. Challenges

The HVAC systems are being used in very large numbers in the building sector with a trend showing a significant increase in the future. Therefore, to decrease energy consumption and minimize the adverse impact on the environment, the correct combination of building physics, geothermal, and solar energy to decarbonize the HVAC solution has to be deployed and is the biggest challenge among the researchers. Especially in India, a geothermal closed vertical ground loop is a relatively grey area to design an efficient cooling system for hot climates around the year without exploiting much of the conventional resources. Researchers have tried different systems and found that some systems can offer an energy-efficient performance along with occupant comfort but the challenge is the hybridization of such systems.

3.3.2. Opportunities in Ladakh, India

As shown in a geothermal potential map of India (Figure 1), extremely cold climate conditions of Ladakh region have a huge geothermal potential to explore as an opportunity in India, where the use of various conventional sources for heating the space is deteriorating people's health, the temperature remains below 0°C for more than seven months. Irregular rainfalls in this region lead to a shortfall of potable water. Conventional fuels such as LPG, coal, kerosene, etc. are costly due to the high transportation cost. On the other hand, extracted energy by combustion of fossil fuels is poor due to the lack of sufficient oxygen at an altitude above 2500 m. Hence, there is a need to develop environment-friendly sustainable technologies for heating of buildings such as geothermal to overcome the existing problems and develop generic models for different built-up area buildings with payback and quantified guarantees.

4. Study on Ground Source Heat Pump

GSH pumps may further resolve numerous environmental issues. This exploration of renewable resource has started back in the 1940s that continue with modifications. Table 2 gives an overview of the research papers on GSH pumps reviewed and analyzes the advancements and categorizes them majorly based on energy and CO_2 emission reduction, coefficient of performance (COP), and energy efficiency ratio (EER), i.e., the ratio of useful heating and cooling provided to the work required. Since the installation cost is higher compared to some of the conventional systems, therefore, contemplating the payback period becomes necessary.

Figure 6 shows the processes involved in the machine room of the ground source heat pump with the help of a Carnot cycle: At point A, the evaporator will increase the temperature of the refrigerant with the help of a buffer tank and then the refrigerant will move to the compressor and this cycle will be repeated; at point B, the temperature and pressure of the compressed refrigerant (in the form of gas) is high; at point C, the brine solution will take the energy from the refrigerant; at point D, the rejection of heat takes place; at point E, the temperature of the refrigerant will be lower and the pressure will be high; at point F, the expansion of the refrigerant takes place; at point G, the temperature and pressure of the refrigerant (in the form of liquid) is lower; and point H is the buffer tan. In Figure 6, AHU is the air handling unit and FCU is the fan coil unit; whereas, Figure 7 shows the types of heat exchangers used in the GSH pump. Figure 7a shows the vertical ground heat exchanger (also known as a borehole) used for longer depths. Figure 7b shows the horizontal ground heat exchanger, mostly used for depth less than 1.5 m. With proper arrangements, a combination of the horizontal and vertical system can also be used. Figure 7c shows the spiral ground heat exchanger (GHE).

Table 2. Salient features of the geothermal energy and its impact on the environment.

Authors	Location	Study	Energy Reduction	CO_2 Reduction	COP	Pay Back (Years)
Neves et al. [43]	Memphis, Tennessee	Techno-Economic analysis	26%	-	-	-
Olabi et al. [44]	France	Hybrid system	-	-	-	-
Kljajić et al. [45]	Serbia	Shallow GSHP	30%	-	-	4.9
Maoand Chen [46]	China	Experiment on GSHP	-	-	1.56–2.01	-
Lee et al. [47]	Korea	GSHP vs. DH	-	-	-	-
Liuand Hong [48]	US	VRF system vs. GSHP	-	-	-	-
Zhao et al. [49]	China	GSHP for roadheating	-	-	1.97–2.22	-
Athresha et al. [50]	UK	Open looped GSHP	-	-	2.7–3.9	-
Franzen et al. [51]	Sweden	Conventional vs. Ectogrid geothermal	61% 70%	12% 20%	-	-
Momin [52]	Pune	Experiments on GSHP	40–60%	-	3.42–3.61	-
Gao et al. [53]	China	DXGSHP vs. GCHP	26%	40%	6.03–6.25	4.4–5.6
Salem and Hashim [54]	Dubai	GCHP feasibility	198 millionKWh	-		8
Bu et al. [55]	China	Continuous SWGH	448.49 KW	-	3.8	7.17
		Intermittent SWGH	619.12 KW	-	4.5	5.16

