Geothermal Energy: A Future Prospective

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Abstract

Geothermal energy is also a very cheap and clean source of energy, but in its current form, it has limitations. There are limited geothermal resources, and the supply may not have the potential to be increased substantially without further technological breakthroughs.Geothermal energy is the energy contained as heat in the Earth's interior. This overview describes the internal structure of the Earth together with the heat transfer mechanisms inside mantle and crust. It also shows the location of geothermal fields on specific areas of the Earth. The Earth's heat flow and geothermal gradient are defined, as well as the types of geothermal fields, the geologic environment of geothermal energy, and the methods of exploration for geothermal resources including drilling and resource assessment.

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

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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 communityabouthumanactivitiesforheatingtheEarth'ssurfaceandhumanbeingsareaccountable for global warming. Dino and Akgül [10] investigated various residential buildings having a large shareofCO_2emissionsandprojectedthatby2060theannualmeantemperatureisexpectedtoriseby

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 therewillbeahugethermaldiscomfortforthepeoplelivinginbuildingswithoutspaceconditioning. Thisalarmingsituationaroundtheworldhasforcedresearcherstostudyanddevelopsystemsbased onrenewableenergysources.KuczyńskiandStaszczuk[12]investigatedhowcoolingdemandgets 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.Variousresearchersaddressedtheproblemseriouslylookingintothefutureofextremecold 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 bythecommercialandresidentialsectoroutofwhichabout64%oftheelectricityisutilizedbyheating, ventilation, and air conditioning (HVAC) systems. For addressing these issues, Singh et al. [14] analyzedthegeothermalpotentialresourcesofIndia;asIndiaisgrowingrapidlyamongthedeveloping countries in terms of both energy production and energy demands. Figure1shows 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,andSonatageothermalprovinces[14],asshown inFigure1.

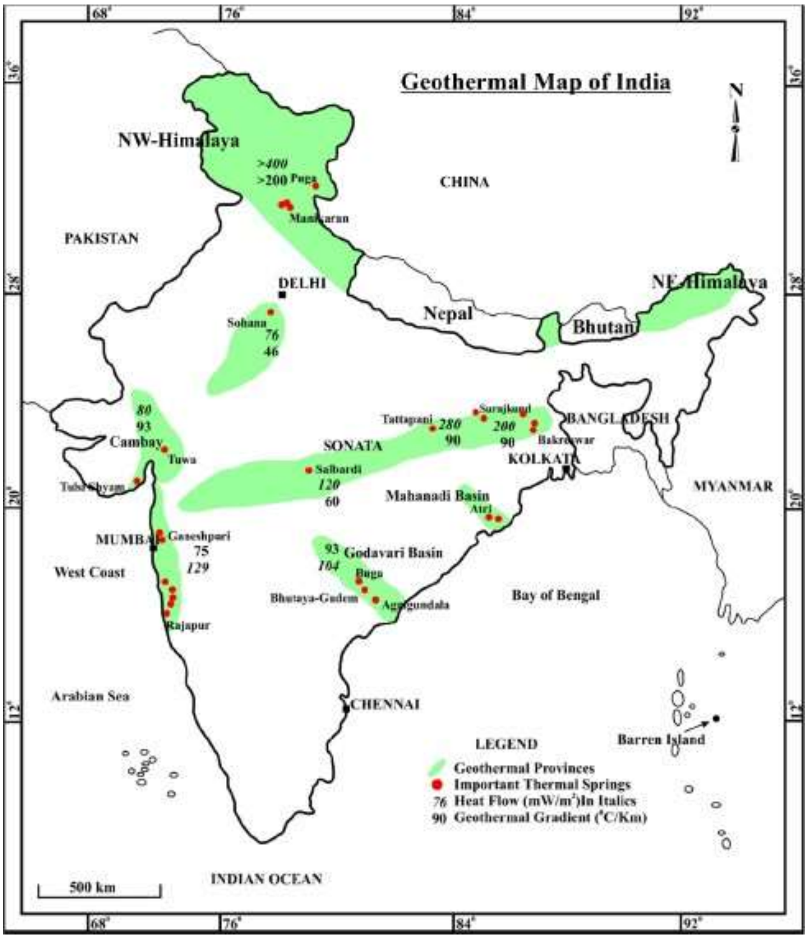


Figure 1. Geothermal map of India [15].

Therefore,asystematicmethodologyisfollowedinthisarticletoexplorethepotentialofgeothermal energyforspaceconditioninginbuildingsinIndiaandaroundtheworld.Figure2showstheresearch articles,technicalreports,andreviewarticlespublishedinEnglishandavailableontheInternetthatare relatedtonumericalandexperimentalstudiesongroundsourceheatpumpandboreholetechniques duringthelastfifteenyears(2005–2020)worldwide. Itindicateshowtheresearchhasevolvedoverthe 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 technicalreports.

