Design and Development of Geothermal Heat Pump System

Session 2019-2023

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DECLARATION

We hereby declare that this project report is based on our original work except for citations and quotation which have been to acknowledged. We also declare that it has not been previously and currently submitted for any degree award at Wah Engineering College or other institutions.

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CERTIFICATION

This is to certify that project entitled “Design and Development of Geothermal Heat Pump System” which is submitted in partial fulfillment of their requirement for the award of degree, Bachelor of Mechanical Engineering is a record of the candidates own work carried out by them under my supervision. The matter embodied in this report is original and has not been submitted for the award of any other degree.

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DEDICATION

We dedicate this project to our families, whose unwavering support and love have been the driving force behind our pursuit of knowledge and academic achievements. Their belief in our abilities and sacrifices made on our behalf have been the pillars of strength throughout our educational journey.

This project is also dedicated to the future generations of aspiring students, researchers, and innovators. May our work serve as an inspiration and contribute to the advancement of knowledge in our field, paving the way for new discoveries and breakthroughs.

May this project be a testament to the collective efforts, determination, and passion of all those involved, and may it leave a lasting impact on our academic and professional journeys.

ACKNOWLEDGEMENT

We would like to express our heartfelt gratitude to **Engr. Shahid Iqbal**, our dedicated supervisor, for his invaluable guidance, support, and encouragement throughout the development of our Final Year Project Report. His vast knowledge, expertise, and commitment to our success have been instrumental in shaping our project and ensuring its completion.

We extend our deepest appreciation to **Dr, Ammar Ul Hassan Khawaja** for his valuable insights and assistance in this report. His extensive experience and expertise have significantly enriched our understanding of the subject matter and added depth to our work.

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Lastly, we express our sincere gratitude to our friends and colleagues who havesupportedusthroughouttheproject.Theirencouragement,feedback,andcollaboration have been invaluable in shaping our ideas and refining our work.

We are indebted to all those mentioned above for their contributions, and we acknowledge their invaluable role in the successful completion of our Final Year Project Report.

ABSTRACT

Geothermal Heat Pump Systems are an innovative technology that utilize the constant temperature of the earth to heat and cool buildings. These systems work by circulating a fluid through underground pipes, which either absorb heat from earth or heat release into it, depending on the season. Geothermal Heat Pump Systems offer several advantages over traditional HVAC systems, including higher energy efficiency, lower operating costs, and reduced environmental impact. They can be used in a variety of applications, from residential homes to large commercial buildings. Ground source heat pumps are known as a high-efficiency renewable energy heating and cooling system. The ground heat exchanger (GHE) plays an important role to achieve a higher coefficient of performance in GSHP system. GHE technology has known very well and a significant research has been done over the last decades.

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Chapter # 01

1. Introduction

A. Geothermal Heat Pump System

A geothermal heat pump system, also referred to as a ground-source heat pump, is an innovative and highly efficient technology that harnesses the earth's natural heat to provide heating, cooling, and hot water for both residential and commercial buildings. By tapping into the renewable and constant energy stored within the ground, this system offers a sustainable and environmentally friendly solution for controlling indoor temperatures.

The geothermal heat pump system comprises three key components: the heat pump unit, the ground loop, and the distribution system. The heat pump unit facilitates the transfer of heat between the building and the ground, while the ground loop acts as the conduit for heat exchange. The distribution system is responsible for circulating the heated or cooled air or water throughout the building.

The central component of a geothermal heat pump system is the heat pump unit, which includes a compressor, a heat exchanger, refrigerant, and controls. The compressor elevates the refrigerant's temperature, while the heat exchanger facilitates heat transfer between the refrigerant and the building. The controls manage system operations to optimize energy efficiency and maintain desired indoor temperatures.

The ground loop, an enclosed system of pipes buried near the building, is crucial to the geothermal heat pump setup. Two common configurations exist: horizontal and vertical. Horizontal loops are laid in trenches, while vertical loops are installed in boreholes. These loops are filled with a heat transfer fluid, typically a mixture of water and antifreeze, which absorbs or releases heat from the ground.

The ground loop acts as a heat exchanger, utilizing the consistent underground temperatures to exchange heat with the building. In winter, the fluid absorbs heat from the ground, conveying it to the heat pump unit, where it warms the air or water for space heating. In summer, the process is reversed, as the heat pump unit extracts heat from the building and transfers it to the ground, providing cooling.

For distributing the conditioned air or water, the system employs various methods. Forced air or radiant floor heating can be used for space heating and cooling. Additionally, the system can be integrated with a water heater or a dedicated heat exchanger for hot water production.

A geothermal heat pump system offers several advantages. It is an environmentally friendly technology, significantly reducing greenhouse gas emissions compared to conventional heating and cooling systems. By harnessing the earth's natural energy, it operates without relying on fossil fuels, making it both renewable and sustainable.

Geothermal heat pump systems exhibit remarkable energy efficiency, surpassing conventional HVAC systems in terms of energy savings. These systems can achieve heating and cooling efficiencies of over 300%, meaning they generate more energy than they consume. Consequently, building owners can enjoy reduced utility bills and long-term cost savings.

Durability and longevity are additional advantages of geothermal heat pump systems. The underground components, including the ground loops, are designed to endure for decades, often backed by warranties ranging from 25 to 50 years. The heat pump unit typically functions for 15 to 25 years. With appropriate maintenance, the system can deliver reliable and efficient heating and cooling for an extended period.

Flexibility in design is a notable feature of geothermal heat pump systems. They can be tailored to suit various building sizes and specific requirements, making them suitable for both new constructions and retrofitting in existing buildings. Moreover, these systems operate relatively quietly compared to traditional HVAC systems, contributing to a more comfortable and tranquil indoor environment.

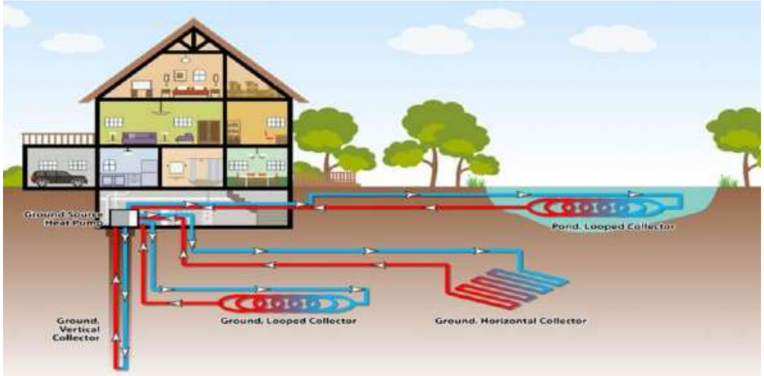


Figure 1: Geothermal Heat Pump System

i.Advantages

a.Renewable and Sustainable

Geothermal heat pump systems use the naturally occurring heat of the ground, which is a sustainable and renewable energy source. Compared to conventional heating and cooling systems, they dramatically lower greenhouse gas emissions and do not rely on fossil fuels. Geothermal energy systems help create a cleaner, greener world by using the steady, renewable energy that is already present in the earth.

b.Consistent Performance

Unlike air-source heat pumps, geothermal heat pump systems are not impacted by changes in outside temperature. The ground's generally constant temperature makes it a reliable heat source for winter heating and a heat sink for summer cooling. Due to its steadiness, the system performs consistently and dependably no matter the weather outside

c.Long Lifespan

Geothermal heat pump systems are designed to be durable and long-lasting. The underground components, such as the ground loops, have a lifespan of several decades, often with warranties of 25 to 50 years. The heat pump unit typically lasts 15 to 25 years. With proper maintenance, the system can provide reliable and efficient heating and cooling for a long time, reducing the need for frequent replacements.

d.Design Flexibility

Geothermal heat pump systems offer design flexibility, making them suitable for various building sizes and requirements. They can be installed in both new constructions and retrofitted into existing buildings. The ground loop configurations can be customized to fit the available space, whether through horizontal loops in trenches or vertical loops in boreholes. This flexibility allows for efficient utilization of the available land area.

e.Quiet Operation

Geothermal heat pump systems operate quietly compared to traditional HVAC systems. The absence of noisy outdoor units or compressors contributes to a more peaceful and comfortable indoor environment. This feature is particularly beneficial in residential areas, offices, or other noise-sensitive environments.

f. Reduced Maintenance

Geothermal heat pump systems have relatively low maintenance requirements. The underground components are protected from external weather conditions, reducing the likelihood of wear and tear. The absence of outdoor units also minimizes exposure to debris, damage, and vandalism. Regular maintenance typically involves checking the fluid levels, inspecting the heat exchanger, and ensuring proper system operation.

g.Potential Financial Incentives

Depending on your location, there may be financial incentives, tax credits, or rebates available for installing a geothermal heat pump system. These incentives aim to promote the adoption of renewable energy technologies and can help offset the initial installation costs. It is advisable to research local incentives and consult with professionals to determine eligibility and potential savings.

Overall, geothermal heat pump systems provide efficient, sustainable, and long-term solutions for heating, cooling, and hot water needs. Their high energy efficiency, reliability, and environmental benefits make them an attractive choice for residential, commercial, and institutional buildings.

ii.Disadvantages

While geothermal heat pump systems offer many advantages, there are also some disadvantages to consider. These include:

High Initial Installation Cost

The upfront cost of installing a geothermal heat pump system is generally higher than that of traditional heating and cooling systems. The excavation and installation of the ground loop can be costly, especially if there are site-specific challenges such as rocky terrain or limited space. However, it's important to note that the long-term energy savings and potential incentives or tax credits can help offset the initial investment.

Site Suitability Requirements

Geothermal heat pump systems require suitable land or space for the installation of the ground loop. The feasibility of the system depends on factors such as soil composition, available land area, and access for drilling equipment. In some cases, the site may not be suitable for installing a ground loop, which can limit the feasibility of the system.

Design and Sizing Complexity

Designing and sizing a geothermal heat pump system requires expertise and careful consideration. Factors such as the heating and cooling load calculations, ground loop configuration, and equipment selection must be accurately determined to ensure optimal system performance. Improper design or sizing can lead to reduced efficiency, inadequate heating or cooling, or increased operating costs.

Potential Ground Loop Installation Challenges

The installation of the ground loop can pose challenges, especially in existing buildings or urban areas with limited space. Horizontal ground loops require extensive trenching, which can disrupt landscaping or require significant excavation. Vertical ground loops involve drilling boreholes, which may be constrained by factors such as underground utilities, rock formations, or building restrictions.

Maintenance and Repair Complexity

While geothermal heat pump systems have relatively low maintenance requirements, any maintenance or repairs related to the ground loop can be complex and costly. If a leak occurs in the ground loop, locating and repairing it may involve excavation or drilling. Additionally, specialized equipment and knowledge are required for any repairs or modifications to the ground loop.

Potential System Freezing

In cold climates, there is a slight risk of the heat transfer fluid freezing within the ground loop if the system is not properly designed or protected. However,this risk can be mitigated by utilizing a proper concentration of antifreeze in the heat transfer fluid and ensuring the ground loop is buried at an appropriate depth below the frost line.

System Disruption during Ground Loop Repairs

If repairs or modifications to the ground loop are required, the system may need to be shut down temporarily, resulting in a loss of heating or cooling until the repairs are completed. This can cause inconvenience for building occupants, particularly during extreme weather conditions.

Limited Availability of Qualified Installers

Geothermal heat pump systems require specialized knowledge and expertise for proper installation and maintenance. The availability of qualified and experienced installers may be limited in some areas, which can potentially lead to longer wait times or higher costs for installation and repairs.

Despite these disadvantages, many building owners find that the long-term energy savings, environmental benefits, and comfort provided by geothermal heat pump systems outweigh the initial investment and associated challenges. It is important to carefully evaluate these factors and consult with professionals to determine the suitability and feasibility of a geothermal heat pump system for a specific building or location

B. Historical Background

The history of geothermal heat pump systems dates back several centuries, with the concept of utilizing geothermal energy f or heating and cooling purposes originating from ancient civilizations. Here is a historical background of geothermal heat pump systems

i.Ancient Use of Geothermal Energy

Humans have been aware of the Earth's geothermal energy for thousands of years. Ancient civilizations, such as the Romans, Greeks, and Chinese, utilized natural hot springs for bathing and heating purposes. They understood the concept of harnessing the Earth's heat for their daily needs.