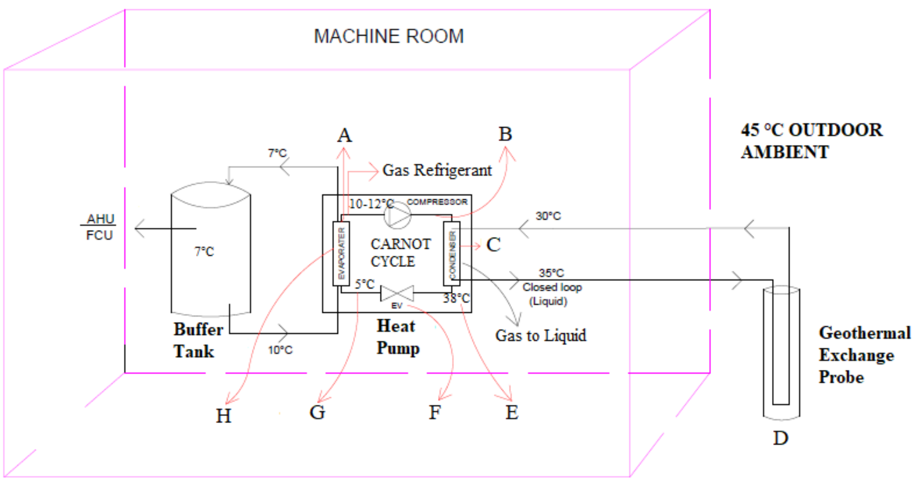

Figure 6. Schematic diagram of the machine room of the ground source heat pump.

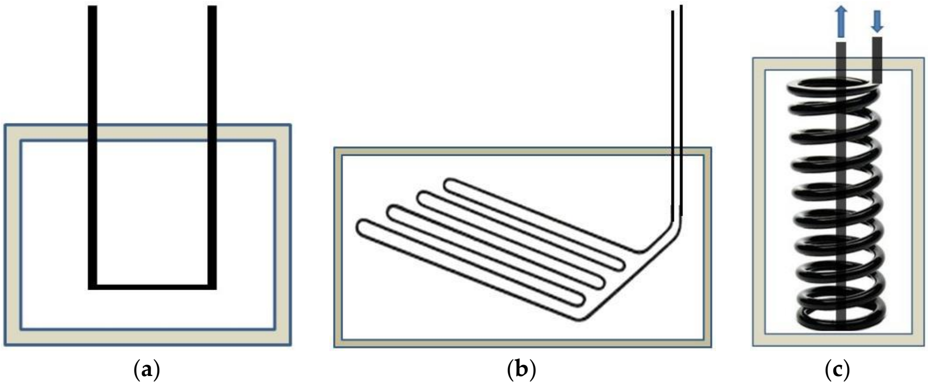

Figure 7. Types of heat exchangers used in GSH pumps. (**a**) Vertical ground heat exchanger (GHE), (**b**) horizontal GHE, (**c**) spiral GHE.

Table 3 summarizes the various important studies based on a vertical single U type borehole used in the GSH pump and various other parameters used are shown while designing the boreholes.

Table 3. Studies carried out on borehole specifications in GSH pumps.

Authors	Year of Study	Borehole Specifications			
		Type	Depth (m)	Spacing(m) b/w Boreholes	Number of Boreholes
Zhao et al. [49]	2020	Vertical loop single U Type	100	-	10
Momin [52]	2013	Vertical closed loop U Type	23–150	5	-
Bayer et al. [56]	2014	Vertical loop single U Type	78	6	54
Cocchi et al. [57]	2013	Vertical loop single U Type	100 each	10	14
Ma et al. [58]	2019	Vertical loop single U Type	100 each	4	32
Zhai et al. [59]	2017	Vertical loop single U Type	50, 60, 80	-	3 each

Athresha et al. [50] discussed a comparative study of GSH pump with conventional systems for the same heating demand of the modern boiler with an efficiency of 90% and the GSH pump system that will produce 400% more energy for the same amount of energy consumed by the boiler with a COP ≈ 3.9.

