CERTIFICATION

This is to clarify that thesis entitled

ENERGY AND COST BENEFIT ANALYSIS OF USING GEOTHERMAL ENERGY FOR PASSIVE HEATING AND COOLING OF RESIDENTIAL BUILDINGS: A DESIGN APPROACH

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DECLARATION

We hereby declare that the thesis titled, "Energy and Cost Benefit Analysis of Using Geothermal Energy for Heating and Cooling of Residential Buildings in Pakistan: A Design Approach", submitted by us, is based on actual work carried out by us. Any references to work done by any other person or institution and any material obtained from other sources have been duly cited, referenced and acknowledged. We further clarify that the thesis has not been published or submitted for publication anywhere else.

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ABSTRACT

Geothermal energy is clean and sustainable energy which can be harvested and utilized in many ways. Unfortunately, in Pakistan, the field of geothermal energy has been neglected to a substantial level. Utilization of geothermal energy in heating and cooling of buildings can significantly reduce utility costs in terms of heating and cooling. This energy can answer the ever increasing energy demand, cost saving and sustainability issues. This project aims at introducing the possibility of this low utility cost system in Pakistan and the study of its efficiency for the humid sub-tropical climatic conditions of Islamabad and Rawalpindi region.

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CHAPTER 1

INTRODUCTION

1.1 Background

Many nations around the globe have understood that in order to maintain stability and to provide sufficient amount of energy to people, there should be more efficient utilization of energy because provision of adequate, secure and affordable energy is vital for economic and human development. In developing countries there is more need for inexpensive energy, as it can help in improving life standard. All the things that help people escape destitution and build better life, like, industry, modern agriculture, increased trade and better-quality transportation, are financially supported by reliable energy.

Most of the energy utilized today comes from the hydrocarbons. According to a report, in 2015 the 48.1% of total electricity generated in European Union countries is from conventional sources. Which depicts that modern world is facing serious problems because of these conventional, fossil-fuel based, energy sources. The problems includes emission of pollutant gasses that cause acid rains, triggering global warming, and the ever increasing supply and demand gap. The total carbon emissions has increased many folds from 0.001 Billion metric tons (in 1827) to 10 Billion metric tons in till 2007. (Marland et.al 2007). Moreover the use of fossil fuels is also adding radioactive materials to the atmosphere. During the year 2000 alone near twelve thousand tons of Thorium and five thousand tons of uranium were released into the atmosphere (Gabbard, 2007). Renewable energy sources are considered as perfect wellsprings of energy and the ideal utilization of these assets can curtail environmental impacts.

Speaking of the economy, high fuel prices are also a burden on the world. According to the International energy agency, fossil fuel industry gains about 550 million dollars subsidies from governments across the globe. To face the complications or challenges, worldwide, the energy framework needs to be revolutionized and replaced from fossil-fuels to renewable energy and incorporate necessary advancements. Renewable energy sources results into the minimized pollutants and are sustainable in light of present and future monetary and social societal necessities.

Types of renewable energy are solar, wind, geothermal, nuclear, hydropower, biomass and marine energies. These renewable energy sources can be used for different purposes like electricity production, air and water heating/cooling and off-grid like in rural areas.

Keeping in view the impacts of conventional energy sources on environment and economy, developed countries are investing heavily in renewable energy sources. Unlike conventional or fossil fuel sources which are confined to a limited number of countries and extraction of which is becoming more and more challenging day by day, these renewable energy sources are present in almost every kind of geological and geographical conditions. If utilized in an efficient way these resources can be the insurance of country’s energy security and will reduce its dependency on other countries.

1.2 Renewable Energy in World:

Although the developed countries of the world are not facing serious energy crisis, but keeping in view their projected energy demands, depleting non-renewable energy resources and harmful environmental effects, they are looking for cheap, renewable and environment friendly energy sources. An amount of 286 billion US dollars was invested in renewable technologies in 2015 throughout the world, where China and United States are enjoying top positions in the list. Iceland and Norway are generating almost 100% of their electricity from renewable energy sources on the contrary only 30 countries are producing more than 20% of their total electricity by renewable resources.