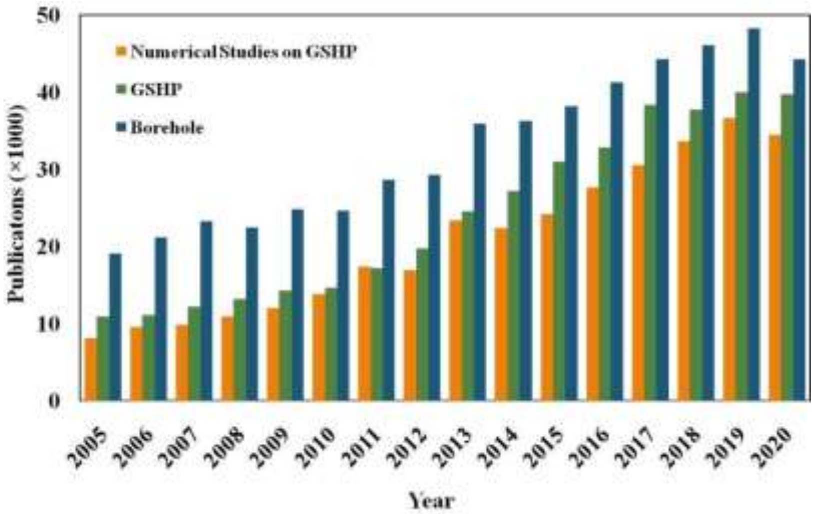


Figure2. Evolutionofresearchpublicationsduringthelastfifteenyearsrelatedtonumericalstudieson groundsourceheatpump(GSHP),experimentalstudiesonGSHP,andboreholeexchangersworldwide.

Figure3shows 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. DatafortheanalysishasbeentakenfromtheInternationalEnergyAgencyReport2007-Energy Policy [16]. From Figure3, 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 energysources.

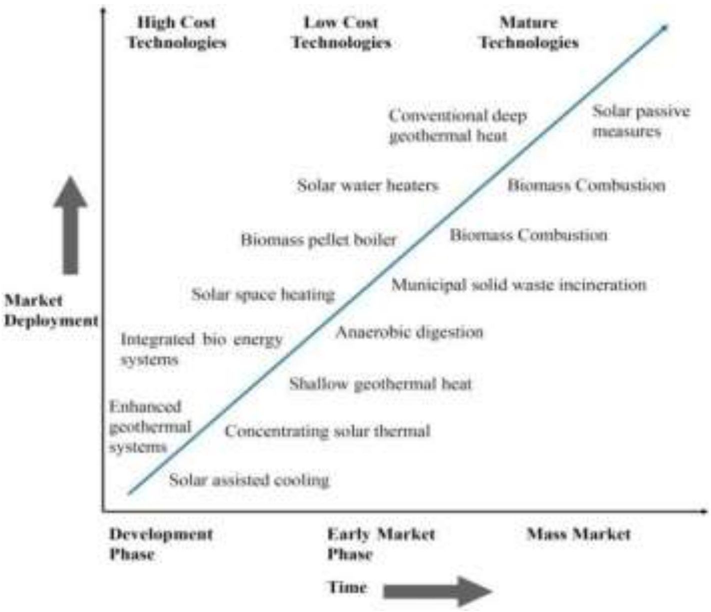


Figure 3. Representation of various renewable energy technologies available in the market [16].

2. Potential of RenewableEnergy

Seybothetal.[16]havereportedspaceconditioningapplicationsinthedifferentbuildingsectors and its benefits from renewable energy are very broad. Although their cost also varies from place to place,almostallrenewabletechnologiesareverymuchcompetitivewithconventionalsystems,ontheir operationalcostanddirectbenefitstotheenvironment.AccordingtotheInternationalEnergyAgency (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 casesmostofthetime,energyefficiencyplaysaveryimportantroleinattractinginvestments.Therole of governments is highlighted to make economic incentives and subsidies on various renewable technologies.Therefore,moreandmorepeoplewillgetattractedtotheresourceanddevelopmentwill take a long jump when demands getboosted.

Laine et al. [18] have published that during the 21st century the global cooling demand will increasesignificantlyduetomanyfactorsandwillcontributetotheadvancementofglobalwarming. Theresidentialcoolingsectorwillbethemajordrivingfactorfortheincreaseindemand.Sachsetal.[19] inferredthatcoolingdemandismainlyinfluencedbyclimaticconditions,geography,populationdensity, andtheselectionofcoolingsystemsareinfluencedbyavailableenergydistributionsystems.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,reducingleakageofrefrigerants,andmakingsaferworkingplaces.Allthesegoalscanonlybe achieved by using a 100% potential of renewable energy sources available on Earth. To achieve these goals,thegeothermalenergyresourceistobereviewedforspaceconditioninginbuildings,asthisis the most important driving factor for an increase in energydemand.

3. GeothermalEnergy

3.1. Role of Geothermal Energy in SpaceConditioning

MolaviandMcDaniel[23]reviewedthebenefitofreplacingtheconventionalHVACsystemswith thegeothermalcentralHVACsystems.Challengesreportedbytheauthorsinusinggeothermalenergy withacentralHVACareexpensivemachinery,extensivesoilandenvironmenttesting,anddifficulties inthedesigningstage.Vibhuteetal.[24]havediscussedthegeothermalHVACsystemandfoundthat aconventionalairconditioningunitutilizesmuchmoreenergythanthegeothermalspaceconditioning 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 conditioningofresidentialhousesorsmallbusinessesinIndiana,USAandconcludedthatgeothermal systems are more efficient in larger installationareas.