4.1. Numerical Approach

A numerical model based on finite elements, that was developed by Farel and Basu [60], showed how water flow in the ground affects the temperature of soil surrounding the geothermal pile. The numerical HVAC modeling system for GSH pumps (thermal response test of ground thermal properties) and WSHP (Tai lake water temperature was used in this case) for a particular building model located in China. The 3D model of this building is substituted as the input. The authors have analyzed the performance of the GSH pump system for various types of building models. Studies showed that there is a notable increase in the ground temperature near the heat exchanger as a result of an imbalance of heat due to the release in summer and absorption during winter (thermal plume).

When a major part of the energy share in the European Union (EU) is covered by building heating and cooling, a need for the replacement of fossil fuel by a renewable and sustainable source is at high demand. The response surface method (RSM), a statistical approach has been discussed by authors [61] with the help of the heat transfer and energy balance equation, mathematical models, EAHE (Earth to air heat exchanger) model considering three influential variables in the context of heating and cooling of buildings. Shu et al. [62] investigated how the groundwater flow for geothermal development is being affected by boundary conditions in hilly areas. FEFLOW, a 3D heat water finite element based model was developed to study how boundary conditions affect the temperature fields and hydrodynamics of aquifers. Table 4 shows the tools used for modeling and simulation of various systems.

Table 4. Different software tools for modeling and simulation of various systems.

Authors	Software	Methodology	Outcome
Yu et al. [25]	TRACE 700	Steady-state model	Calculation of cooling load
Farel and Basu [60]	COMSOL	Coupled heat transfer and Brinkman's momentum equation	Temperature and velocity fields
Shu et al. [62]	FEFLOW	Conservation of mass, momentum, and energy	Impact of boundary conditions on hydrodynamic temperature fields
Akbari et al. [63]	EES	Mass conservation and law of thermodynamics	Performance of Kalina and LiBr/H_2O cycles
Ma et al. [58]	TRNSYS	-	Heating and cooling load
Noorollahi et al. [64]	EnergyPlus	Building energy analysis and thermal load	Heating and cooling load
Stegnar et al. [65]	PETA	GIS Mapping	Heating and cooling demand, potential of RES
Zhang et al. [66]	CMG STARS	-	Reaction kinetic parameters of particle migration and blockage in porous medium
Tu et al. [67]	FLUENT	CFD and RC model	Solve the freezing soil conditions
Liu et al. [68]	YALMIP	Linearization	Solve mixed-integer nonlinear programming (MINLP)
Shah et al. [69]	Mini-REFPROP	Based R-134a	Calculates properties of refrigerant R-134a
Tarnawski et al. [70]	GHEADS	-	GHE sizing and GSHP performance
Madani et al. [71]	TRNBUILD	-	Selects constructional material
Bansal et al. [72]	FLUENT	CFD Model	Thermal performance of EAHE
Fayegh and Rosen [73]	FLUENT	Control volume method	Solve transient integral equation for energy conservation

4.2. Implementation of GSH Pumps in Buildings

Neves et al. [43] simulated a building for the assessment of energy savings that was done by replacing an electric system with a geothermal heat pump system. It has been established that there is almost a 26% reduction in energy use by the replacement of a geothermal heat pump system. Barbaresi et al. [74] studied a different application of geothermal heat exchanger for greenhouse cultivation. In this, a low enthalpy geothermal system is used and analyzed with the help of geothermal heat exchanger and ground source heat pumps in winter for heating in the greenhouses to reduce energy needs, the cost of the process, and take care of CO_2 emissions.

A case study was discussed by Kim et al. [75] comparing the economic factors such as energy consumption, cost between existing three different buildings so that energy savings and cost in incorporating geothermal energy can be estimated. The lifecycle cost (LCC) analysis was also done to check the economic feasibility of installing the system and infers that the system can be selected based on energy consumption and costs or energy cost reduction effect related to a geothermal application.

The Middle East countries [54] such as Egypt, Turkey, Iran, Iraq, Saudi Arabia, UAE, Kuwait, etc. with a never-ending vast developmental process requires continuous energy supply for cooling and ventilation and fluctuating energy needs and accelerated demand due to a significant increase in high rise buildings at a prominent pace. An analysis was performed by Salem and Hashim [54] based on a 20-year life cycle and they came up with the fact that commercial buildings in Dubai had to save energy usage and operating cost with an 8-year payback period.

Hospitals are one of the major energy-consuming buildings, and using renewable energy sources can be a way ahead to sustainability approach [76]. A case study of 300 bedded hospitals considerably signifies that all these renewable energy sources can lead to nearly zero carbon dioxide emissions, in the long run, it is both a cost and energy saving alternative.