Renewable Energy Policy Network for the 21st Century published a report in 2016, renewable sources account for the 23.7% of the electricity generation worldwide in 2015. According to another report by International Energy Agency the share of electricity generation is projected to increase to 26 % in 2020. Eurostat, in 2014, said that about 27.5% of the gross electricity consumption in Europe is fulfilled by renewable sources.

Countries like Sweden, Finland, Iceland and Denmark are meeting more than 40 % of their heating and cooling demands with renewable energy sources.

1.3 Energy Crisis in Pakistan:

Pakistan is an underdeveloped and over populated country which needs a continuous source of energy to keep its progress on track and deliver its people with a reasonable standard of living. It is an accepted fact that energy plays a crucial role in the creation and sustainment of present day economies. Approximately a total of 38 % of the Pakistani population has no access to electricity. About 54% percent of the rural population as of now has no approach to electricity, compelling them to carry along with a substandard existence of poverty and social conflict (Mirza et al., 2011) Pakistan is one of the leading countries which uses maximum portion of its energy consumption for domestic purposes. Domestic sector consumes 45.9%, while industrial sector uses 27.5% of the total energy Consumption. Nearly half of this energy is consumed for cooling and heating purposes (Sohail and Qureshi, 2011).

Thermal (Coal, oil and Natural gas) power plants generate about 64% of the total electrical energy grid in Pakistan. The high fuel prices are putting a huge burden on the already fragile Pakistani economy. Also these thermal power plants especially coal plants are having adverse effects on ecological system and human health. According to a report, energy sector is responsible for 80% of the overall CO_2 emissions. It is estimated that CO_2 emissions will be three times in 2030 than in 2010 similarly NO and SO_2 emissions are also estimated to increase by 4-7 folds as well.

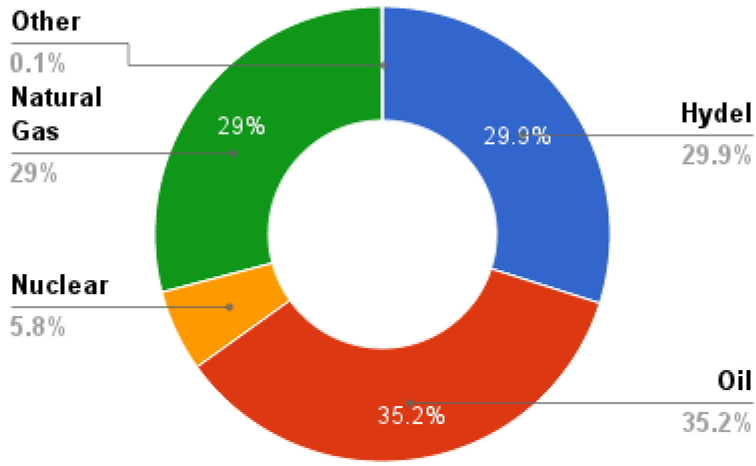


Figure 1.1: *Sources of power generation in Pakistan*

Despite the fact that only 62% of Pakistani population has electricity facility. Pakistan has been facing a serious energy crisis in the recent years. The gap between electricity demand and supply has been increased and the shortfall stretched to 4500 MW in 2010, 6620 MW in 2012 and remained over 5200 MW in 2013, which, on average, establishes over 50% of the country's total generating capacity of that time. The energy demand will intensify in the foreseeable future at a rate of 8-10% per year according to (Shakeel et al. 2016). The reasons for this escalated demand are the rapid development in the agricultural and services sector, use of modern appliances, little or no awareness about energy preservation or efficiencies, projected rise in population and the government's commitment to extend the electricity to the remaining parts of the country.

1.4 Renewable Energy Resources in Pakistan:

In Pakistan renewable energy segment is much undeveloped and provide only 1% (excluding hydropower) of the total energy demand. Pakistan has an immense potential for utilizing renewable energy. Its contribution in the power mixture must be extended to achieve energy security. Reason for this is the recent energy crisis and power shortfalls affecting the already weak Pakistani economy authorities are now showing interest in renewable sources.