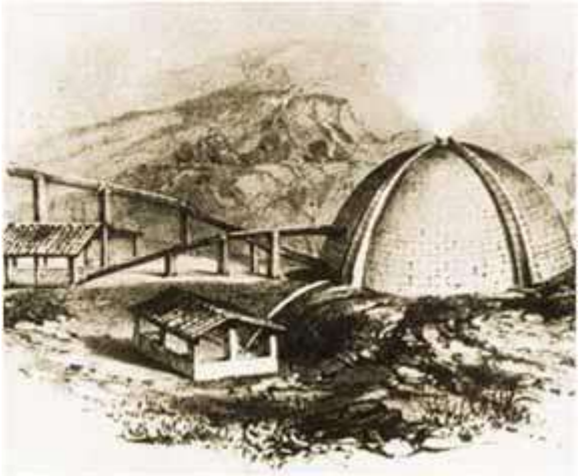


Figure 2: Ancient Use of Geothermal Energy

ii. Early Experimentations

The development of modern geothermal heat pump systems can be traced back to the 19th century. In the 1850s, Lord Kelvin, a Scottish physicist, conducted experiments with heat pumps that utilized water and ammonia as refrigerants. These early systems laid the foundation for later advancements.

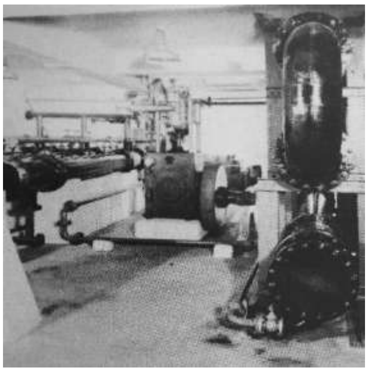


Figure 3: Early Experimentations

iii. Ground-Source Heat Pumps

The first practical application of a ground-source heat pump, which is a type of geothermal heat pump system, occurred in the late 1940s. Robert C. Webber, an American, developed a system that used the constant temperature of the Earth as a heat source and sink. This innovation marked a significant milestone in the development of geothermal heat pump technology.

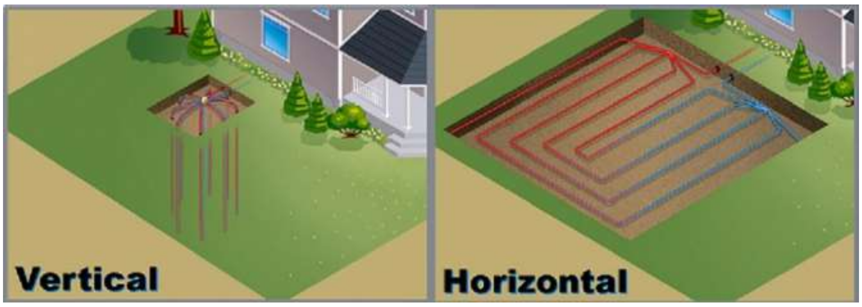


Figure 4: Ground-Source Heat Pumps

C. Problem Statement

i. The adoption of environmentally friendly energy sources in greenhouse cultivation is rapidly increasing due to environmental concerns, the rising costs of fossil fuels, the market's demand for cost-effective greenhouse production, and the necessity of reducing air pollution.

ii. Geothermal Heat Pumps are utilized for the purpose of mitigating air pollution, meeting market demands, and safeguarding the environment.

D. Objective

i. To design the Ground heat exchange loop

An essential part of a geothermal heat pump system is a ground heat exchange loop, commonly referred to as a ground loop. Between the soil and the heat pump, it acts as a conduit for heat transmission. Through a closed-loop network of subterranean pipes, the ground loop circulates a fluid, often a combination of water and antifreeze.Ground heat exchange loops often come in either a horizontal or vertical configuration.

Horizontal Loop

In this configuration, the pipes are buried in trenches that are typically 4 to 6 feet deep. The length of the trenches depends on the heating and cooling load requirements of the building and the soil's thermal properties. The pipes are laid in a coil or a series of loops, and they are spaced several feet apart. This type of loop is suitable when sufficient land area is available.

Vertical Loop

A vertical loop is used when there is limited space available horizontally. In this design, boreholes are drilled vertically into the ground, typically between 100 and 400 feet deep. High-density polyethylene (HDPE) pipes with U-bends are inserted into the boreholes and connected to form a closed loop. The number and depth of the boreholes depend on factors such as the building's size, heating and cooling needs, and the geological conditions of the site.

ii. To design the heat pump for the rise of temperature

Designing a geothermal heat pump system involves several components, including the heat pump itself. Here are the key considerations and components involved in designing the heat pump for a geothermal heat pump system:

a.Heat Pump Selection

Choose a heat pump specifically designed for geothermal applications. Consider factors such as heating and cooling capacity, energy efficiency, and compatibility with the ground heat exchange loop.

b.Heat Pump Sizing

Determine the heating and cooling load requirements of the building to appropriately size the heat pump. Factors such as building size, insulation levels, climate conditions, and desired indoor temperatures influence the sizing calculations.

c.Heat Pump Configuration

Geothermal heat pumps are available in several configurations, including water-to-air, water-to-water, and water-to-refrigerant. Select the configuration based on the desired application (e.g., space heating, radiant floor heating, domestic hot water) and system design requirements.

d.Ground Heat Exchange Loop Integration

The heat pump is connected to the ground heat exchange loop, which consists of the buried pipes. Ensure proper integration of the loop with the heat pump, including the connections, flow rates, and controls.

e.Heat Exchangers

Geothermal heat pumps have internal heat exchangers that facilitate the transfer of heat between the refrigerant and the fluid circulating in the ground loop. These heat exchangers are designed to optimize heat transfer efficiency. Controls and Sensors

f. Backup Heating System

Consider integrating a backup heating system, such as an electric resistance heater or a fossil fuel-based heating system, to provide supplemental heat during extreme weather conditions or in case of heat pump failure.

g.Distribution System

Design the distribution system based on the specific application, whether it's forced-air ductwork, radiant floor heating, or a combination of both. Ensure proper sizing and distribution to achieve optimal comfort and efficiency.

h. Maintenance Access

Provide adequate access for maintenance and service of the heat pump and associated components. This includes considering the placement of the heat pump, piping, and electrical connections.

It's important to note that designing a geothermal heat pump system, including the heat pump itself, often requires the expertise of HVAC professionals or engineers with experience in geothermal systems. They can conduct detailed load calculations, perform site assessments, and provide specific recommendations for equipment selection and system design to ensure optimal performance and efficiency.

iii. To design the distribution system above the ground in a room

When designing the distribution system for a room in a geothermal heat pump system, there are a few key considerations to keep in mind. Here's a general outline of the process:

a.Determine the Heating/Cooling Needs

Calculate the heating and cooling load requirements for the room. Factors such as room size, insulation levels, number of occupants, and desired temperature differentials will influence the design.

b.Choose Distribution Method

Select the appropriate distribution method based on the specific requirements of the room. Common options include forced-air ductwork, radiant floor heating, or a combination of both.

c. Forced-Air Ductwork

- **Duct Sizing**

Calculate the required duct sizes to deliver the necessary airflow for heating and cooling. Consider factors like the distance between the heat pump and the room, friction losses, and static pressure requirements.

- **Duct Layout**

Design the duct layout to ensure balanced airflow to each room. This may involve sizing and positioning supply and return ducts appropriately.

- **Register and Grille Placement**

Determine the optimal locations for supply registers and return grilles to achieve efficient air distribution and return.

d. Radiant Floor Heating

- **Pipe Sizing**

Calculate the appropriate pipe size to deliver the required heat output for the room. Factors such as floor construction, insulation, and desired surface temperature influence the pipe sizing.

- **Pipe Layout**

Design the pipe layout in the floor, considering spacing, loop lengths, and the number of loops. Ensure even distribution of heat across the floor surface.

- **Control Zones**

Divide the room into control zones if desired, allowing for independent temperature control in different areas.

e. Combination System

- **Determine Zoning**

Decide which areas of the room will be served by forced-air ductwork and which areas will utilize radiant floor heating. This may involve dividing the room into zones based on heating and cooling needs.

- **Design Ductwork and Pipe Layouts**

Design the ductwork and pipe layouts separately for each distribution method, following the guidelines mentioned earlier.

f. Controls and Thermostats

Install thermostats or control systems to regulate the heating and cooling in the room. This may involve zone controls for different areas or independent control of the forced-air and radiant floor systems.

g.Insulation

Ensure proper insulation of ductwork (if applicable) and radiant floor systems to minimize heat loss and maximize efficiency.

h. Air Vents and Radiant Floor Diffusers

Install supply air vents or radiant floor diffusers in suitable locations to distribute conditioned air or heat evenly throughout the room.

i. Access and Maintenance

Provide appropriate access panels or openings for inspection, cleaning, and maintenance of the distribution system components.

Remember, the specific design details and requirements may vary based on the room's characteristics, the chosen distribution method, and local building codes. It is advisable to consult with HVAC professionals or engineers experienced in geothermal heat pump systems to ensure an efficient and effective distribution system design.

iv. To Save Energy

Comparing geothermal heat pump systems to traditional heating and cooling systems, the former are already quite energy-efficient. There are, however, a number of actions you can do to further reduce your energy usage and raise the general effectiveness of your geothermal heat pump system.Here are some energy-saving tips:

a.Optimize System Sizing

Ensure that your geothermal heat pump system is appropriately sized for your heating and cooling needs. Oversized or undersized systems can lead to reduced efficiency and increased energy consumption. Consult with a qualified HVAC professional to perform load calculations and select the right-sized system for your home.

b.Programmable Thermostat

Install a programmable or smart thermostat to optimize temperature settings based on your daily schedule. Set energy-saving setbacks during periods when the home is unoccupied or during sleeping hours. This can significantly reduce energy usage without sacrificing comfort.

c.Regular Maintenance

Schedule regular maintenance for your geothermal heat pump system. This includes checking and cleaning air filters, inspecting ductwork, and ensuring proper refrigerant levels. Well-maintained systems operate more efficiently and consume less energy.

d.Airflow Optimization

Ensure proper airflow throughout the distribution system. Clean or replace air filters regularly to prevent clogging and restriction of airflow. Maintain clear and unobstructed supply and return air vents. Proper airflow promotes efficient operation and reduces energy consumption.

e.Insulation and Air Sealing

Improve insulation levels in your home to minimize heat loss during the heating season and heat gain during the cooling season. Insulate walls, attics, and crawl spaces to reduce energy transfer. Additionally, seal any air leaks around windows, doors, and ductwork to prevent drafts and maintain temperature control.

f. Zoning System

Consider implementing a zoning system that allows you to heat or cool specific areas of your home independently. This enables you to customize comfort levels and avoid wasting energy in unoccupied or rarely used spaces.

g. Utilize Natural Ventilation

Take advantage of natural ventilation by opening windows and using ceiling fans during mild weather conditions. This allows fresh air circulation and reduces the need for mechanical cooling or heating.

h. Efficient Water Heating

If your geothermal heat pump system also provides hot water, consider using a heat pump water heater or integrating it with a separate energy-efficient water heating system. These technologies use significantly less energy compared to traditional water heaters.

i. Renewable Energy Integration

If feasible, consider integrating your geothermal heat pump system with a renewable energy source, such as solar panels. Generating clean electricity on-site can further reduce your reliance on the grid and decrease your environmental footprint.

j. Education and Awareness

Stay informed about energy-saving practices and technologies. Keep up to date with the latest advancements in geothermal heat pump systems and energy-efficient solutions to make informed decisions and maximize energy savings.

By implementing these energy-saving measures and adopting good practices, you can optimize the efficiency of your geothermal heat pump system, reduce energy consumption, and lower your utility bills while enjoying a comfortable indoor environment.