3.2. WorldwideScenario

Developedcountrieshavebeengivinggrantstotheresidentialsectortousegeothermal HVACso 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 buildingsby2050and70%by2030.Thiswouldhavecontroloverenergyuseandemission.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 (51,920TJ/year),Turkey(45,892TJ/year),andIceland(26,717TJ/year)accountingforabout65.8%ofthe worldcapacity.GongandWerner[29]reportedananalysisinwhichtheyshowedthegradualshifting of researchers from nuclear energy to geothermal and solarenergy.

Indonesia [30] possesses the world's foremost geothermal potential at 40% of the world's geothermalenergybutonly4.5%isbeingutilizedforgeneratingelectricity.Thestudyconcludesthat thereisahugepotentialatgeothermalsitesinIndonesiatoexploreandextractenergyfromtheground for different applications. Table1shows the installed capacity of geothermal along with key results reported in the literature around the world with specifiedlocations.

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

Investigators	Location	Key Results
Seyboth etal.[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 etal.[31]	Iranand 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.
Demirbas¸[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 etal.[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 etal.[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 etal.[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.

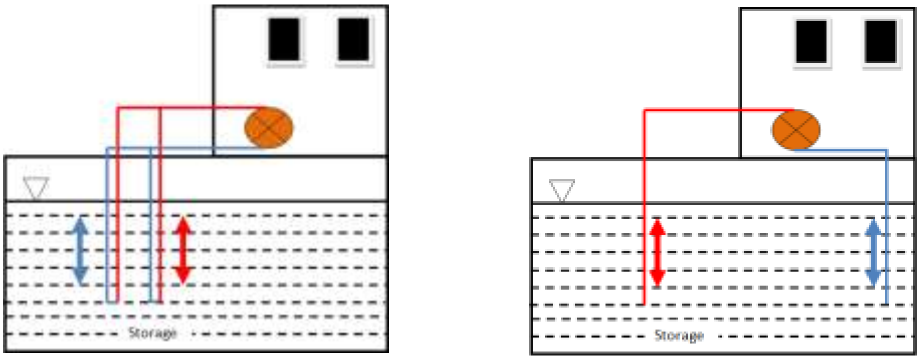
Fernández[40]discussedthreedifferentcountriesusinggeothermalenergyasspaceconditioning intheirsupermarketsandanalyzedthepercentagereductioningreenhousegas(GHG)emissions, aswellasinenergyconsumption:(i)Germanyusedtheshallowgeothermaltechnologysupermarket andrecordedenergyconsumptionreductionupto45%,whereasareductionincarbondioxideemission wasrecordedupto28%;(ii)PortugueseconventionalspaceconditioningsystemswerereplacedbytheGSHPsystemforspaceconditioninganda30%reductionofenergyconsumptionand30%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 carbonemissions.

3.3. IndianScenario

InIndia,utilizationofgeothermalenergyisstillinanimmaturestagewhereonlyafewauthorshave triedtoexplorethegeothermalenergypotentialforspaceconditioning.ShahareandHarinarayana[39] analyzedgeothermalbasedspaceconditioningwiththeheatexchangerbyusingashallowprocessfor coolinginsummerandsolarenergyasthemajorsourceforspaceheatingduringwinter,andvalidated 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 geothermalcooling.

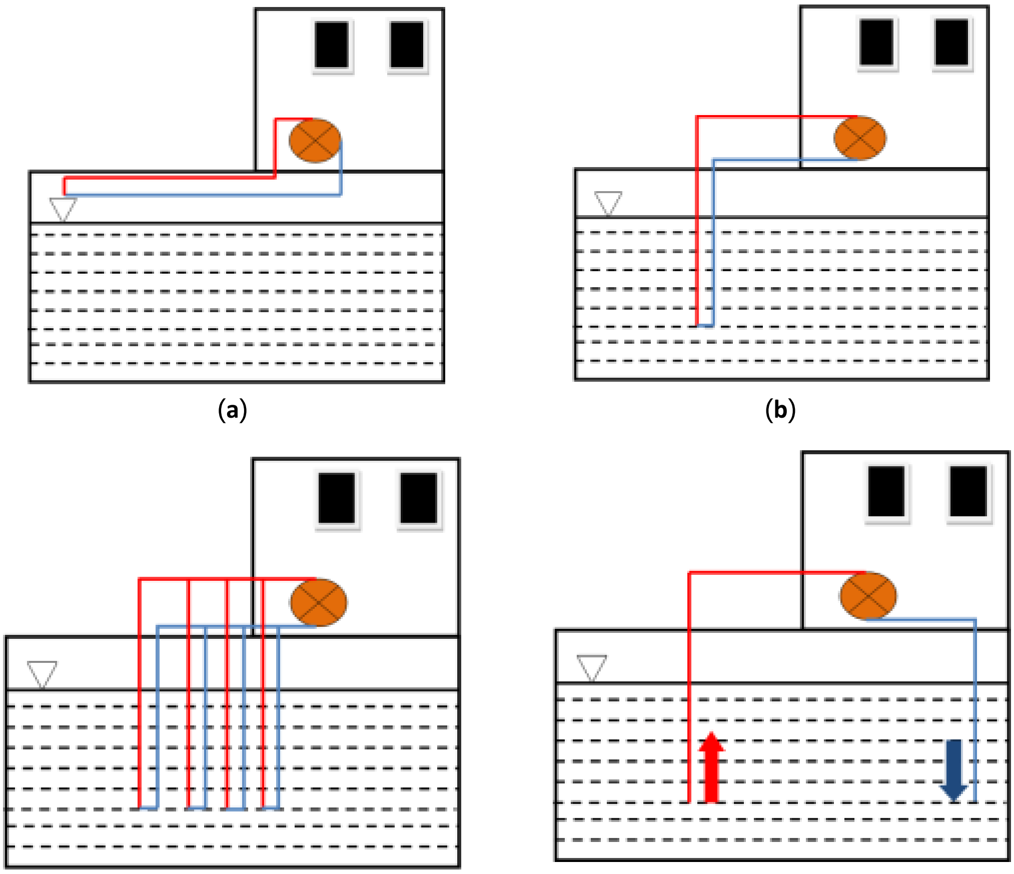
DhepeandKrishna[13]havedonealiteraturereviewongeothermalcoolingandheatingsystems and the advancements in this field. The increasing demand for energy leads to more exploration of renewable energy technologies. Geothermal heating and cooling is the new advancement in the field of HVAC. The analysis of 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 groundtemperatures,aswellastodevelopgenericmodelsfordifferentbuilt-upareabuildingswith quantified performance. Figure4shows how geothermal energy storage takes place. In Figure4a, theboreholethermalenergystorageisshown,whichisusedmostlyforclosedloopapplicationswith multiple borehole heat exchangers. In Figure4b, the aquifer thermal energy storage is shown, which operates aswells.