A detailed study on the modeling of thermally interactive multiple boreholes was conducted [61] and the authors investigated the sustainability, environmental impact, and optimized the performance of the system. As thermal anomalies increase due to the unbalanced heat extraction and injection, it causes local cooling of the ground, which can be mitigated by adjusting seasonal heating and cooling workloads. Ramos et al. [77] have investigated many implemented projects of the GSH pump around the world and concluded that this can be the most sustainable method to opt for space conditioning applications in buildings. Verhoeven et al. [78] have converted a small geothermal project to a large sustainable hybrid structure for heating and cooling.

Therefore, from the above studies, it can be inferred that there is a need to carry out the study on space heating and cooling from GSH pumps and hybridization on the way to nZEBs.

4.3. Comparative Study of GSH Pump

Researchers investigated certain boreholes of German cities having depth of 20m, where the groundwater temperature reaches 13 to 18 °C [79]. The study concludes that GSH pumps systems are efficient, sustainable, and have the potential for space conditioning applications. Table 5 shows the comparison of the GSH pump with various other systems available in the market. In Table 5 the GSH pump is compared with two-pipe fan coils, four-pipe fan coils, packaged terminal air conditioners (PTAC)/packaged terminal heat pump (PTHP), and variable air volume (VAV) control system. Studies investigated concluded that GSH pumps are more efficient and feasible to use over other systems. In terms of ease of design and installation, GSH pumps are highly efficient. The maintenance and operating costs of GSH pumps are very low when compared with other systems.

Table 5. Comparison of geothermal GSH pump with other systems available in the market.

System	Ease of Design	Ease of Installation	Installation Space	Maintenance Requirements	Maintenance Cost	Operating Costs	Sound Levels	System Life
Two-Pipe Fan Coils	Low	Low	High	High	High	Med.	Low	Med.
Four-Pipe Fan Coils	Low	Low	High	High	High	High	Low	Med.
PTAC/PTHP	Low	Low	Low	High	High	High	High	Low
VAV	Low	Low	High	High	High	Med.	Med.	Med.
Geothermal GSHP	High	High	Low	Low	Low	Low	Low	High

5. Future Prospects of Geothermal Energy Hybrid Systems

The studies reviewed above inferred that geothermal energy is a renewable, reliable, environmentally-friendly, sustainable energy available almost everywhere around the world. Thus, hybridization between two or more renewable energy sources might be the solution. The comparison between the different hybrid geothermal systems showed that each system has its characteristics. The combination of geothermal energy with other renewable sources is the most preferable hybridization, especially from an environmental point of view. On the other hand, it is quite important to mention that the efficiency, COP and plant capital, and operating costs are not only related to the energy sources used but there are several other factors such as soil properties, ambient conditions, drilling cost, materials, equipment, cycle conditions, and heat transfer enhancement of working fluid [80,81]. The use of a renewable source of energy will help reduce the ozone layer depletion and other pollution hazards on our ecological system [82,83]. The major requirements for low energy buildings using geothermal and other sources of energy as the source for space conditioning and domestic hot/cold water needs are to be standardized.

Figure 8 shows various steps needed for achieving a nearly zero energy building with the help of hybrid systems and geothermal space conditioning systems. From this figure, the hybridization approach is suggested which shows that for achieving ultra-low energy buildings, three important factors to be considered are—Building Physics, Generation with renewable sources, and Distribution. For complying airtightness in buildings, the MVHR (mechanical ventilation with heat recovery) system is installed, as MVHR will help in reducing heat losses from stale air and maintains a constant fresh air supply in buildings [84]. Other important considerations in building physics are shown in the flow chart to reduce the thermal load of the building. The thermal load will help in analyzing further calculations for the space conditioning in buildings, as shown in the flow diagram. Finally, by selecting the suitable methods and technology, ultra-low energy buildings or nearly zero energy buildings (nZEBs) are achieved.