Being an agrarian country there is lot of agricultural leftover, biomass that can be used for electricity generation. There are vast barren lands in Punjab, Sindh and Cholistan in form of deserts and these can hardly be used for any agricultural purposes so these can be used for solar plant installations. If only the 0.25% area of Baluchistan is covered with solar panels of 20% efficiency sufficient electricity will be produced to fulfill electricity demand of entire country. As the average daily sunshine time for Baluchistan is 8.5 hours.

Area between Gharro and Kati Bandar has the potential of generating 40-50 thousand megawatt electricity by wind as wind speed here ranges from6.2-6.9 meter per second. Total electricity production from wind power sources in Pakistan was 106MW in 2014. Wind energy contributes only 0.2% of the total electricity consumption.

Hydroelectricity is the most common source of power generation among renewable sources in Pakistan. As it is cheapest source of electricity generation. Pakistan has an estimated hydropower potential of 60,000 MW approximately and only 11% of this total potential is exploited (Qureshiet.al 2014)

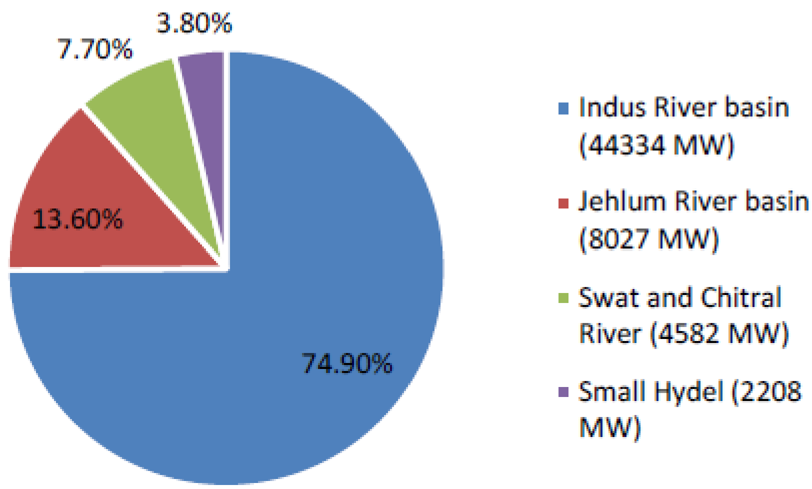


Figure 1.2: *Distribution of hydropower potential in Pakistan*

Other renewable energy sources like tidal and geothermal are have zero contribution to the national grid and no one is even paying any kind of attention to these resources.

1.5 Geothermal Energy and world

Geothermal energy is one form of renewable energy. It is considered to be renewable because any expected heat withdrawal from the Earth is very small as compared to its overall heat content. Geothermal energy is considered to be sustainable because of its power to sustain the Earth's complex ecosystems. Due to low greenhouse gas emissions, geothermal energy is considered to have outstanding potential for reducing global warming. Geothermal energy can be used either directly or indirectly. Indirectly this energy is used for electricity generation.

Direct use of geothermal energy refers to immediate use of this energy for space heating and cooling, heating swimming pools and baths, in agriculture, aquaculture and to provide heat for industrial processes and heat pumps. About 80 countries of the world are using geo-thermal energy directly for the said purpose.

According to WGC (World geothermal congress) the installed electricity generation capacity from deep geothermal systems in 2015 was around 12,635 MW_E. With United States at the top of list with an installed capacity of 3450 $MW_{e.}$ Other countries among top five are Philippines, Indonesia, Mexico and New Zealand.