Figure5shows the direct utilization of geothermal energy in di fferent ways with heat pumps showing an exchange from different exchange mediums. Shallow geothermal systems extract heat energyfromthegroundforsupplyingtothebuildingsandotherpurposes.Itcanbeaclosed-loopor open-loop system, as shown in Figure5. In many regions, cooling with the help of a ground source heatpumpisgainingmoreinterest[42].Mostly,closed-loopsystemsareusedinwhichgroundheatis exchanged with the help of fluid flowing through tubes, boreholes, energy piles, etc. Ground source heat (GSH) pump is shown in Figure5a with a horizontal heat exchanger mainly used for a shallow geothermal(fordepth<5m).InFigure5b,theGSHpumpwithaverticalboreholeheatexchangerfor depthgreaterthan10misshown.InFigure5c,energypilesareshownwithmultipleverticalboreholes installed in the foundation of new buildings. In Figure5d, the open-loop (GWHP) is shown, which utilizes groundwater directly as a heatcarrier.



(a) (b)

Figure 4. Thermal energy storage: (**a**) Borehole thermalenergystorage;(**b**)aquiferthermal energystorage.



(**a**) (**b**) (**c**) (**d**)

Figure5. Useofgeothermalenergy:(**a**)Groundsourceheat(GSH)pump;(**b**)groundsourceheat(GSH) pumpwithboreholeheatexchanger(BHE);(**c**)energypiles;(**d**)groundwaterheatpump(GWHP).

3.3.1. Challenges

The HVAC systems are being used in very large numbers in the building sector with a trend showingasignificantincreaseinthefuture.Therefore,todecreaseenergyconsumptionandminimize theadverseimpactontheenvironment,thecorrectcombinationofbuildingphysics,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 systemscanofferanenergy-efficientperformancealongwithoccupantcomfortbutthechallengeisthe hybridization of suchsystems.

3.3.2. Opportunities in Ladakh,India

AsshowninageothermalpotentialmapofIndia(Figure1),extremelycoldclimateconditionsof Ladakhregionhaveahugegeothermalpotentialtoexploreasanopportunityin India,wheretheuse ofvariousconventionalsourcesforheatingthespaceisdeterioratingpeople'shealth,thetemperature 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-friendlysustainabletechnologiesforheatingofbuildingssuchasgeothermaltoovercome theexistingproblemsanddevelopgenericmodelsfordifferentbuilt-upareabuildingswithpayback and quantifiedguarantees.

4. Study on Ground Source HeatPump

GSHpumpsmayfurtherresolvenumerousenvironmentalissues.Thisexplorationofrenewable resourcehasstartedbackinthe1940sthatcontinuewithmodifications.Table2givesanoverviewofthe researchpapersonGSHpumpsreviewedandanalyzestheadvancementsandcategorizesthemmajorly basedonenergyandCO_2emissionreduction,coefficientofperformance(COP),andenergyefficiency ratio (EER), i.e., the ratio of useful heating and cooling provided to the work required. Since the installationcostishighercomparedtosomeoftheconventionalsystems,therefore,contemplatingthe payback period becomesnecessary.