Chapter # 02

1. Literature Review

Sr. No.	Research Papers	Author	Summary
1.	Geothermal heat pump systems: Status review and comparison with other heating options [1]	Stuart J. Self, Bale V. Reddy, Marc A. Rosen	Geothermal heat pumps are becoming increasingly popular in response to growing energy needs and concerns over pollution emissions. These systems provide economic benefits during periods of low electricity prices and exhibit the lowest emissions when powered by low-emission energy sources.
2.	Modeling and performance evaluation of ground source (geothermal) heat pump systems [2]	Onder Ozgener, Arif Hepbasli	In this study, an examination is conducted on the energetic and exergetic modeling of solar-assisted vertical and horizontal ground-source heat pump (GSHP) systems. The objective is to evaluate their performance by employing energy and exergy analysis methods. The findings demonstrate that these systems exhibit notable exergy efficiency and hold significant potential in terms of design, simulation, and testing, offering valuable insights.
3.	Techno-economic assessment of the horizontal geothermal heat pump systems: A comprehensive review [3]	Yuanlong Cui, Jie Zhu, Ssennoga Twaha, Junze Chu, Hongyu Bai, Kuo Huang, Xiangjie Chen, Stamatis Zoras, Zohreh Soleimani	This paper discusses horizontal geothermal heat pump systems, focusing on cost-effective approaches and analyzing ground heat exchangers. It discusses advantages and disadvantages, discusses economic evaluation methods, and suggests future research.
4.	Effect of borehole array geometry and thermal interferences on geothermal heat pump system [4]	Tomislav Kurevija, Domagoj Vulin, Vedrana Krapec	In geothermal heat pump systems, an effective borehole heat exchanger is essential to minimize long-term temperature imbalances caused by factors like thermal interferences and the geometry of the borehole array. Analytical computer programs utilize g-functions to simulate variations in the temperature of the fluid in the ground loop. This research paper presents a demonstration of how the spacing between adjacent boreholes and thermal interferences impact the necessary borehole length for efficient heat transfer. By examining these factors, the study provides insights into optimizing the design and performance of borehole heat exchangers in geothermal heat pump systems.

5.	A review of methods to evaluate borehole thermal resistances in geothermal heat-pump systems [5]	Louis Lamarche, Stanislaw Kajl, Benoit Beauchamp	In the design of ground-source heat pumps, careful consideration is given to thermal borehole resistance and interference resistance. To evaluate and compare different approaches, this research paper examines empirical and experimental methods. The goal is to identify effective practices for heat exchanger design. By analyzing and comparing these methods, the study provides valuable insights and recommendations for optimizing the design of ground-source heat pump systems.
6.	Sustainability aspects of geothermal heat pump operation, with experience from Switzerland [6]	Ladislaus Rybacha, Walter J. Eugster	Geothermal heat pumps utilize shallow geothermal resources, with reliable long-term operation and proper design ensuring sustainability.
7.	Efficiency of Vertical Geothermal Heat Exchangers in the Ground Source Heat Pump System [7]	Heyi Zeng, Nairen Diao, Zhaohong Fang	The development of a quasi-three-dimensional model for vertical ground heat exchangers enhances our comprehension of heat transfer mechanisms. This model enables us to define borehole efficiency and accurately determine the inlet and outlet temperatures. By utilizing this model, we gain a deeper understanding of the complex heat transfer processes involved in vertical ground heat exchangers. This research contributes to advancing our knowledge and optimizing the performance of such systems.
8.	Criteria for use of groundwater as renewable energy source in geothermal heat pump systems for building heating/cooling purposes [8]	Dejan Milenic´, Petar Vasiljevic´, Ana Vranjes	Environmental protection measures involve renewable energy sources, with cities in Europe focusing on sustainable energy development. Geothermal resources, particularly subgeothermal groundwater, provide 6600 MWt of heat energy, with a growth trend of 50 MWt annually. Serbia's energy reconstruction of existing flats could significantly reduce energy consumption through subgeothermal energy and heat pumps.
9.	A comparative study on exergetic assessment of two ground-source (geothermal) heat pump systems for residential applications [9]	Ebru Kavak Akpinar, Arif Hepbasli	In this study, the exergetic performance of two ground-source heat pump (GSHP) systems in Turkey is evaluated, with specific emphasis on low-temperature and vertical ground heat exchanger systems. The research applies four balance equations to assess the exergy efficiency values and identify areas for potential improvements. Furthermore, the study explores the potential applications of these systems for sustainable development, considering their exergetic performance and environmental impact.

10.	Environmental analysis of geothermal heat pump and LPG greenhouse heating systems [10]	Giovanni Russo, Alexandros S. Anifantis, Giuseppe Verdiani, Giacomo Scarascia Mugnozza	The demand for environmentally-friendly energy sources in greenhouse cultivations is on the rise, driven by both environmental concerns and market demand. This research paper presents a comparison between the efficiency of a photovoltaic-geothermal heat pump (PV-GHP) integrated system and conventional hot air generators. The findings reveal that the GHP system achieves a significant reduction of carbon emissions by approximately 50%. Moreover, the study calculates the payback time for the PV-GHP system to be 1 year and 2.25 years, making it a financially viable and environmentally sustainable option.

A. Growth and Refinements

In the following decades, geothermal heat pump systems underwent further refinements and improvements. Engineers and scientists worked on enhancing the efficiency and performance of the systems, making them more reliable and cost-effective.

B. Ground-Source Heat Pump Advancements

The establishment of the International Ground Source Heat Pump Association (IGSHPA) took place in the United States in 1987. This organization has been instrumental in advancing the adoption of geothermal heat pump systems through its focus on research, education, and the development of industry standards. Over time, IGSHPA has extended its influence beyond national borders and now operates on an international scale.

C. Environmental Benefits

Geothermal heat pump systems have garnered significant interest for their environmental advantages. These systems are recognized as clean and sustainable energy solutions because they harness the natural heat stored in the Earth, eliminating the need to burn fossil fuels. As a result, they contribute to the reduction of greenhouse gas emissions and decrease reliance on non-renewable energy sources.

D. Government Support and Adoption

With growing concerns about climate change and energy efficiency, governments around the world started promoting geothermal heat pump systems through incentives and subsidies. This support has led to increased adoption in residential, commercial, and industrial buildings.

E. Ongoing Advancements

The field of geothermal heat pump technology is constantly advancing, with ongoing research and development endeavors aimed at enhancing system efficiency. This includes exploring deeper geothermal resources and finding ways to optimize the integration of geothermal systems with other renewable energy sources, such as solar and wind power.

In the present day, geothermal heat pump systems are widely acknowledged as dependable and sustainable solutions for heating and cooling buildings. They have gained significant traction across various sectors and are poised to play a pivotal role in the global shift towards a greener and more energy-efficient future.

F. Geo-exchange Development

In the 1970s, the term "geo-exchange" was coined by the American engineer Charles Keeling. Geo-exchange refers to the use of the Earth's stable temperature for heating and cooling buildings. This term helped differentiate geothermal heat pump systems from traditional geothermal power plants that generate electricity from underground steam.

G. International Development

Geothermal heat pump systems gained traction globally in the 1980s and 1990s. Countries such as Sweden, Switzerland, and Germany became early adopters of the technology, driven by their commitment to renewable energy and energy independence. These countries pioneered the use of geothermal heat pumps in residential and commercial applications.

H. Geothermal Heat Pump Association

The establishment of the International Ground Source Heat Pump Association (IGSHPA) dates back to 1987 in the United States. This organization has played a crucial role in advancing the adoption of geothermal heat pump systems through its dedication to research, education, and the development of industry standards. Over time, IGSHPA has expanded its influence and now operates on an international scale.

I. Technological Advances

Over the years, technological advancements have further improved geothermal heat pump systems. Innovations such as variable speed compressors, advanced heat exchanger designs, and smart controls have increased system efficiency, performance, and user comfort.

J. Large-Scale Applications

Geothermal heat pump systems are not limited to small-scale residential or commercial applications. They have also been successfully employed in larger installations. For example, some universities, hospitals, and industrial facilities utilize geothermal heat pumps for space conditioning and hot water production.

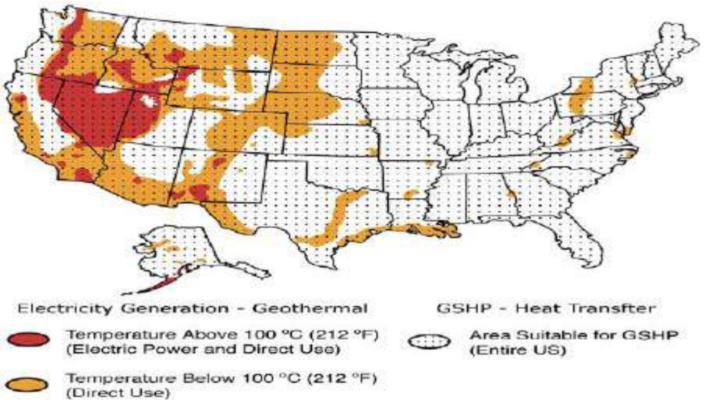


Figure 5: Large-Scale Applications

K. Deep Geothermal Systems

While conventional geothermal heat pump systems utilize shallow ground

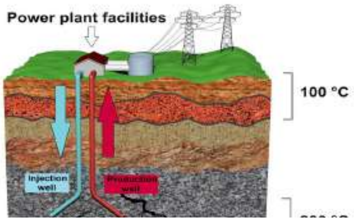


Figure 6: Deep Geothermal Systems

temperatures, advancements have been made in exploring deeper geothermal resources. Deep geothermal systems, also known as ground source heat pumps (GSHPs) or deep borehole heat exchangers, can tap into deeper geological layers to extract heat for heating and cooling.

L. Integration with Renewable Energy

Geothermal heat pump systems are often integrated with other renewable energy technologies. For instance, coupling geothermal heat pumps with solar panels or wind turbines allows for a hybrid system that maximizes energy efficiency and reduces overall environmental impact.

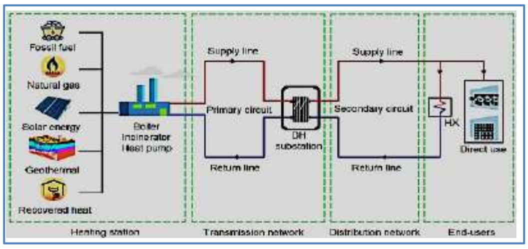
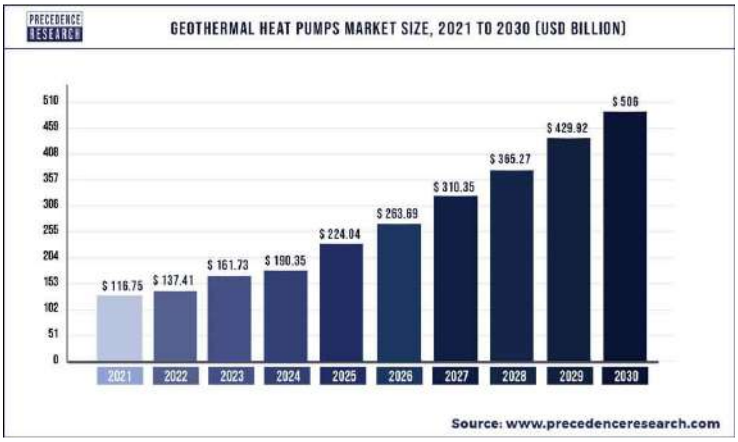


Figure 7: Integration with Renewable Energy

M. Growing Market and Recognition

The market for geothermal heat pump systems has been steadily expanding. Increasing environmental consciousness, stricter energy regulations, and the desire for energy independence have contributed to their growing popularity. Geothermal heat pumps have received recognition from organizations and certifications, further establishing their credibility and viability.



Source: www.precedenceresearch.com

Figure 8: Growing Market and Recognition

N. Future Outlook

Geothermal heat pump systems continue to evolve and offer promising solutions for sustainable heating and cooling. Ongoing research focuses on improving system performance, exploring advanced drilling techniques, and developing new materials for heat exchangers. The integration of geothermal systems with smart grid technologies and energy storage is also an area of active exploration.

As the world seeks more environmentally friendly and energy-efficient solutions, geothermal heat pump systems are poised to play a crucial role in the transition to a sustainable energy future.

The heat pump market is estimated to grow from USD 53.2 billion in 2021 to USD 83.5 billion by 2026, at a CAGR of 9.5%.

Asia Pacific is expected to be the largest market for heat pumps owing to the growing urbanization and rising industrial activities.

The heat pump market is expected to witness healthy growth during the review period due to their growing adoption to reduce carbon footprint, supported by the lucrative government policies.

The integration of Internet of Things (IoT) with heat pumps is expected to offer lucrative opportunities for the market players in the next 5 years.

COVID-19 has adversely affected the growth of the heating, ventilation, and air conditioning market globally, which has consequently hampered the demand for heat pumps.

North America is expected to be the second-largest market for heat pumps owing to the increasing installation of energy-efficient water heating systems in the residential and commercial sectors.

e-estimated, p-projected © 2009 - 2020 MarketsandMarkets Research Private Ltd. All rights reserved

Figure 9: Future Outlook

O. Classifications of Geothermal Heat Pump System

Geothermal heat pump systems can be classified based on various factors. Here are some common classifications:

i. Closed Loop vs. Open Loop Systems

a. Closed Loop

Most geothermal heat pump systems predominantly employ closed loop systems, which involve the installation of a continuous loop of pipes either underground or in a water source. Within this loop, a heat transfer fluid, commonly a mixture of water and antifreeze, facilitates the exchange of heat with the surrounding environment.