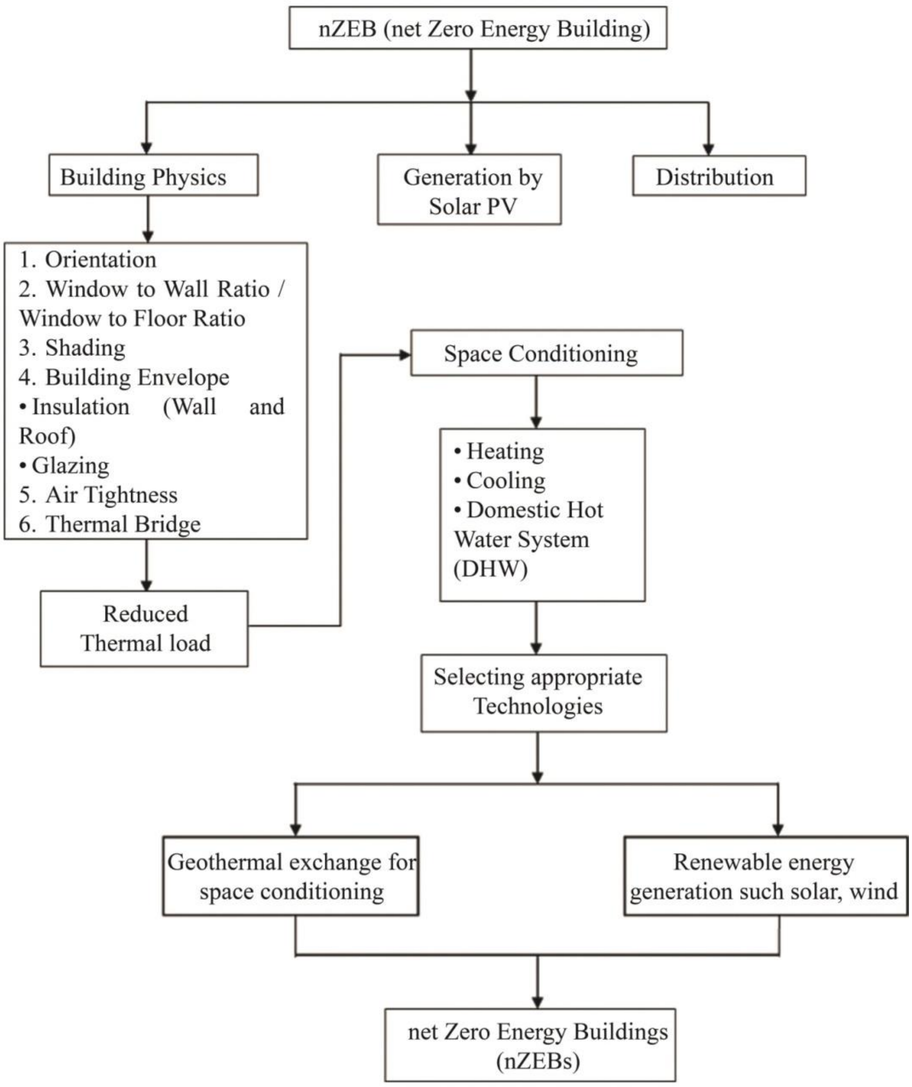

Figure 8. Nearly zero energy buildings (nZEBs) with geothermal hybrid systems.

In the context of cooling of buildings, EAHEs (Earth to air heat exchangers) can also be used for a hot and humid climate with the above technologies. EAHEs are the systems in which air is passed through the pipe (buried under the Earth) with the help of a blower and outlet of the pipe is connected to the building for cooling. Wei et al. [85] investigated that increasing the depth and reducing the diameter of the EAHE pipe will result in a decrease in the outlet temperature and moisture content of the air.

Hybrid System for Solving Problems of Energy Shortage for High Energy Requirements

Hybrid systems with a solar PV (Photovoltaic) integrated with the ground source heat pump system may help in solving energy shortage problems, particularly for high energy requirements [86]. The optimization of the system parameters can be done by using software/tools available for assessing the efficiency and payback time of the proposed system. For simulation, e-QUEST or Energy Plus Software can be used to determine the heating and cooling load and energy consumption.

Figure 9 shows that the solar PV can be utilized for the GSH pump for solving problems of energy shortage. Therefore, further research is needed to develop various space conditioning generic designs for different types of buildings having different built-up areas and to validate the system under real-time conditions. The systems can be optimized for maintaining comfort parameters. The payback period studies are also desirable to establish the life cycle cost of the hybrid systems to establish the superiority of these systems in the longer periods.