Figure6showstheprocessesinvolvedinthemachineroomofthegroundsourceheatpumpwith the help of a Carnot cycle: At point A, the evaporator will increase the temperature of the refrigerant withthehelpofabuffertankandthentherefrigerantwillmovetothecompressorandthiscyclewill berepeated;atpointB,thetemperatureandpressureofthecompressedrefrigerant(intheformofgas) ishigh;atpointC,thebrinesolutionwilltaketheenergyfromtherefrigerant;atpointD,therejection ofheattakesplace;atpointE,thetemperatureoftherefrigerantwillbelowerandthepressurewillbe high;atpointF,theexpansionoftherefrigeranttakesplace;atpointG,thetemperatureandpressure oftherefrigerant(intheformofliquid)islower;andpointHisthebuffertan.InFigure6,AHUisthe air handling unit and FCU is the fan coil unit; whereas, Figure7shows the types of heat exchangers usedintheGSHpump. Figure7ashowstheverticalgroundheatexchanger(alsoknownasaborehole) usedforlongerdepths.Figure7bshowsthehorizontalgroundheatexchanger,mostlyusedfordepth less than 1.5 m. With proper arrangements, a combination of the horizontal and vertical system can also be used. Figure7c 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	PayBack (Years)
Nevesetal. [43]	Memphis, Tennessee	Techno-Economic analysis	26%	-	-	-
Olabietal. [44]	France	Hybridsystem	-	-	-	-
Kljajic´etal. [45]	Serbia	ShallowGSHP	30%	-	-	4.9
MaoandChen [46]	China	Experimenton GSHP	-	-	1.56–2.01	-
Lee etal.[47]	Korea	GSHPvs.DH	-	-	-	-
LiuandHong [48]	US	VRFsystemvs. GSHP	-	-	-	-
Zhao etal.[49]	China	GSHPfor roadheating	-	-	1.97–2.22	-
Athreshaetal. [50]	UK	GSHP Openlooped	-	-	2.7–3.9	-
Franzen et al. [51]	Sweden	Conventional vs. Ectogridge othermal	61% 70%	12% 20%	-	-
Momin[52]	Pune	Experiments on GSHP	40–60%	-	3.42–3.61	-
Gao etal.[53]	China	DXGSHPvs. GCHP	26%	40%	6.03–6.25	4.4–5.6
Salem and Hashim [54]	Dubai	GCHPfeasibility	198 millionKWh	-		8
Bu etal.[55]	China	Continuous SWGH	448.49KW	-	3.8	7.17
		Intermittent SWGH	619.12KW	-	4.5	5.16

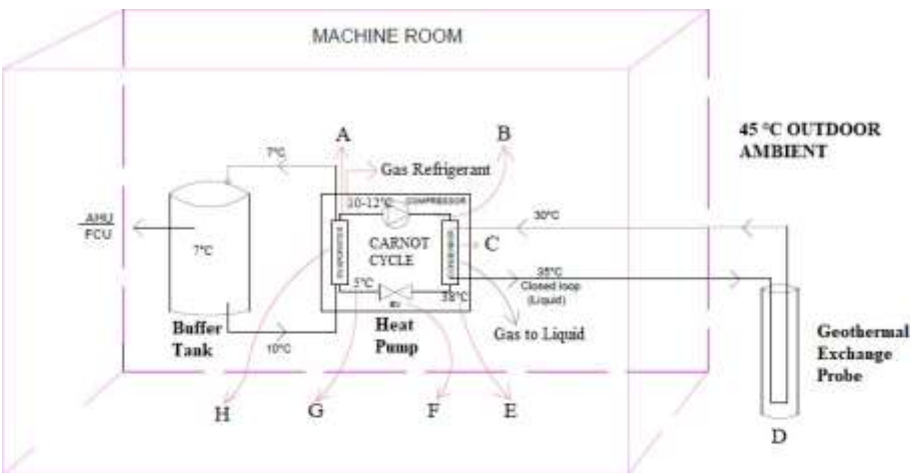


Figure 6. Schematic diagram of the machine room of the ground source heat pump.

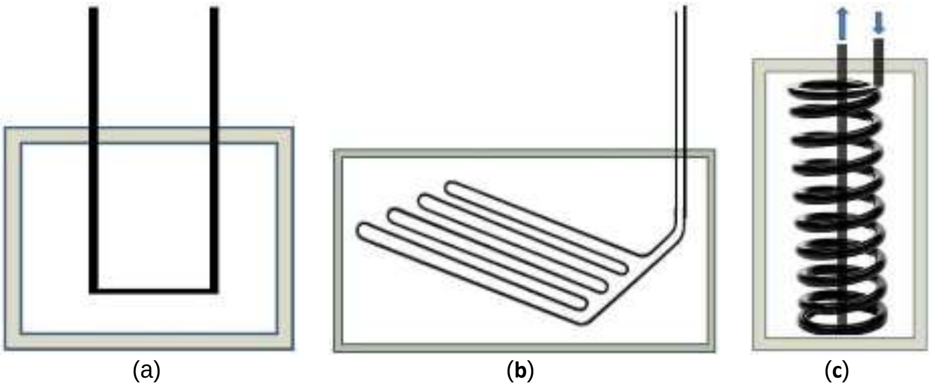


Figure 7. Types of heat exchangers used in GSH pumps. (**a**) Vertical ground heat exchanger (GHE), (b) horizontal GHE, (**c**) spiralGHE.