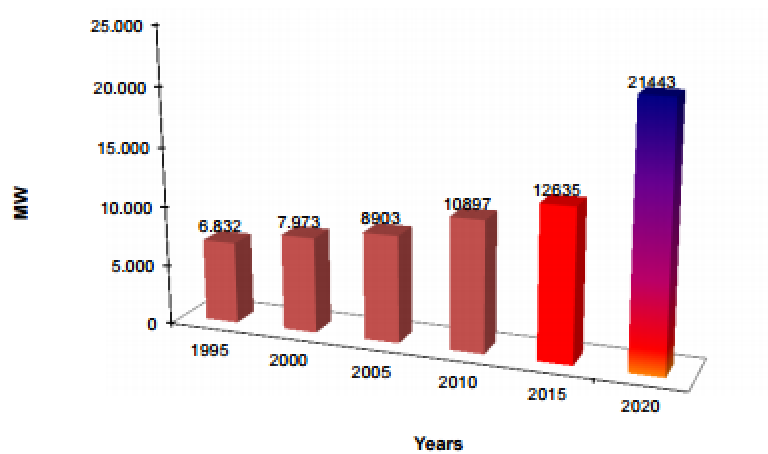


Figure 1.3: *Forecasting of the installed capacity in 2020.*

The most common use of geothermal energy is for space heating and cooling of residential or commercial buildings through use of heat pumps with 42 countries using such Ground source heat pump systems. The installed capacity of direct system is 79,253 MW (World Geothermal Congress, 2015). About 72% of which is used for space heating and cooling and for domestic hot water provision through individual units having size ranges from 5.5kw to 150kw in case of commercial buildings. The direct use is increasing at a compound rate of 11% per annum.

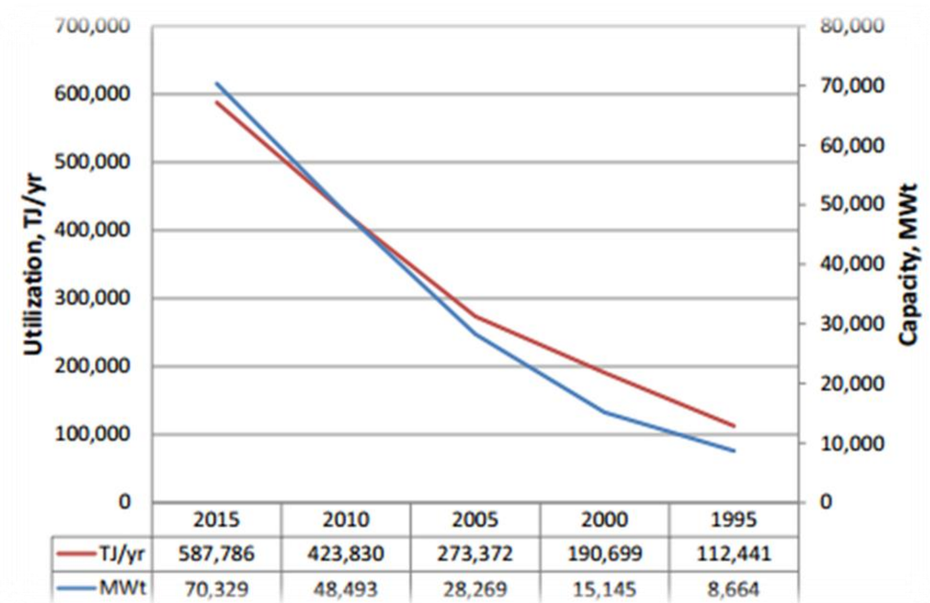


Figure1.4: *Direct use of geothermal energy production from 1995-2015*

1.6 Geothermal Energy and Pakistan:

Use of geothermal energy for heating/cooling of a building is an established practice throughout the world and is a cheap and sustainable substitute to the conventional HVAC systems driven by electricity having high per unit cost rate. About 54-60% of the total energy demand of a building is utilized on heating and cooling. In Pakistan the only direct use of geothermal energy is from hot water springs, mainly for bathing. In Pakistan there are hot water springs in Northern areas, Baluchistan and Sindh. These hot water springs can be used for power generation with surface temperature ranging from 62 °C to 212 °C. Bulk of these hot water springs are in the seismic belt of Pakistan (Younas et.al 2016). According to a report Pakistan has a capacity of 12000 MW. But not even a single MW is being utilized. To harvest this tremendous amount of energy, micro finance and other creative budgetary ways should be introduced to advance regional stimulation through renewable energies in the nation.