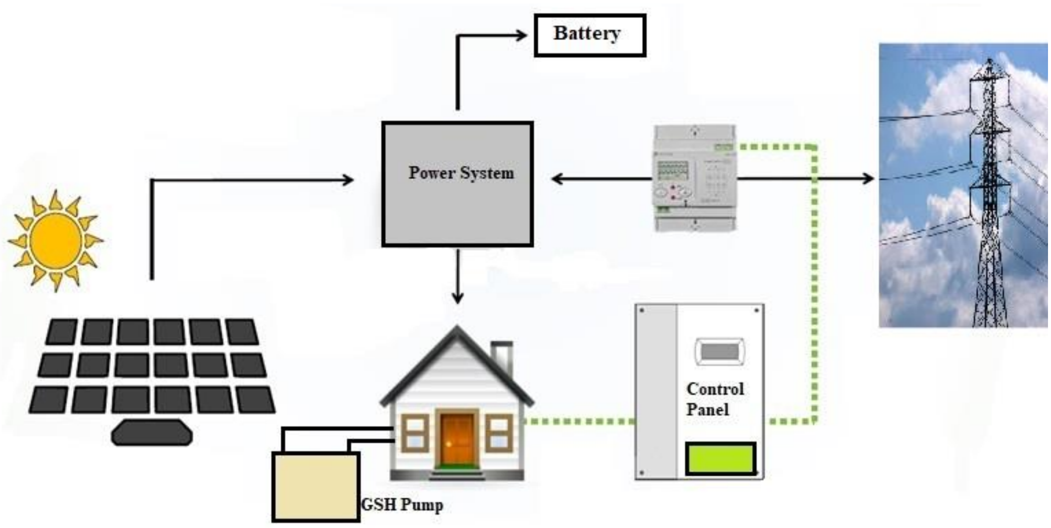

Figure 9. Photovoltaic based GSH pump.

6. Conclusions and Remarks

This review paper focused on various low energy consuming and low refrigerant usage systems, which can effectively deliver space conditioning comfort parameters in line with SDG goals and ICAP goals of India. In the process, this will help in reducing the heat urban island (HIU) or usage of ODP refrigerants, thereby reducing the global warming potential (GWP) and effectively addressing climate change. This will also be in line with the Paris Climate Change Agreement and Kigali Amendment with two main foci—energy consumption and refrigerant use with goals: 25–40% reduction in cooling energy requirements and 25–30% reduction in refrigerant demand. Therefore, the focus on a hybrid solar-geothermal for space conditioning is explored, which is 65% of the building energy consumption parameter to use as a primary tool in low energy buildings or nZEBs.

Most of the parts of India are hot, warm, and humid, thereby this will not only increase the cooling degree days but also reduce the peak load demand. The researchers take cognizance of the fact that future buildings must be capable of mitigating the peak load, especially through building physics. In a country as hot as India and with longer cooling degree days, it is pertinent to use the best possible thermal exchange in the form of GSH pumps with vertical probes and run the mechanical systems with solar-generated electricity especially during the business as usual (BAU) hours.

The climate change parameters focus on the facts that India will figure out a strategy for combining building physics, geothermal exchange, and solar generation to eventually reach low carbon and low energy parameters as the world is heading towards it by 2030. India has a fair knowledge of building physics and the standards compared to world-class material and knowledge but the missing link is low energy, low refrigerant, and low emission space conditioning systems with domestic hot water (DHW) systems in cogeneration. Hence, the necessity is to study quickly and find out the GSH pumps in conjunction with the two other interventions. It is estimated that in the next 20 years India will build 1.3 billion square meters of the built-up area mostly in urban areas that will feature space conditioning as a major design parameter. Therefore, it is pertinent to have the know-how and feature of GSH pumps exchange as the primary intervention in space conditioning in the pursuit of low energy buildings or nZEBs. Moreover, this will have sizable contributions on the economy by saving the KW or MW. The low enthalpy geothermal exchange can be done in any climatic condition, and hence our focus is on space conditioning and domestic hot water (DHW). Areas such as Ladakh can benefit immensely from the geothermal exchanges and solar generation combinations solving the existing problems of many years.

A detailed review on the GSH pump system potential for space conditioning in buildings shows that the installed capacity of GSH pump systems has increased during the last two decades with applications of geothermal energy on the HVAC system and ground-coupled heat pump technology, concentrated on GSH pump systems and their impact on buildings. This study shows that GSH pumps have a huge potential in space conditioning and water heating over conventional systems. It could play a significant role in reducing CO_2 emissions, refrigerant use, energy demand, human health, dipping global warming, etc.

The geothermal exchange addresses the problem of UHI and coupled with building physics, it will reduce the quantum of heat that needs to be rejected into the ground. The proper geothermal exchange design will ensure that there is no rejection of heat into the atmosphere.

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