Table3summarizesthevariousimportantstudiesbasedonaverticalsingleUtypeboreholeused intheGSHpumpandvariousotherparametersusedareshownwhiledesigningtheboreholes.

Table 3. Studies carried out on borehole specifications in GSHpumps.

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 UType	100	-	10
Momin [52]	2013	Vertical closed loop UType	23–150	5	-
Bayer et al. [56]	2014	Vertical loop single UType	78	6	54
Cocchi et al. [57]	2013	Vertical loop single UType	100 each	10	14
Ma et al. [58]	2019	Vertical loop single UType	100 each	4	32
Zhai et al. [59]	2017	Vertical loop single UType	50, 60, 80	-	3 each

Athresha et al. [50] discussed a comparative study of GSH pump with conventional systemsfor thesameheatingdemandofthemodernboilerwithaneﬃciencyof90%andtheGSHpumpsystem that will produce 400% more energy for the same amount of energy consumed by the boiler with a COP ≈3.9.

4.1. NumericalApproach

AnumericalmodelbasedonfiniteelementsthatwasdevelopedbyFarelandBasu[60],showedhowwaterflowinthegroundaﬀectsthetemperatureofsoilsurroundingthegeothermalpile.ThenumericalHVACmodelingsystemforGSHpumps(thermalresponsetestofgroundthermalproperties)andWSHP(Tailakewatertemperaturewasusedinthiscase)foraparticularbuildingmodel located in China. The 3D model of this building is substituted as the input. Theauthors haveanalyzedtheperformanceoftheGSHpumpsystemforvarioustypesofbuildingmodels.Studiesshowedthatthereisanotableincreaseinthegroundtemperatureneartheheatexchangerasaresultofanimbalanceofheatduetothereleaseinsummerandabsorptionduringwinter(thermalplume).

WhenamajorpartoftheenergyshareintheEuropeanUnion(EU)iscoveredbybuildingheatingandcooling,aneedforthereplacementoffossilfuelbyarenewableandsustainablesourceisathigh demand.Theresponsesurfacemethod(RSM),astatisticalapproachhasbeendiscussedbyauthors[61] withthehelpoftheheattransferandenergybalanceequation,mathematicalmodels,EAHE(Earthto airheatexchanger)modelconsideringthreeinfluentialvariablesinthecontextofheatingandcoolingof buildings. Shuetal.[62]investigatedhowthegroundwaterflowforgeothermaldevelopmentisbeing affectedbyboundaryconditionsinhillyareas.FEFLOW,a3Dheatwaterfiniteelementbasedmodel wasdevelopedtostudyhowboundaryconditionsaffectthetemperaturefieldsandhydrodynamicsof aquifers. Table4shows the tools used for modeling and simulation of varioussystems.

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 inBuildings

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.Inthis,alowenthalpygeothermalsystemisusedandanalyzedwiththehelpofgeothermal 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_2emissions.

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 incorporatinggeothermalenergycanbeestimated.Thelifecyclecost(LCC)analysiswasalsodoneto checktheeconomicfeasibilityofinstallingthesystemandinfersthatthesystemcanbeselectedbased onenergyconsumptionandcostsorenergycostreductioneffectrelatedtoageothermalapplication.

TheMiddleEastcountries[54]suchasEgypt,Turkey,Iran,Iraq,SaudiArabia,UAE,Kuwait,etc. with a never-ending vast developmental process requires continuous energy supply for cooling and ventilationandfluctuatingenergyneedsandaccelerateddemandduetoasignificantincreaseinhigh 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 paybackperiod.

Hospitalsareoneofthemajorenergy-consumingbuildings,andusingrenewableenergysources canbeawayaheadtosustainabilityapproach[76].Acasestudyof300beddedhospitalsconsiderably 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 savingalternative.

Adetailedstudyonthemodelingofthermallyinteractivemultipleboreholeswasconducted[61] andtheauthorsinvestigatedthesustainability,environmentalimpact,andoptimizedtheperformance of the system. As thermal anomalies increase due to the unbalanced heat extraction and injection, itcauseslocalcoolingoftheground,whichcanbemitigatedbyadjustingseasonalheatingandcooling workloads.Ramosetal.[77]haveinvestigatedmanyimplementedprojectsoftheGSHpumparound 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 andcooling.

Therefore,fromtheabovestudies,itcanbeinferredthatthereisaneedtocarryoutthestudyon space heating and cooling from GSH pumps and hybridization on the way tonZEBs.

4.3. Comparative Study of GSHPump

Researchers investigated certain boreholes of German cities having depth of 20m, where the groundwatertemperaturereaches13to18°C[79].ThestudyconcludesthatGSHpumpssystemsare efficient, sustainable, and have the potential for space conditioning applications. Table5shows the comparison of the GSH pump with various other systems available in the market. In Table5the GSH pump is compared with two-pipe fan coils, four-pipe fan coils, packaged terminal air conditioners (PTAC)/packagedterminalheatpump(PTHP),andvariableairvolume(VAV)controlsystem.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 othersystems.