1.7 Objectives:

The main objectives of this project are:

- To study the feasibility of using Geothermal Energy for passive heating and cooling of residential buildings
- To develop a working model based on simulations as per local conditions.
- To carry out cost-benefit analysis of such systems over conventional heating and cooling systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Geothermal Energy:

Geothermal energy is the heat energy generated and stored in earth. It originates from the radioactive decay of the materials in core of the earth and naturally flows upward, in form of heat, because of geothermal gradient. It is a limitless source of energy on human timescale. It is scattered extensively throughout the earth, irrespective of the weather, season or other patterns. This energy can be harvested manually through deep or shallow well systems.

2.1.1 Deep Geothermal Energy

In the core of earth because of radioactive decay of different isotopes of uranium, thorium etc. a large amount of heat is generated and temperature rises to 6000 °C. This heat travels gradually to the surface of earth. It is not distributed evenly on the surface but is concentrated along active tectonic plate boundaries because the volcanic activity magma comes nearer to the surface. When water comes in contact with magma, temperature of this water rises and this hot water is then used for electricity generation in geothermal power plants. Also, groundwater moving through the fracture zones can gather this heat and can store it in shallow reservoirs at a distance from the tectonic regions. This hot water or highly compressed steam can be extracted by drilling boreholes. Normally it requires more than 600 meters of digging to harvest this deep geothermal energy.

2.1.2 Shallow Geothermal Energy

At a sure depth below the ground surface, normally below frost line the temperature rests persistent (Omer, 2006). This is because of the high thermal inertia of soil which moderates the temperature variations on the surface with increase in depth. Owing to thermal insulation provided by foliage and surface soil layers, cyclic changes in soil temperature deep in the ground are much less than and lag considerably behind seasonal changes in overlying air temperature (Florides and Kalogirou, 2007). So in spring, the soil naturally warms more gradually and to a reduced extent than the air, and by summer, it has become cooler than the overlying air and is a natural sink for eliminating heat from a building.

In this fashion, at a certain depth temperature is always greater than air temperature in winter and lesser in summer. This temperature difference b/w ground and air can be used as a source of heating in winter and of cooling in summer by implying ground heat exchangers.

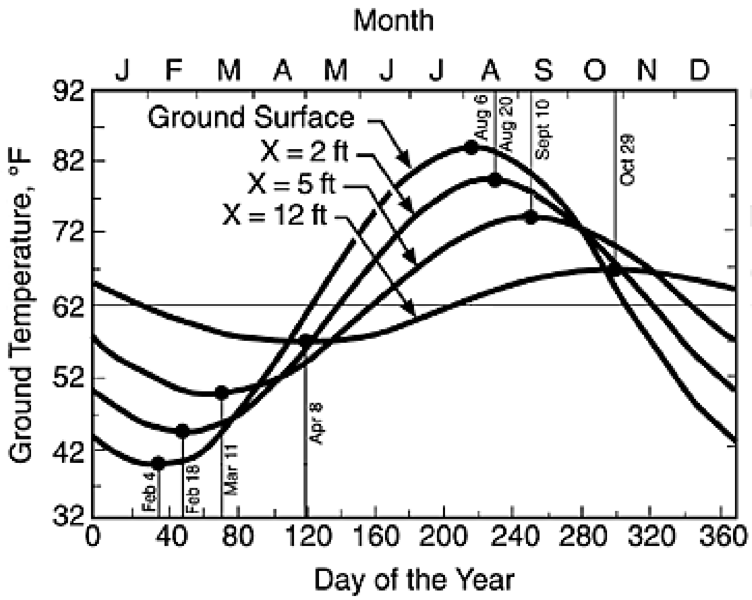


Figure 2.1: Temperature vs depth Virginia, USA

2.2 Geothermal heating and cooling system:

Geothermal heating and cooling systems are heat pumps which use ground as heat source or heat sink. And they do so by transferring or collecting heat from the ground through a series of underground vertically or horizontally laid water or an anti-freeze solution carrying pipes. These are also known as Earth energy systems.

Energy delivered by GSHPs is clean and its provision is constant. There is no dust or air blast around the building. When compared to the conventional fossil fuel system for heating and cooling of a building, GHG emission by GSHPs is 66% less. Also, these systems consume about 75% less electricity than conventional systems. And operating costs are about one-fourth of the conventional systems (Omer, 2006).