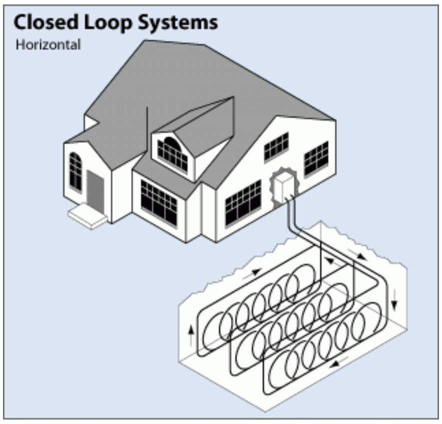


Figure 10: Closed Loop

- **Horizontal Loop**

Pipes are buried horizontally in trenches.

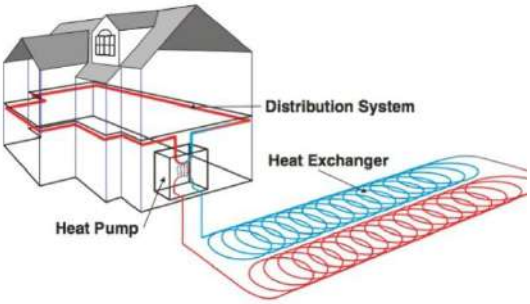


Figure 11: Horizontal Loop

- **Vertical Loop**

Pipes are installed vertically in boreholes.

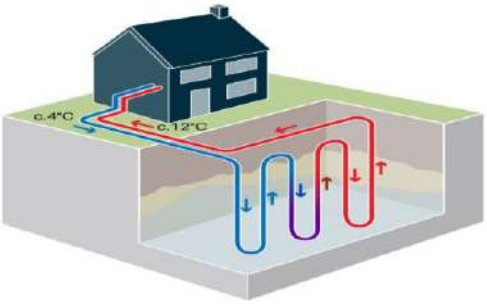


Figure 12: Vertical Loop

- **Pond/Lake Loop**

Pipes are submerged in a water body.

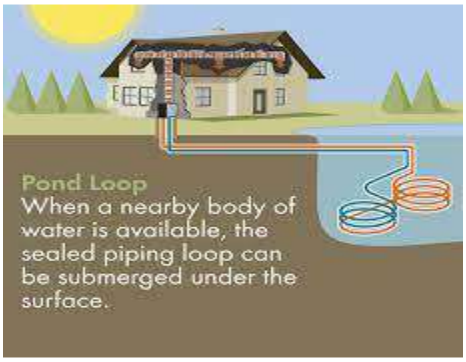
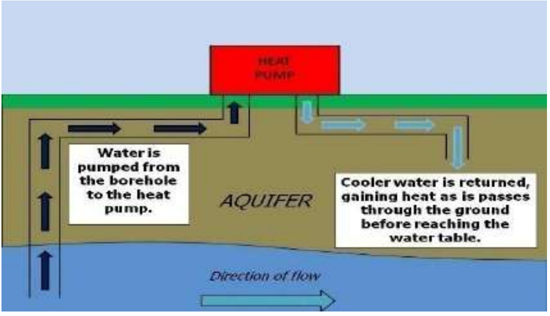


Figure 13: Pond/Lake Loop

b. Open Loop

Open loop systems in geothermal heat pump installations involve the direct utilization of groundwater or surface water as the heat transfer medium, eliminating the requirement for a closed loop. This is achieved by pumping water from a well or a body of water, and following the heat exchange process, the water is discharged back into the ground or a separate water source.



.

Figure 14: Open Loop

ii. Water-to-Air vs. Water-to-Water Systems

a. Water-to-Air

These systems transfer heat from the ground to air, providing heating and cooling through forced-air distribution. They are similar to conventional air-source heat pumps but utilize geothermal heat exchange for greater efficiency.

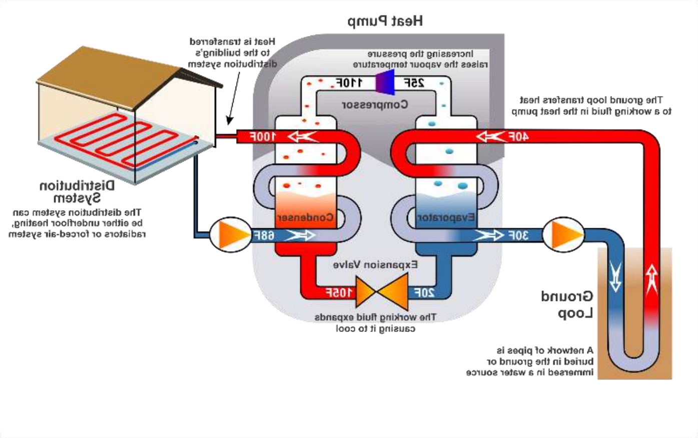


Figure 15: Water-to-Air

b. Water-to-Water

These systems transfer heat from the ground to water, providing heating and cooling through hydronic distribution. They can be used for radiant floor heating, radiators, or even domestic hot water production.

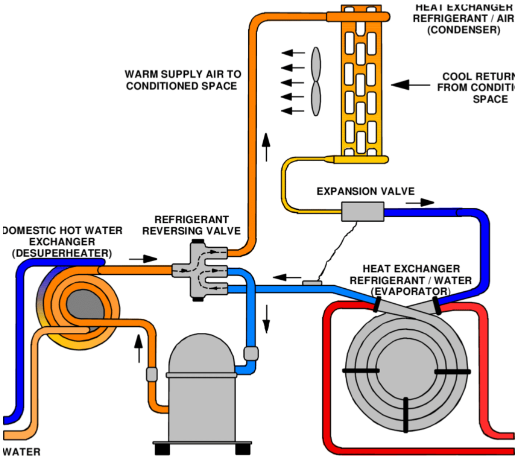


Figure 16: Water-to-Water

iii. Single-Stage vs. Two-Stage Systems

a. Single-Stage

Single-stage geothermal heat pumps operate at a fixed heating/cooling capacity and provide a constant output. They are suitable for smaller applications with consistent heating and cooling loads.

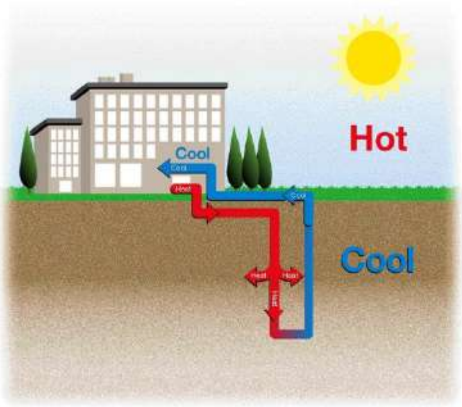


Figure 17: Single-Stage

b. Two-Stage

Two-stage geothermal heat pumps have variable capacity and can operate at both low and high stages based on the required heating/cooling load. They offer greater flexibility and efficiency in handling varying demands.

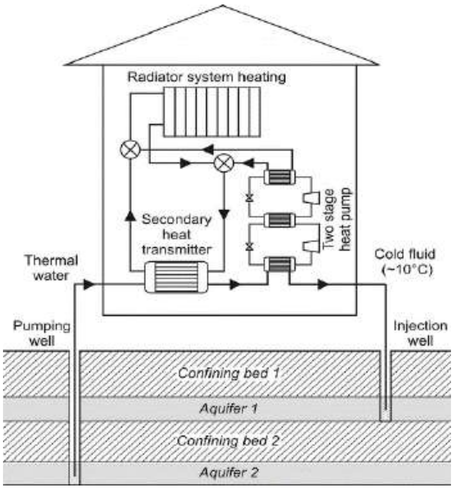


Figure 18: Two-Stage

iv. Ground Source Heat Pump (GSHP) vs. Water Source Heat Pump (WSHP)

a. Ground Source Heat Pump

This term is often used interchangeably with geothermal heat pump systems. GSHP refers to systems that extract heat from the ground using closed loop configurations.

Figure 19: Ground Source Heat Pump

b. Water Source Heat Pump

WSHP systems extract heat from a water source, such as a lake or pond, using closed or open loop configurations. WSHPs can also utilize cooling towers or other water sources for rejecting heat.

Figure 20: Water Source Heat Pump

v. Residential vs. Commercial/Industrial Systems

a. Residential Systems

Geothermal heat pump systems designed for residential applications, typically serving individual homes or small-scale multi-family buildings.

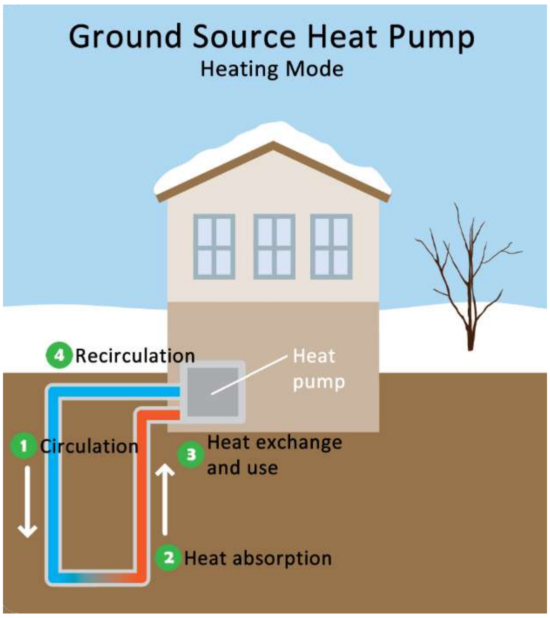


Figure 21: Residential Systems

b. Commercial/Industrial Systems

Geothermal heat pump systems designed for larger-scale applications, such as commercial buildings, industrial facilities, schools, or large residential complexes.