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

System	Easeof Design	Ease of Installation	Installation Space	Maintenance Requirements	Maintenance Cost	Operating Costs	Sound Levels	System Life
Two-PipeFan Coils	Low	Low	High	High	High	Med.	Low	Med.
Four-PipeFan 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 HybridSystems

Thestudiesreviewedaboveinferredthatgeothermalenergyisarenewable,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 differenthybridgeothermalsystemsshowedthateachsystemhasitscharacteristics.Thecombination of geothermal energy with other renewable sources is the most preferable hybridization, especially fromanenvironmentalpointofview.Ontheotherhand,itisquiteimportanttomentionthatthe efficiency,COPandplantcapital,andoperatingcostsarenotonlyrelatedtotheenergysourcesused buttherearseveralotherfactorssuchassoilproperties,ambientconditions,drillingcost,materials, equipment, cycle conditions, and heat transfer enhancement of working fluid [80,81]. The use of a renewablesourceofenergywillhelpreducetheozonelayerdepletionandotherpollutionhazardson ourecologicalsystem[82,83].Themajorrequirementsforlowenergybuildingsusinggeothermaland othersourcesofenergyasthesourceforspaceconditioninganddomestichot/coldwaterneedsareto bestandardized.

Figure8shows 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 factorstobeconsideredare—BuildingPhysics,Generationwithrenewablesources,andDistribution. Forcomplyingairtightnessinbuildings,theMVHR(mechanicalventilationwithheatrecovery)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 flowcharttoreducethethermalloadofthebuilding.Thethermalloadwillhelpinanalyzingfurther calculationsforthespaceconditioninginbuildings,asshownintheflowdiagram. Finally,byselecting the suitable methods and technology, ultra-low energy buildings or nearly zero energy buildings (nZEBs) areachieved.

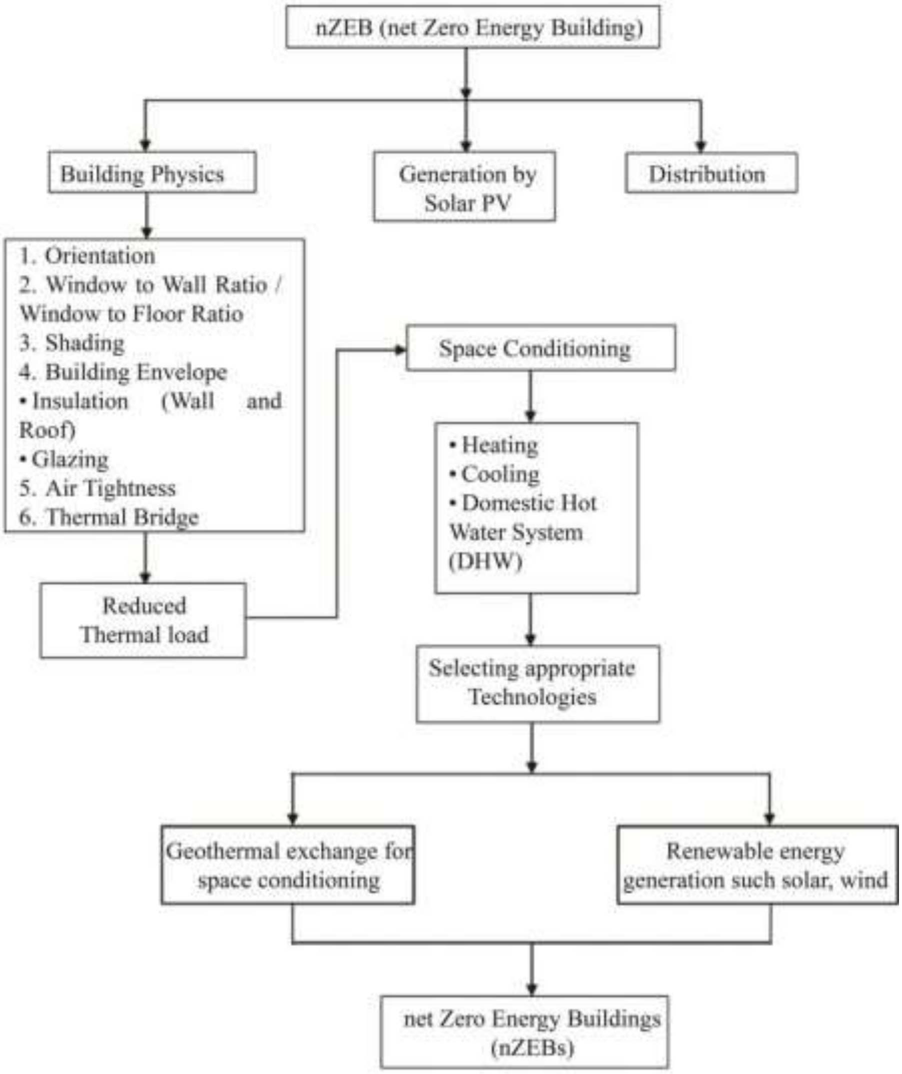


Figure 8. Nearly zero energy buildings (nZEBs) with geothermal hybrid systems.

Inthecontextofcoolingofbuildings,EAHEs(Earthtoairheatexchangers)canalsobeusedfora hot and humid climate with the above technologies. EAHEs are the systems in which air is passed throughthepipe(buriedundertheEarth)withthehelpofablowerandoutletofthepipeisconnected to the building for cooling. Wei et al. [85] investigated that increasing the depth and reducing the diameteroftheEAHEpipewillresultinadecreaseintheoutlettemperatureandmoisturecontentof theair.