There are three major components of a ground source heat pump.

a) A Ground Loop Heat Exchanger
b) A Heat Pump
c) Building Internal Energy Distribution System

2.3 Ground Heat Exchangers:

Ground Heat Exchanger is the component that extracts the heat from the ground in winter or returns it to the ground in summer. Ground heat exchangers can generally be categorized into two groups.

2.3.1 Open Loop Heat Exchangers:

Open loop systems use surface/ground water or air directly as a carrier medium for heat transfer, for heating and cooling of building. This system is suitable where there is a surface water source present near the building for which we have to design this system. Ground water can also be used but there are chances that it will become polluted if any impurity is added to it through system.

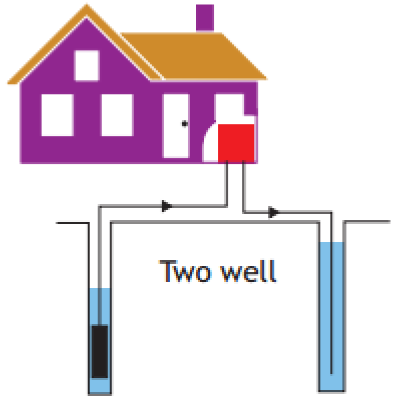


Figure 2.2: Ground water open loop heat exchanger

2.3.2 Closed Loop Heat Exchangers:

In a closed loop usually an anti-freeze solution circulates through a plastic tubing buried in the ground either horizontally or vertically (Sarbu and Sebarchievici, 2013).

Horizontal closed loop systems are installed where abundant ground area is available and can be further divided into two types (Self et al. 2013).

a) Trench Connections
b) Slinky Closed Loops

In horizontal trench a connection, GHE is buried usually a couple of meters below ground surface in a backfilled trench. In frost prone areas these pipes should be laid below the frost line (Self et al. 2013). In regions where small area is available GHE pipes are connected in a dense pattern either in series or parallel.

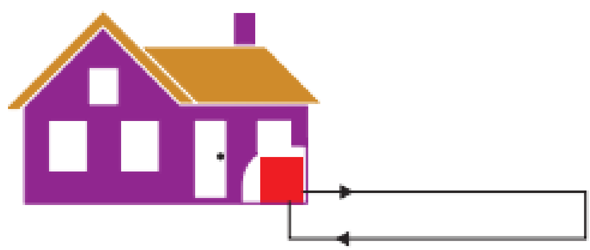


Figure 2.3: Horizontal Closed Loop Heat Exchanger

In closed spiral/slinky loops the piping is laid within the trench in circular loops. Spiral loops require less area than simple horizontal loops but for a fixed load, piping requirement increases (Cui et al. 2011).

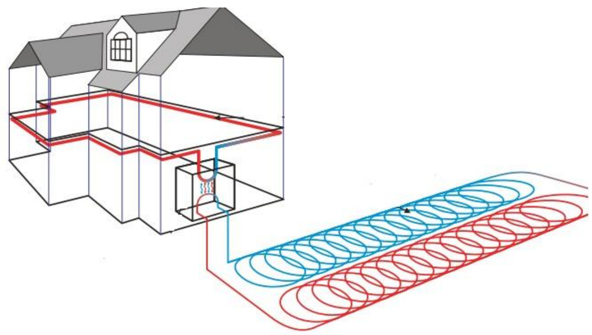


Figure 2.4: Horizontal Slinky/Spiral Heat Exchanger

A vertical closed loop system comprises a loop field consisting of vertically oriented U-tube heat exchange pipes. These U-tubes have a diameter ranging from 19-38 mm and a depth of 20-100 m (Yang et al. 2010) depending upon the requirement of either residential or commercial building and on the properties of soil. The bore hole is then back filled with some suitable grouting material. These vertical GHEs have higher investment cost than horizontal GHEs and are normally installed where ground area available is very small.