Figure 22: Commercial/Industrial Systems

Chapter # 03

1. Heating Load Calculations Of Office

1.1. *Layout Of An Office*

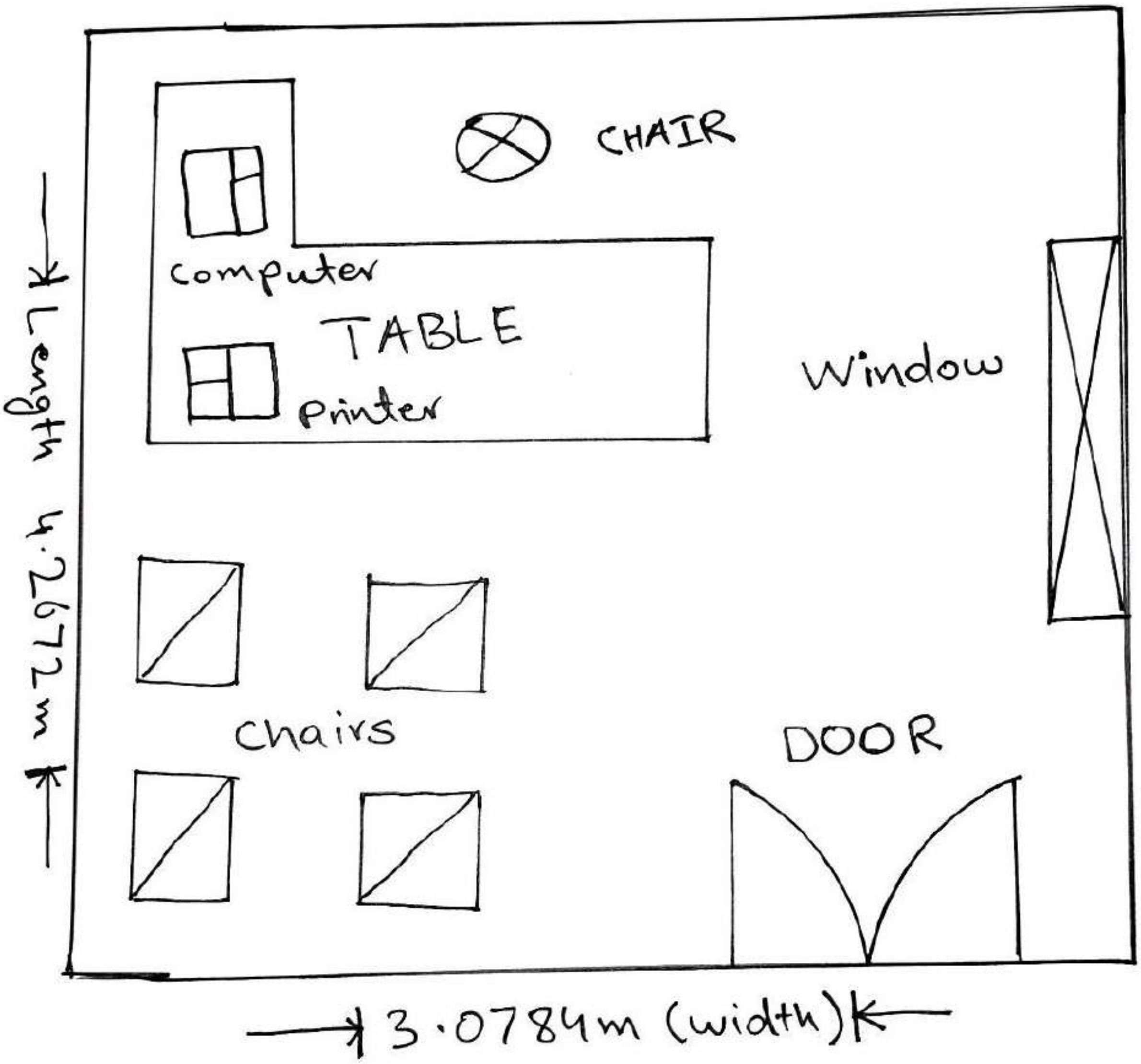
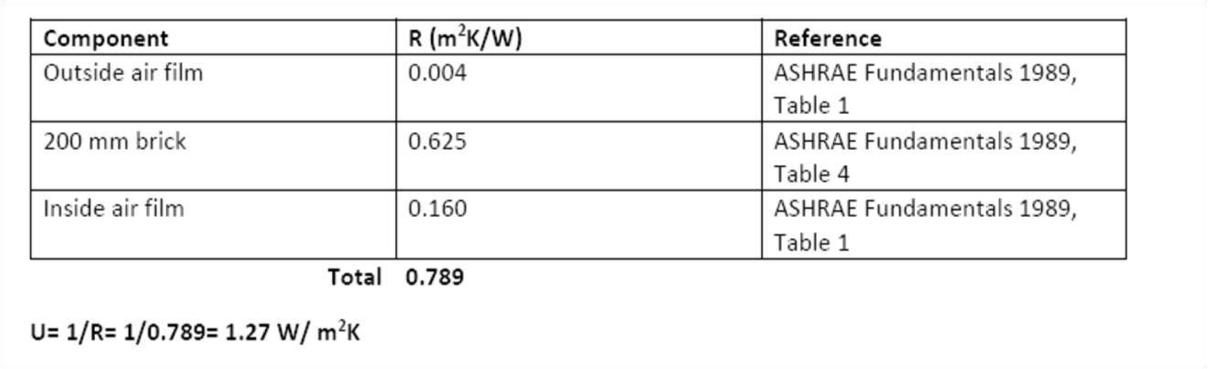


Figure 23: Layout Of An Office

1.2. U Value Calculation

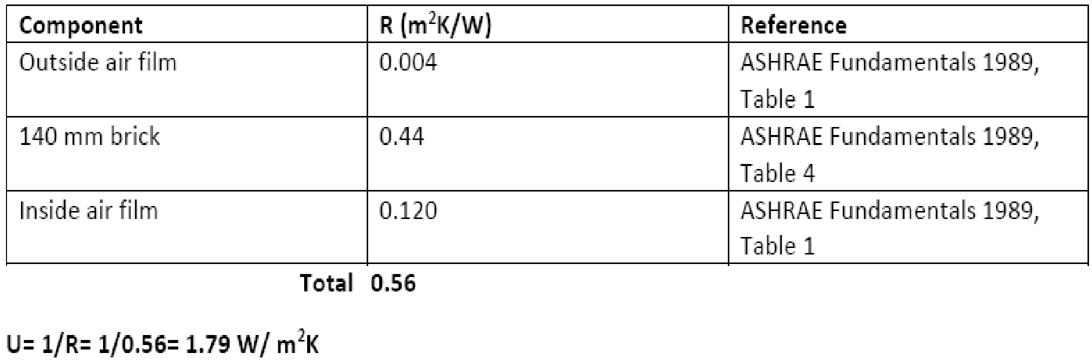
Table 1



Component	R (m^2K/W)	Reference
Outside air film	0.004	ASHRAE Fundamentals 1989, Table 1
200 mm brick	0.625	ASHRAE Fundamentals 1989, Table 4
Inside air film	0.160	ASHRAE Fundamentals 1989, Table 1
Total	**0.789**	

U= 1/R= 1/0.789= 1.27 W/ m^2K

Table 2

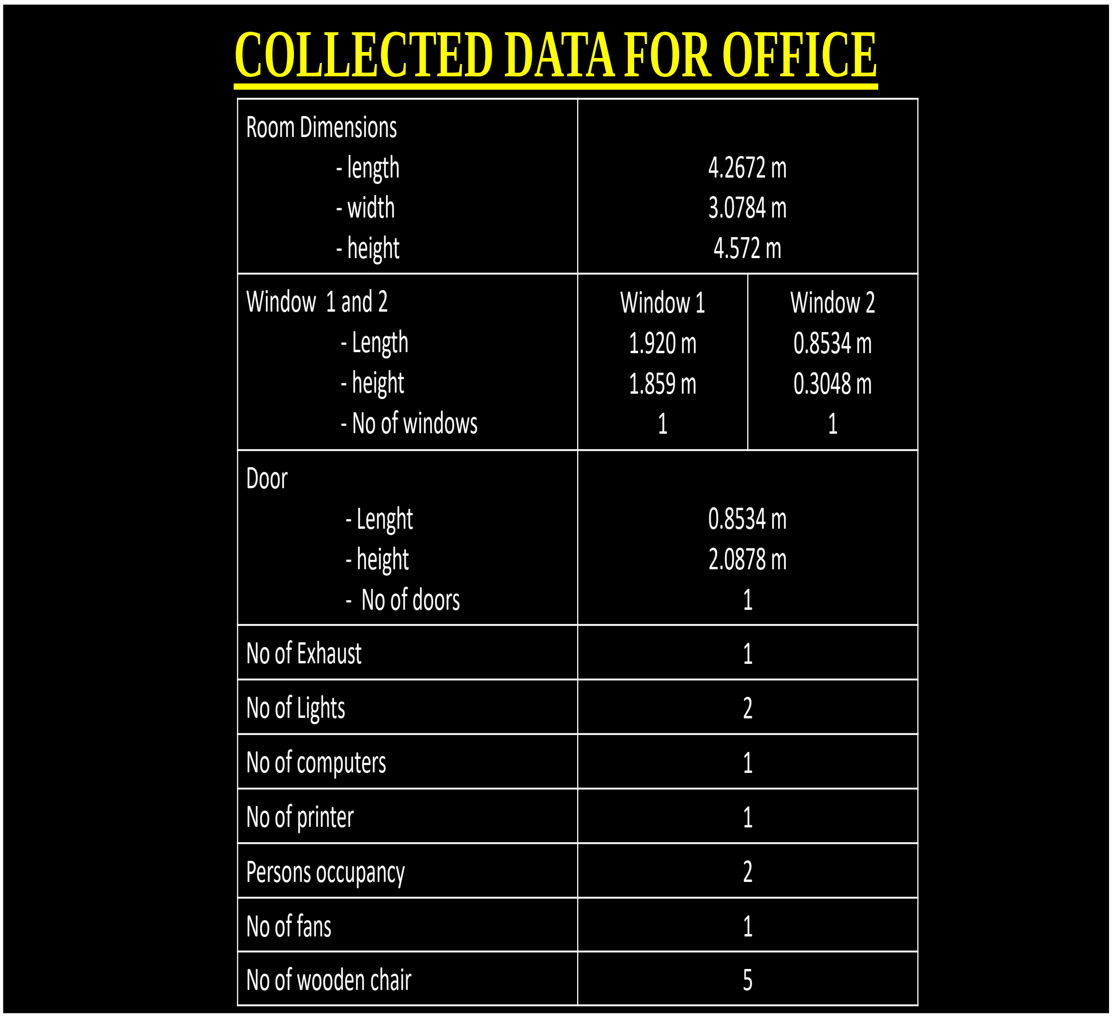


Component	R (m^2K/W)	Reference
Outside air film	0.004	ASHRAE Fundamentals 1989, Table 1
140 mm brick	0.44	ASHRAE Fundamentals 1989, Table 4
Inside air film	0.120	ASHRAE Fundamentals 1989, Table 1
Total	**0.56**	

U= 1/R= 1/0.56= 1.79 W/ m^2K

1.3. Collected Data For An Office

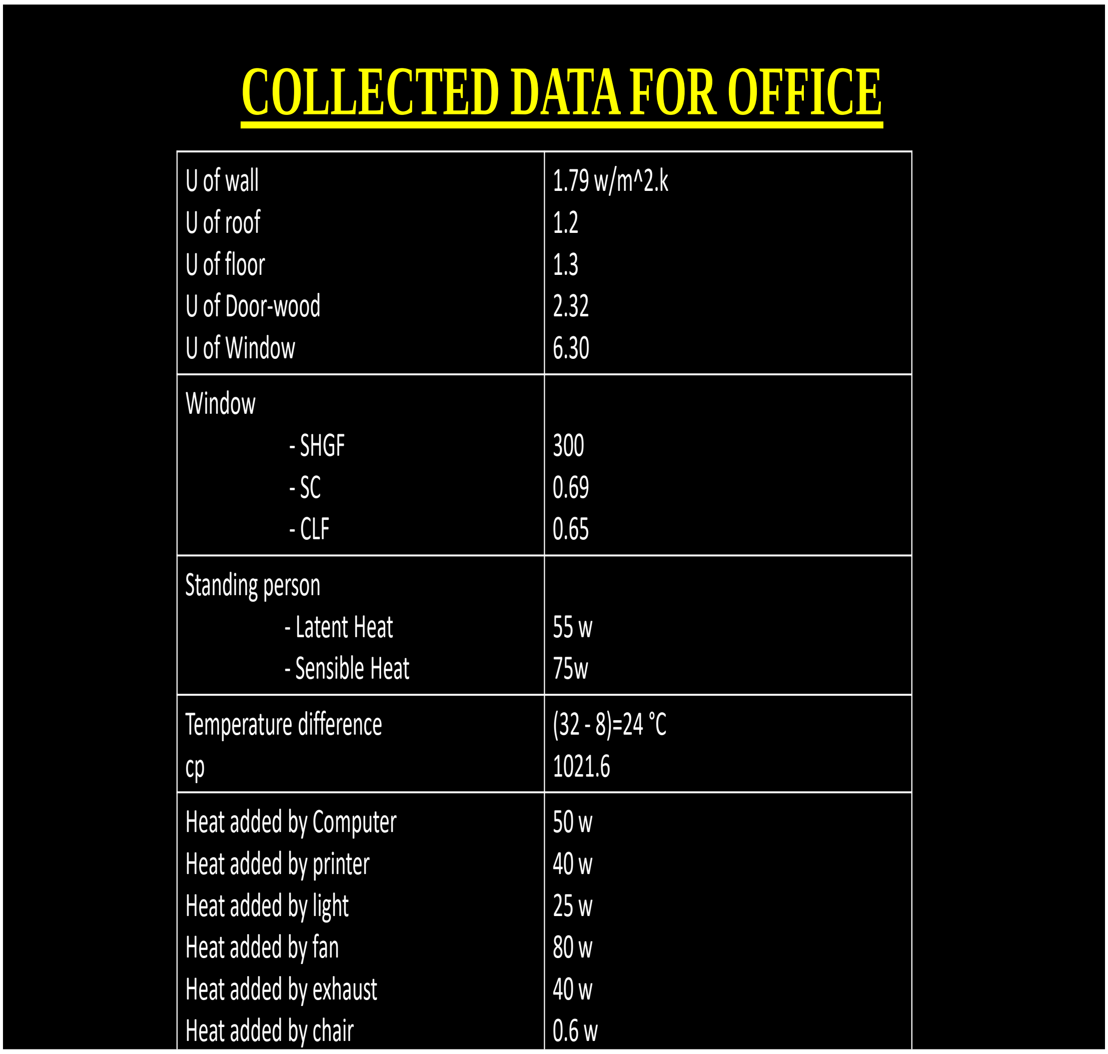
Table 3



COLLECTED DATA FOR OFFICE

Room Dimensions		
- length	4.2672 m	
- width	3.0784 m	
- height	4.572 m	
Window 1 and 2	Window 1	Window 2
- Length	1.920 m	0.8534 m
- height	1.859 m	0.3048 m
- No of windows	1	1
Door		
- Lenght	0.8534 m	
- height	2.0878 m	
- No of doors	1	
No of Exhaust	1	
No of Lights	2	
No of computers	1	
No of printer	1	
Persons occupancy	2	
No of fans	1	
No of wooden chair	5	