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 systemmayhelpinsolvingenergyshortageproblems,particularlyforhighenergyrequirements[86]. Theoptimizationofthesystemparameterscanbedonebyusingsoftware/toolsavailableforassessing 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 energyconsumption.

Figure9shows that the solar PV can be utilized for the GSH pump for solving problems of energyshortage.Therefore,furtherresearchisneededtodevelopvariousspaceconditioninggeneric designsfordifferenttypesofbuildingshavingdifferentbuilt-upareasandtovalidatethesystemunder real-timeconditions.Thesystemscanbeoptimizedformaintainingcomfortparameters.Thepayback period studies are also desirable to establish the life cycle cost of the hybrid systems to establish the superiority of these systems in the longerperiods.

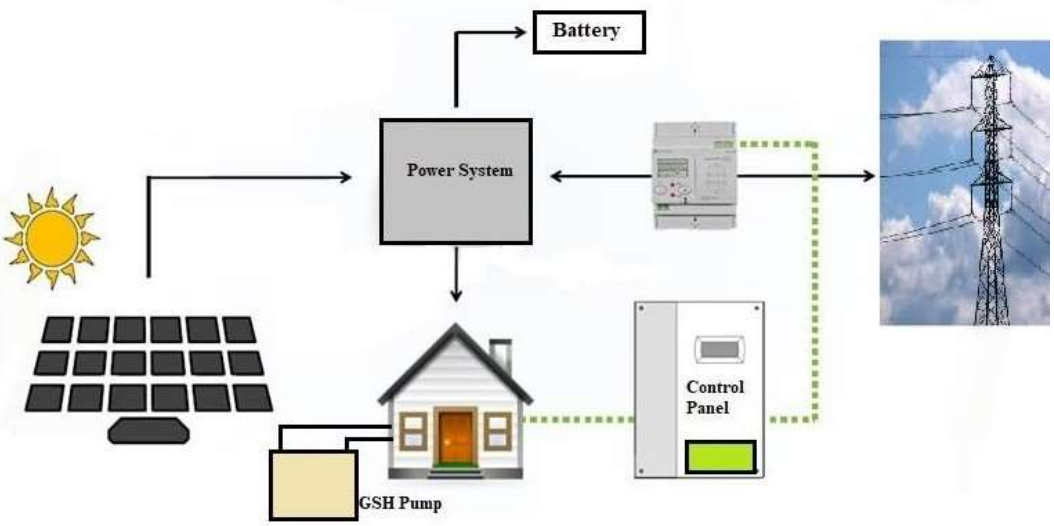


Figure 9. Photovoltaic based GSH pump.

6. Conclusions andRemarks

Thisreviewpaperfocusedonvariouslowenergyconsumingandlowrefrigerantusagesystems, whichcaneffectivelydeliverspaceconditioningcomfortparametersinlinewithSDGgoalsandICAP goals of India. In the process, this will help in reducing the heat urban island (HIU) or usage of ODP refrigerants,therebyreducingtheglobalwarmingpotential(GWP)andeffectivelyaddressingclimate change. This will also be in line with the Paris Climate Change Agreement and Kigali Amendment withtwomainfoci—energyconsumptionandrefrigerantusewithgoals:25–40%reductionincooling energy requirements and 25–30% reduction in refrigerant demand. Therefore, the focus on a hybrid solar-geothermalforspaceconditioningisexplored,whichis65%ofthebuildingenergyconsumption parameter to use as a primary tool in low energy buildings ornZEBs.

MostofthepartsofIndiaarehot,warm,andhumid,therebythiswillnotonlyincreasethecooling degree days but also reduce the peak load demand. The researchers take cognizance of the fact that futurebuildingsmustbecapableofmitigatingthepeakload,especiallythroughbuildingphysics.Ina 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.

Theclimatechangeparametersfocusonthefactsthatlndiawillfigureoutastrategyforcombining 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 buildingphysicsandthestandardscomparedtoworld-classmaterialandknowledgebutthemissing link is low energy, low refrigerant, and low emission space conditioning systems with domestic hot water(DHW)systemsincogeneration.Hence,thenecessityistostudyquicklyandfindouttheGSH 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 conditioningasamajordesignparameter.Therefore,itispertinenttohavetheknow-howandfeature ofGSHpumpsexchangeastheprimaryinterventioninspaceconditioninginthepursuitoflowenergy buildingsornZEBs.Moreover,thiswillhavesizablecontributionsontheeconomybysavingtheKW or MW. The low enthalpy geothermal exchange can be done in any climatic condition, and hence ourfocusisonspaceconditioninganddomestichotwater(DHW).AreassuchasLadakhcanbenefit immensely from the geothermal exchanges and solar generation combinations solving the existing problems of manyyears.

AdetailedreviewontheGSHpumpsystempotentialforspaceconditioninginbuildingsshows 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, concentratedonGSHpumpsystemsandtheirimpactonbuildings.ThisstudyshowsthatGSHpumps 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 theatmosphere.

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