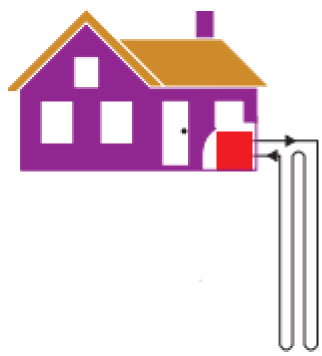


Figure 2.5: Vertical Closed Loop Heat Exchanger

2.4 Heat Pump:

A heat pump is basically a device which moves heat from a low temperature zone to high temperature zone under supply of work. A heat pump has four main components. The working of these components in heating mode is explained below:

a) Evaporator: It takes heat from the ground during winter. The refrigerant in the evaporator is at very low temperature. Water or anti-freeze solution takes up energy from ground and transfers it to the refrigerant in the evaporator.
b) Compressors: Refrigerant after taking energy from heat carrier fluid moves towards the compressor in form of vapors. Here in compressor it is compressed to a liquid form and its temperature and pressure is increased according to need.
c) Condenser: It exchanges the heat with the liquid/air moving inside the building. In condenser liquid refrigerant drops its temperature and is ejected from here as low temperature low pressure liquid.

d) Expansion valve: After passing through expansion valve the temperature of liquid refrigerant is decreased significantly. And this reduced temperature refrigerant is then moved toward evaporator.

In cooling mode the system is reversed by a reversing valve and the same heat pump starts delivering energy. In winters building act as heat sink for condenser's heat while in summers or in cooling season ground act as a sink for condenser's heat.

Working conditions of heat pump's evaporator and condenser have to be set according to the requirements i.e. temperature to be delivered to the internal distribution system, undisturbed ground temperature etc. These geothermal heat pumps are normally of two types, liquid to liquid and liquid to air heat pumps.

2.4.1 Liquid to liquid heat pumps:

This type of heat pump produces chilled water having a temperature of 10-14 Celsius when operating in cooling mode and hot water with temperature ranging from 40-50 Celsius when operating in heating mode.

The COP of performance of a GSHP is calculated using second law of thermodynamics. Normally the COP of heat pump is 3-4. Two other important factors are seasonal energy efficiency ratio and heating season performance factor. SEER is the ratio of cooling energy delivered by heat pump in BTU in a season to the electrical energy in KWh it consumed during that season.

$$SEER = \frac{Total\ cooling\ energy\ delieverd\ in\ BTUs\ in\ a\ season}{Total\ electrical\ energy\ input\ in\ Whr\ in\ a\ season}$$

The United States department of energy specifies that the SEER values should be greater than equal to 13 for both packaged and spilt systems. Same is the case for HSPF, which is ratio of total heating delivered by GSHP in a season to the electrical energy it consumed in the same heating season. The specified value for HSPF by department of energy is 7.

2.5 Internal Distribution System

Energy extracted by GSHP is delivered to the building by an internal distribution system. This internal distribution system can be a radiant floor or a chilled beam system.

In under floor heating or cooling systems also called as radiant floors or hydronic distribution systems water or anti-freeze fluid moves through a series of pipes embedded in the building floor.