Table 4



COLLECTED DATA FOR OFFICE

U of wall	1.79 w/m^2.k
U of roof	1.2
U of floor	1.3
U of Door-wood	2.32
U of Window	6.30
Window	
- SHGF	300
- SC	0.69
- CLF	0.65
Standing person	
- Latent Heat	55 w
- Sensible Heat	75w
Temperature difference	(32 - 8)=24 °C
cp	1021.6
Heat added by Computer	50 w
Heat added by printer	40 w
Heat added by light	25 w
Heat added by fan	80 w
Heat added by exhaust	40 w
Heat added by chair	0.6 w

1.4. Thumb Rule Method

By volume

Ton of refrigeration(fans)= volume of room/2000 * Fos

=2121 feet^3/2000 * 1.25

=1.32 ton

By Area

T.R= Area of room/120 * Fos

= 13.137 m^2/120 * 1.25

= 1.47 ton

Average = 1.32+1.47/2

= 1.395 ton

1.5. External Load Calculations For Wall

1.5.1. For North Wall

Q_{north} = U* A* (Ti - To)

A= Area= 4.572 × 3.07848 m^2

To – Ti= Dry Bulb Temperature Difference = 24 °c

U= Overall heat Transfer Coefficient = 1.7 W/ m^2 K

$Q_{wall-North}$ = 574.252 w

1.5.2. Q for East wall

$Q_{east=}$ U* (Awall-Awindow(1))* (Ti - To)

=1.7 × (19.51-3.569) m^2 × 24= 650 w

1.5.3. For west Wall

Q_{west} = U* A* (Ti - To)

A= Area= 4.572 × 4.2672 m^2

To – Ti= Dry Bulb Temperature Difference = 24 °c

U= Overall heat Transfer Coefficient = 1.7 W/ m^2 K

$Q_{wall-west}$ = 796 w

1.5.4. Q for south wall:

$Q_{south=}$ U* (Awall-Awindow(2)-Adoor)* (Ti - To)

=1.7 × (14.0748-0.2601-1.7817) m^2 × 24= 490.94 w

1.6. External Load Calculations For Roof And Floor

QRoof = U* A* (Ti - To)

A =Area of roof = 13.137m^2

U for roof = 1.2W/ m^2 K

Q_{Roof} = 378.34 w

Q_{floor}= U* A* (Ti - To)

U for floor= 1.3W/m^2 K

Q_{floor} = 409.87 w

1.7. External Load Calculations For Glass Windows

1.7.1. Window 1

Q_{window}= U× A× (To - Ti) + A ×(SHGF × CLF × SC)

Uncoated Single glazing glass (Operable)

A =Area of Window=1.859 x 1.920= 3.569 m^2

U(glass) = 6.30 W/ m^2 K

SHGF = 300

CLF = 0.65

SC = 0.69

Q_{window}= 1019.84w

1.7.2. Window 2

Qwindow= U× A× (To - Ti) + A ×(SHGF × CLF × SC)

Uncoated Single glazing glass (Operable)

A =Area of Window=0.3048 x 0.8534= 0.2601 m2

U(glass) = 6.30 W/ m2 K

SHGF = 300

CLF = 0.65

SC = 0.69

Qwindow= 74 w

1.8. External Load Calculations For Door

Q_{Door}= U* A* (Ti - To) + SHGF * CLF * SC

A =Area of Doors = 1.7817 m^2

To – Ti = Dry Bulb Temperature Difference =24 ˚C

U = 2.32 W/ m^2 K

SHGF =300

CLF =0.65

SC =0.69

Q_{Door}= 233.75 W

1.9. Internal Load Calculations

1.9.1. Occupancy Load

Total No. of Persons = 2

Seating persons = 2

Sensible heat (Q_S)= 75 w

latent heat (Q_L) = 55 w

Sensible heat (Q_S)= No. of persons x Sensible heat = 150 W

Latent heat (Q_L)= No. of persons x Latent heat = 110 W

Computer load= 50 w

Printer load= 40 w

Exhaust load= 40 w

Load of chair= 5 * 0.6w=3w

1.9.2. Lightning Load

Q_{lights} = N * watts * Ballast factor

Ballast Factor =1 (incandscent)

Q_{lights} = 2 x 25 x 1 = 50 W

1.10. External Load Calculations

1.10.1. Infiltration Load

$Q_{inf} = \dot{m}$ x Cp x ΔT x Air change Per Hour

=[ρ*V*Cp*(To-Tin)* 0.5]/3600

Density= 1.095

V=60.06 m^3

Cp = 1021.6

Q_{inf} = 223.95 W

1.11. Total Load Calculation

1.11.1. Total load

$Q_{total} = Q_{sensible} + Q_{latent}$

Q_{total} = 5263.942 + 110 = 5373.942 W

= 5.374 kw

1.12. Tons Of Refrigeration

TR= Q(total)/3.5 X 1.25

TR= 5.374/3.5 X 1.25

TR=1.91 TON

ABOUT TR=2 TON

1.13. Rshf(Ratio Sensible Heat Factor)

RHSF=Q(total,sensible)/Q(total)

RHSF=5263.942/5373.942

RHSF=0.97

1.14. Rcc (Required Cooling Capacity

RCC=Q(total) X FOS

RCC=5373.942 X 1.25

RCC= 6717.4275 W

RCC= 6.718 KW

2. Design Decision

On the basis of the heating and cooling load calculations one ton geothermal heat pump system is recommended to develop and fabricate one ton capacity geothermal heat pump system.

Chapter # 04

1. Design and Calculation

As per our design following are the data of Refrigeration system cycle used in this Geothermal heat pump system.

Known data:

Refrigerant is r410a

Evaporating Temp = 10 C

Absolute Suction Pressure = 9 bar

Saturation Pressure = 12 bar

Absolute Discharge pressure = 30 bar

Compressor efficiency = 80 %

Hence the Absolute suction pressure is the pressure form in the evaporator due to evaporating temperature which is 10 C. this calculated from the refrigerant r410a PT chart properties. Which is denoted by P1` .

The saturation pressure is the pressure in which the refrigerant enters into the compressor also called inlet pressure which in refrigeration cycle is called P1. This find out in PT chart properties of r410a.

Absolute Discharge pressure is the pressure at which the refrigerant is discharged in the condenser. denoted by P2` in refrigeration cycle.

Evaporating temperature (T.1) = 10 C

2. PH Chart of refrigerant r410a

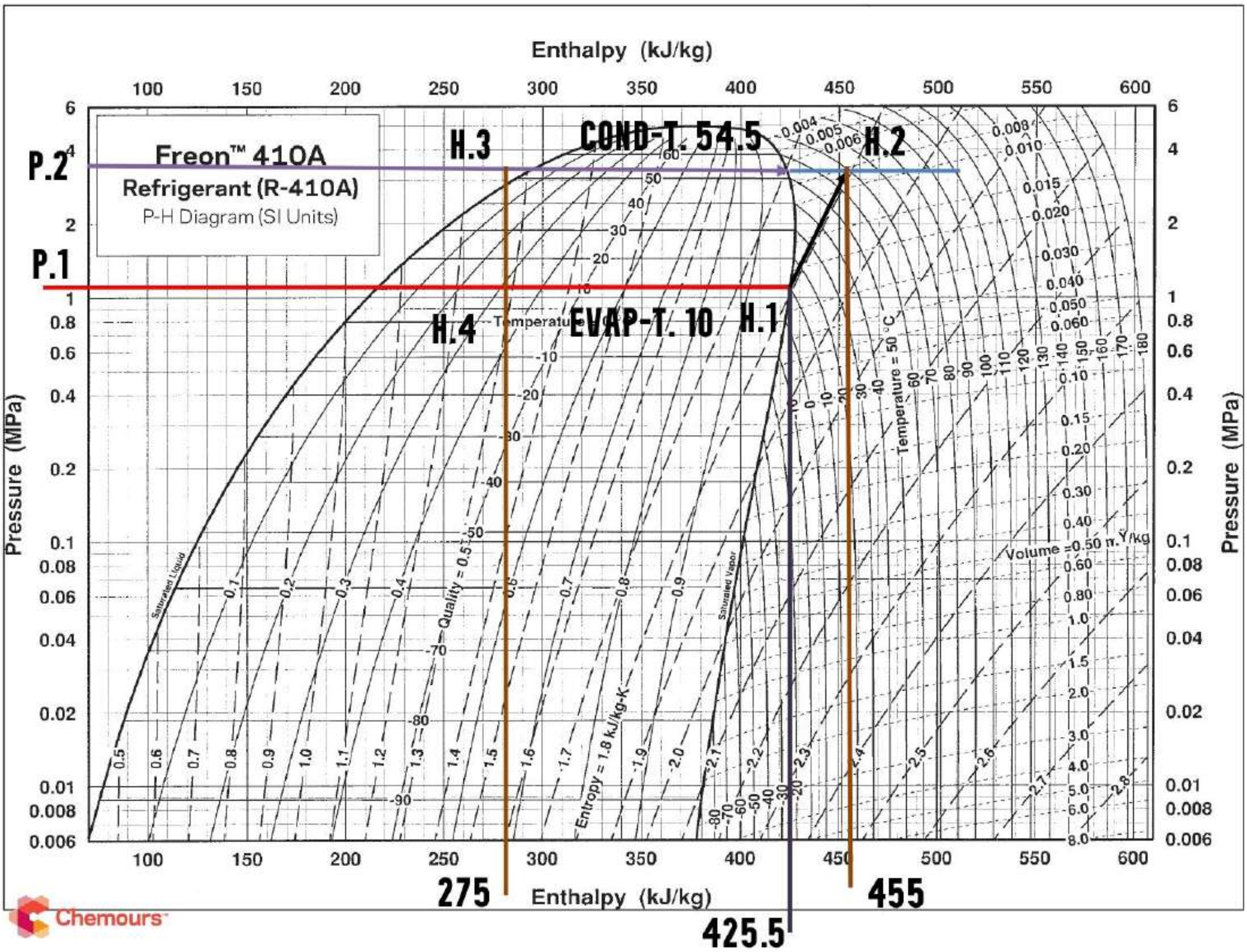


Figure 24: PH Chart of refrigerant r410a

3. Refrigeration cycle calculations

Enthalpy of vapor compression refrigeration system from the above PH chart of r410a, following are the calculated data.

h.1 = 425.5 (kj/kg)

h.2 = 455

h.3, h.4 = 275

Evaporating temp = 10 C

P.1 = 12 bar

P.2` = 30 bar

3.1. *Calculation of condensing temperature*

Given

The condensing pressure is

Discharge pressure (P2`) – Atmospheric pressure

30 bar – 1 bar

Condensing Pressure (P2) =29 bar

Specific Heat Ratio (K) for R410A ≈ 1.16 kJ/(kg·°C)

The Condensing temperature (T.2) is found out = 54.4 C

To calculate the condensing temperature, we can use the pressure-temperature relationship for the refrigerant. However, it's important to note that the pressure-temperature relationship can vary slightly depending on the specific properties of the refrigerant and the refrigeration system.

For R410A, we can refer to a pressure-temperature chart or tables to determine the condensing temperature corresponding to the given condensing pressure of 29 bar.

Using typical R410A properties, at 29 bar (condensing pressure), the corresponding condensing temperature is approximately 54.4°C.

Therefore, the estimated condensing temperature for a condensing pressure of 29 bar and R410A refrigerant is approximately 54.4°C.

4. Discharge temperature T2` calculations

Discharge temperature T2` which is find out from the following calculation

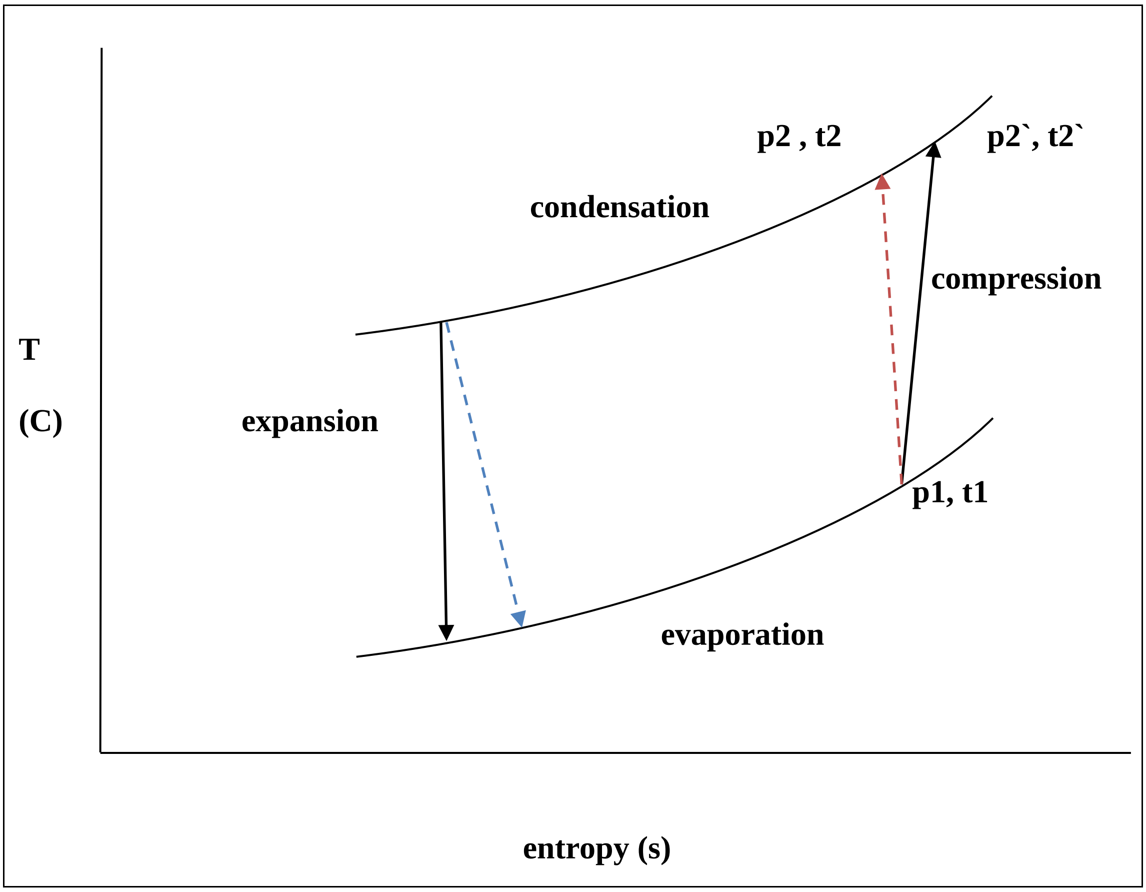
$\eta c = \frac{\text{T2}-\text{T1}}{\text{T2`}-\text{T1}}$

$0.8 = \frac{54.4-10}{\text{T2`}-\text{ 10 C}}$

0.8T.2` = 54.4 – 10 + 8

T.2` = 65.5 C

5. Refrigeration cycle diagram



5.1. *Obtained result calculation*

Essential calculation from our geothermal heat pump system using vapor compression refrigeration cycle,

From the above data the following observation and calculations were obtained.

heat pump capacity = 1 ton (3.5 ton)

heating load capacity = 1 x 3.5 kw = 3.5 kw (3500 watt)

Refrigeration capacity = 1 ton or 3.5 kw

compressor efficiency = 80 %

Evaporating temperature = 10 C

condensing Temperature = 54.4 C

using the above r410a PH chart observation the following parameters are calculated of the vapor compression refrigeration cycle.

5.2. Parameters calculation

i. Refrigeration effect

Rf = h1 – h4

RF = 425.5 – 275

RF = 150.5 (kj/kg)

This is actually the heat energy added.

Qa = 150.5 (kj/kg)

Refrigeration cycle

$\dot{m} = Q / (h_1 - h_4)$

$\dot{m} = \frac{3.5\ kw}{(425.5-275)}$

$\dot{m}$ = 0.023 kg/sec

ii. Power

$P = \dot{m}(h2 - h1)$

P = 0.023(455 – 425.5)

P = 0.7375 kw or 737.5 watt

5.3. C.O.P of the refrigeration system

$C.O.P = \frac{N}{w}$

$C.O.P = \frac{3.5\ kw}{0.737.5\ kw}$

C.O.P = 4.745

5.4. Heat Rejection

H.R = ma(h2 – h3)

H.R = 0.023(455 – 275)

H.R = 4.14 kw (heat energy Rejected)

5.5. C.O.P of the vapour compression refrigeration cycle

$$\text{C.O.Pr} = \frac{h1-h4}{h2-h1}$$

$$\text{C.O.Pr} = \frac{425.5 - 275}{455 - 425.5}$$

C.O.Pr = 5.10

6. Sizing of the geothermal heat pump system components

Typically the sizing for the one ton heat pump is the following.

Evaporator : 4.16 hp (horse power)

Condenser : for the condenser size in a one-ton refrigeration system is equal to 1 HP

Compressor : one ton (r410a compressor)

Expansion valve

Drier

4-way valve

these components were used in the vapor compression refrigeration cycle.

Length of pipe

For 1-ton refrigeration system typically requires a 1/2 inch (12.7 mm) copper pipe

Length of pipe in evaporator is 26 feet this is the standard size for one tone geothermal heat pump system evaporator.

7. Schematic diagram

These are the schematic diagrams of vapor compression refrigeration system of this project Geothermal heat pump system. Due to four way valve this system can work in both modes i.e heating and cooling mode

i. In Heating mode

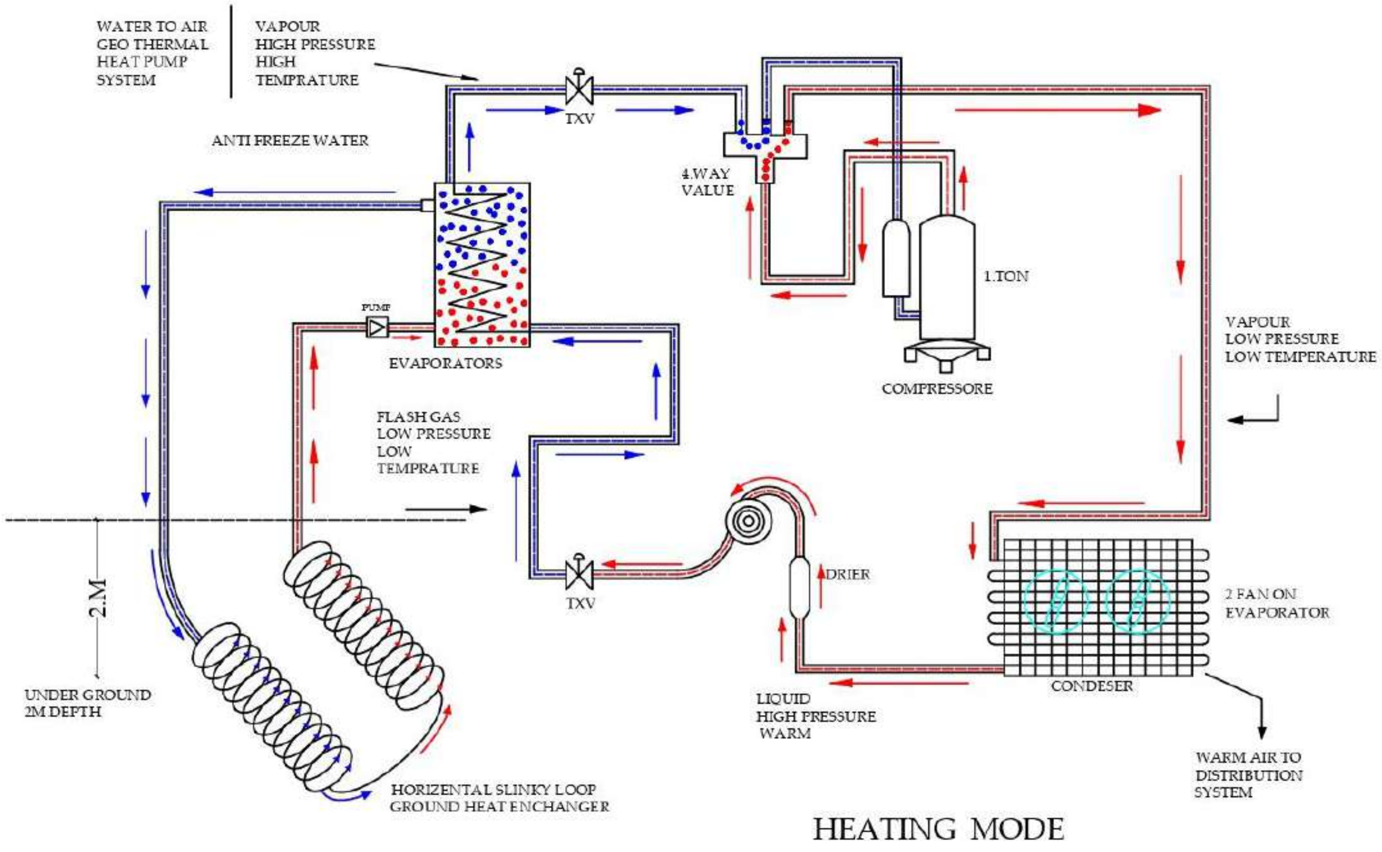


Figure 25: In Heating mode

ii. In Cooling mode

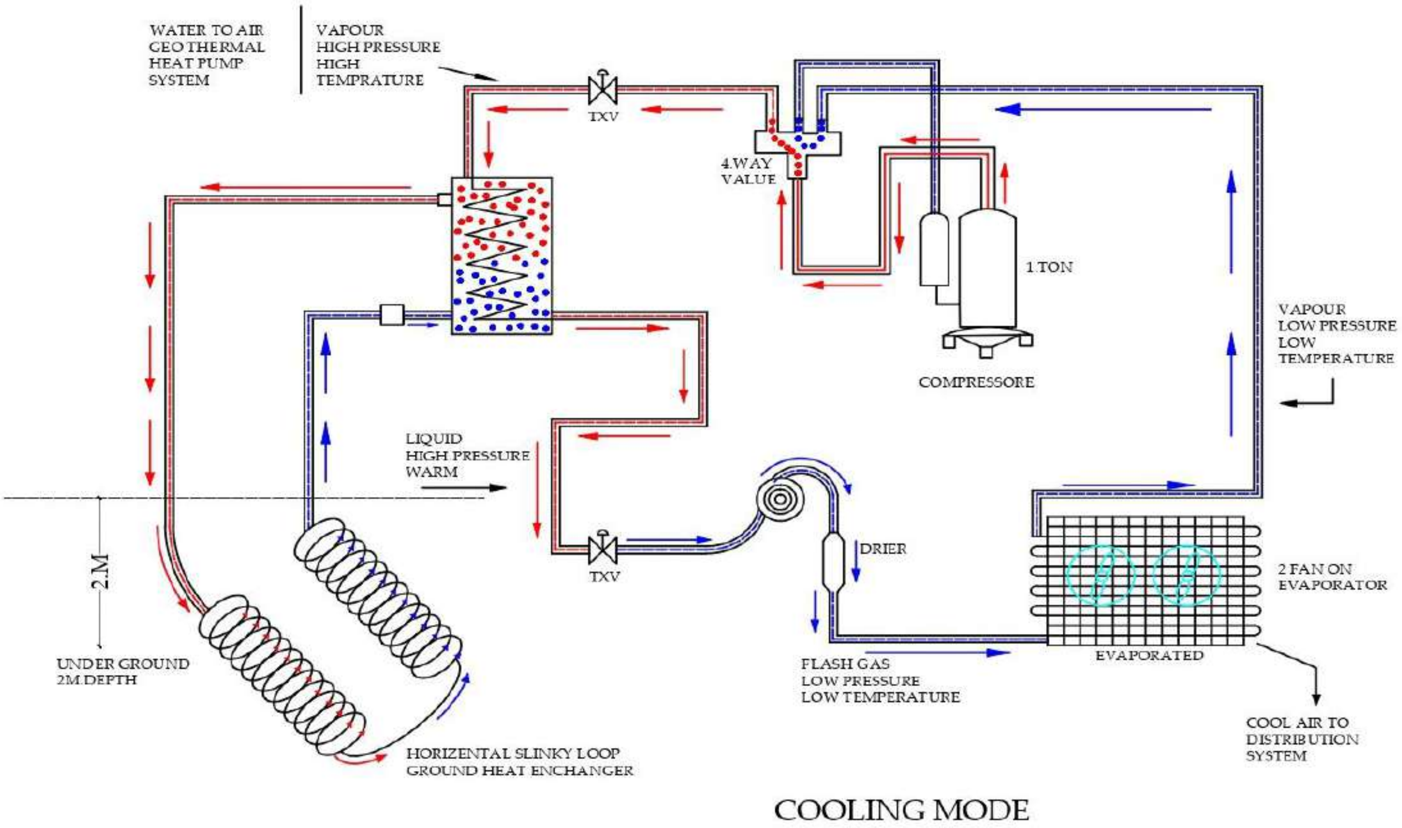


Figure 26: In Cooling mode

8. Heat pump components

These are the components of making the vapor compression refrigeration system, the following components are the fabrication part these all components were installed in one ton geothermal heat pump system.

8.1. *Scroll Compressor of r410a one ton capacity*

Figure 27: Scroll Compressor of r410a one ton capacity

8.2. *Condenser 1 HP*

Figure 28: Condenser 1 HP

8.3. *Fan*

Figure 29: Fan

8.4. *Fans on condenser*

Figure 30: Fans on condenser

8.5. *Evaporator 4.16 HP*

Figure 31: Evaporator 4.16 HP

8.6. *Copper Pipe*

Figure 32: Copper Pipe

8.7. *Four Way Valve*

Figure 33: Four Way Valve

8.8. *Service Valves for Spray of Refrigerant Inside the System*

Figure 34: Service Valves for Spray of Refrigerant Inside the System

8.9. *Refrigerant r410a*

Figure 35: Refrigerant r410a

9. Fabricated Heat pump

These are the pictures of fabricated heat pump

9.1. SST body of heat pump

Figure 36: SST body of heat pump

9.2. Internal view of heat pump

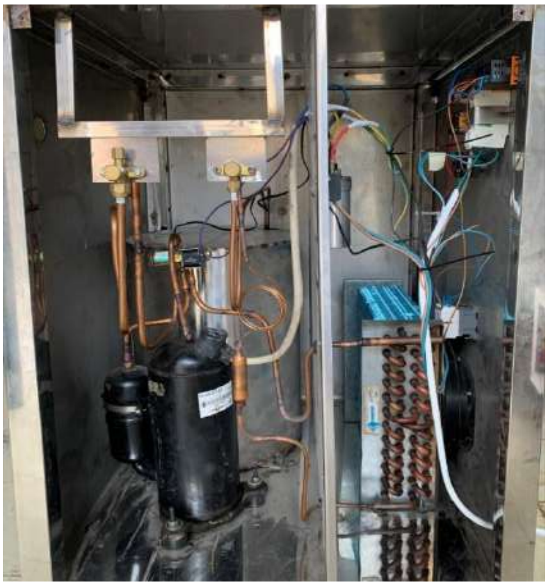


Figure 37: Internal view of heat pump

Front view

Figure 38: Internal view of heat pump

Side view

Results and Discussion

1. Results

1.1. Introduction

The geothermal heat pump system is to extract heat and reject the heat during heating and cooling mode, in this section the analysis of geothermal heat pump with respect to its operational steps is going to be present this is efficient and environmental friendly heating and cooling aspects that use the stable temperature found underground to provide heating and cooling for residential and commercial buildings.

System Design and Calculations

- **System Capacity**

The designed geothermal heat pump system has a capacity of 1 ton or 3.5 kW. This capacity is suitable for providing heating and cooling for the intended application.

- **Refrigerant and Properties**

The system utilizes R410a refrigerant. Various refrigerant properties were obtained from the R410a pressure-temperature (PT) chart. The saturation pressure at the evaporating temperature of 10°C is 12 bar, and the absolute discharge pressure is 30 bar.

- **Compression Ratio and Efficiency**

The compression ratio of the system is 2.5:1, which is calculated by dividing the absolute discharge pressure by the absolute suction pressure. The compressor efficiency is assumed to be 80%.

- **Operational Parameters**

The evaporating temperature (suction temperature) is 10°C, and the condensing temperature is estimated to be approximately 54.4°C based on the pressure-temperature relationship for R410a.

Refrigeration Effect and Load Capacity

The refrigeration effect is calculated as the difference in enthalpy between the evaporator (h1) and the condensed refrigerant (h4), which results in a value of 150.5 kJ/kg. The system has a heating load capacity of 3.5 kW (3500 watts).

Power Consumption and Coefficient of Performance (COP)

The power consumption of the system is estimated to be 0.7375 kW (737.5 watts), calculated by multiplying the mass flow rate of the refrigerant by the enthalpy difference between the evaporator and the compressed refrigerant (h2 - h1). The COP of the system is determined to be 4.745, which indicates its efficiency in converting electrical energy to heating or cooling capacity.

Heat Rejection and COP of the Refrigeration Cycle

The heat rejection from the system, known as the Heat Rejection (HR), is calculated as 4.14 kW. The COP of the vapor compression refrigeration cycle (C.O.Pr) is determined to be 5.10, which indicates the system's efficiency in utilizing the refrigerant for heat transfer.

Sizing and Components

Based on the system capacity, the geothermal heat pump system componentsare selected and sized accordingly. The evaporator requires a 4.16 HP(horsepower) capacity, and the condenser size is determined to be 1 HP. Thesystem also includes a compressor, expansion valve, drier, and 4-way valve.

Piping:

The evaporator pipe length is determined to be 26 feet, utilizing a 1/2 inch (12.7 mm) copper pipe. This piping configuration is suitable for the designed one-ton geothermal heat pump system.

1. Discussion

1.1. Introduction

The geothermal heat pump system is an efficient and environmentally-friendly heating and cooling technology that utilizes the stable temperatures found underground to provide heating, cooling, and hot water for residential and commercial buildings.

1.2. System Components

The geothermal heat pump system consists of several key components, including:

Ground Heat Exchanger

This component consists of a network of buried pipes, typically made of high-density polyethylene (HDPE), which is responsible for exchanging heat with the ground. It can be installed horizontally in trenches or vertically through boreholes, depending on the available space.

Heat Pump Unit

The heat pump unit contains a compressor, condenser, expansion valve, and evaporator. It circulates a refrigerant through the ground heat exchanger to extract or reject heat from the ground, depending on the mode of operation.

Distribution System

The distribution system delivers the conditioned air or hot water to the building's interior spaces. It includes ductwork for forced air systems or radiant heating systems for hydronic heating.

2. Operational Steps

The geothermal heat pump system operates in both heating and cooling modes. The following steps outline the operation of the system.

2.1. Heating Mode

The heat pump extracts heat from the ground through the ground heat exchanger using the refrigerant in the evaporator coil.

The heat extracted from the ground is transferred to the refrigerant, causing it to evaporate.

The evaporated refrigerant is compressed by the compressor, which increases its temperature and pressure.

The high-pressure refrigerant then flows to the condenser coil where it transfers its heat to the distribution system (forced air or hydronic) through the condenser.

The cooled refrigerant, after transferring heat, is expanded through the expansion valve, which reduces its pressure and temperature.

The cycle repeats as the refrigerant flows back to the evaporator coil in the ground heat exchanger.

2.2. Cooling Mode

The heat pump operates in reverse, rejecting heat from the building to the ground.

The refrigerant in the evaporator coil absorbs heat from the distribution system.

The absorbed heat causes the refrigerant to evaporate.

The evaporated refrigerant is compressed by the compressor, raising its temperature and pressure.

The high-pressure refrigerant releases heat to the ground through the condenser coil.

The refrigerant is expanded through the expansion valve, reducing its pressure and temperature.

The cycle continues as the refrigerant returns to the evaporator coil.

3. Efficiency and Benefits

The geothermal heat pump system offers several advantages:

A. High Energy Efficiency

The system leverages the constant ground temperature, resulting in high energy efficiency and reduced operating costs compared to traditional HVAC systems.

B. Environmental Benefits

By utilizing renewable energy from the ground, the system reduces greenhouse gas emissions and dependence on fossil fuels.

C. Versatility

The system can provide both heating and cooling, as well as domestic hot water, making it a comprehensive solution for year-round comfort.

D. Long Lifespan

Properly designed and maintained systems can have a lifespan of over 20years, offering durability and reliability.

4. Conclusion

This study presents a detailed analysis of a geothermal heat pump system utilizing a horizontal slinky loop ground heat exchanger. The system design and calculations were based on the given data, which included an evaporating temperature of 10°C, suction pressure of 12 bar, discharge pressure of 30 bar, compression ratio of 2.5:1, and compressor efficiency of 80%. The refrigerant used in the system is R410a.

Through the vapor compression refrigeration cycle, the system demonstrated efficient operation in both heating and cooling modes. The refrigeration effect, calculated as the difference in enthalpy between the evaporator and condensed refrigerant, was determined to be 150.5 kJ/kg. The power consumption of the system was estimated to be 0.7375 kW (737.5 watts), while the coefficient of performance (COP) was found to be 4.745, indicating the system's efficiency in converting electrical energy to heating or cooling capacity.

The horizontal slinky loop ground heat exchanger proved to be an effective method of exchanging heat with the ground. By utilizing a network of buried pipes, heat transfer between the refrigerant and the ground was enhanced. The length of the pipe used in the evaporator was determined to be 26 feet, with a diameter of 1/2 inch (12.7 mm). This configuration facilitated efficient heat exchange and distribution.

Sizing of the system components was based on the calculated capacity of 1 ton (3.5 kW). The evaporator required a capacity of 4.16 HP, while the condenser size was determined to be 1 HP. Other components, including the compressor, expansion valve, drier, and 4-way valve, were selected to match the system's requirements.

In conclusion, the geothermal heat pump system with a horizontal slinky loop ground heat exchanger offers an environmentally-friendly and efficient solution for heating and cooling applications. The calculated refrigeration effect, power consumption, COP, and sizing of system components indicate the system's capability to provide reliable and sustainable heating and cooling. The horizontal slinky loop ground heat exchanger design ensures effective heat transfer with the ground, contributing to the system's overall efficiency.

References

[1] S. J. Self, B. V. Reddy, and M. A. Rosen, “Geothermal Heat Pump Systems: Status Review and comparison with other heating options,” *Applied Energy*, vol. 101, pp. 341–348, 2013

[2] O. Ozgener and A. Hepbasli, “Modeling and performance evaluation of Ground Source (geothermal) Heat Pump Systems,” *Energy and Buildings*, vol. 39, no. 1, pp. 66–75, 2007.

[3] Y. Cui *et al.*, “Techno-economic assessment of the horizontal geothermal heat pump systems: A comprehensive review,” *Energy Conversion and Management*, vol. 191, pp. 208–236, 2019.

[4] T. Kurevija, D. Vulin, and V. Krapec, “Effect of borehole array geometry and thermal interferences on Geothermal Heat Pump System,” *Energy Conversion and Management*, vol. 60, pp. 134–142, 2012.

[5] L. Lamarche, S. Kajl, and B. Beauchamp, “A review of methods to evaluate borehole thermal resistances in geothermal heat-pump systems,” *Geothermics*, vol. 39, no. 2, pp. 187–200, 2010.

[6] L. Rybach and W. J. Eugster, “Sustainability aspects of geothermal heat pump operation, with experience from Switzerland,” *Geothermics*, vol. 39, no. 4, pp. 365–369, 2010.

[7] H. Zeng, N. Diao, and Z. Fang, “Efficiency of vertical geothermal heat exchangers in the ground source heat pump system,” *Journal of Thermal Science*, vol. 12, no. 1, pp. 77–81, 2003.

[8] D. Milenić, P. Vasiljević, and A. Vranješ, “Criteria for use of groundwater as renewable energy source in geothermal heat pump systems for building heating/cooling purposes,” *Energy and Buildings*, vol. 42, no. 5, pp. 649–657, 2010.

[9] E. K. Akpinar and A. Hepbasli, “A comparative study on exergetic assessment of two ground-source (geothermal) heat pump systems for residential applications,” *Building and Environment*, vol. 42, no. 5, pp. 2004–2013, 2007.

[10] G. Russo, A. S. Anifantis, G. Verdiani, and G. S. Mugnozza, “Environmental analysis of geothermal heat pump and LPG Greenhouse Heating Systems,” *Biosystems Engineering*, vol. 127, pp. 11–23, 2014.

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