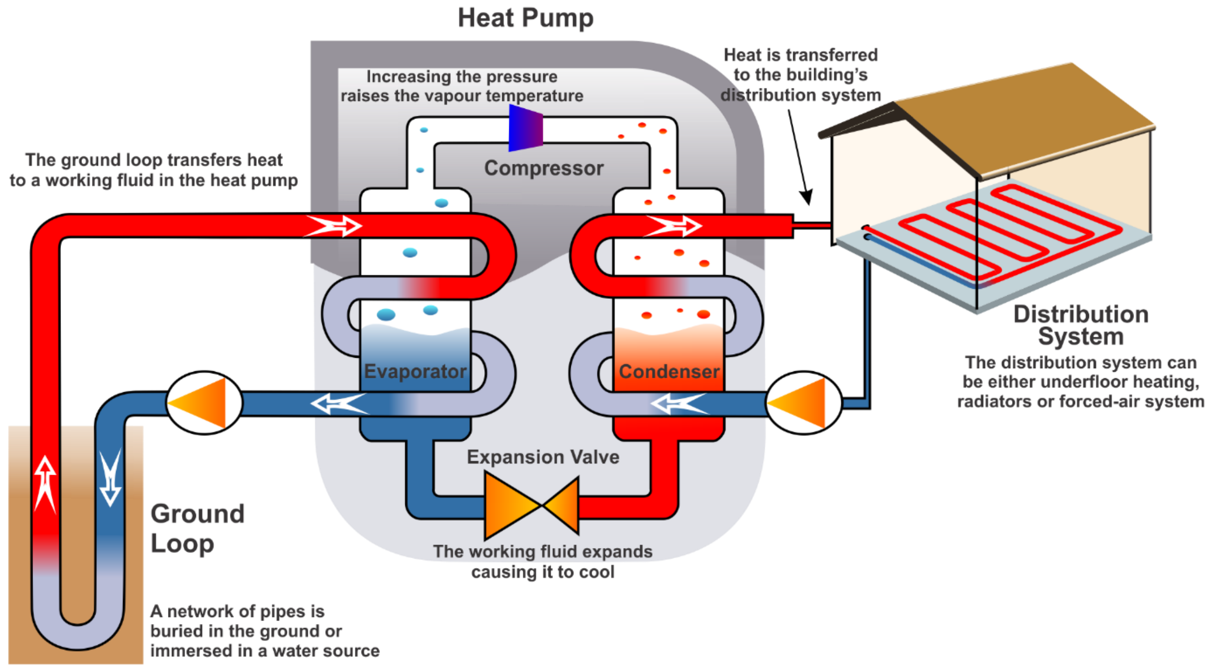


Figure 2.6: Schematics of Complete System

2.6 Heat Transfer Mechanism of GHE:

A number of studies pointed out that the heat-transfer of GHE in subsurface is mainly affected by thermo-physical properties of the ground. The heat transmission in subsurface is composed of heat transfer in solid ground and static water. So for better understanding the heat transferal of GHE/BHE in sub-surface, it is necessary to clarify the specific ground thermal and hydraulic conditions. These properties can be analyzed once we have the geological profile of the area where this GHE (in trench or borehole) is installed. For buildings having loads less than 30 kW these thermo-physical properties are enough for estimating BHE heat transfer and there is no need of performing thermal response test because of its economic infeasibility (Luo et al. 2016).

Thermal properties of soil include volumetric heat capacity (here after termed as VHC), thermal conductivity and thermal diffusivity. According to (Yun and Santamarina, 2008; Bertermann et al. 2014) parameters like texture, bulk density and water content of soil, grain size distribution and mineral composition of soil/rock are important in assessing these thermal properties. If soil is homogeneous then the VHC and thermal conductivity of soil remains constant with depth. VHC is the ability of any given volume of any substance to store internal energy while going through a temperature change but without going through any phase change. VHC and thermal conductivity have a direct relation with bulk density of soil. As the contact between soil particles increases, the porosity decreases. Also, as the soil texture becomes more and more fine its heat transfer proficiency tends to increase. Increase in water content of soil increases its thermal conductivity because the water fills the pores between the soil particles, and as the thermal conductivity of the water is 20 times more than that of air, so it increases the thermal conductivity of soil.

In closed loop GHE, groundwater affects heat transfer by conduction. The change in the ground water temperature because of thermal load can be slowed down due to large thermal capacity of water. In order to evaluate the groundwater advection effects on the heat transfer of borehole heat exchanger, the flow velocity and direction of flow are necessary.

2.7 Thermal Examination of GHE:

A thermal examination of GHE is necessary for determining the temperature of the heat carrying fluid circulating in the U-tube. Heat transfer in borehole heat exchanger is a complex process and involves several factors like ground thermal properties, the ground-water flow rate and building loads over a long lifespan of several years. According to (Cui et al. 2011), keeping in mind the said complications, the heat transfer process should be analyzed in two separate regions. One is solid ground outside the borehole field where heat conduction is a transient process and the second region is inside borehole including grout, GHE U-tube pipe, and circulating fluid. Analysis on these two regions is interlinked on the borehole wall.

2.8 Design techniques for GSHP systems and GHEs:

A GHE design is stable and reliable if the heat buildup or heat loss in the ground in long term is not high. There are number of factors which influence the final sizing of GHE like

a) Heat pump entering and leaving liquid temperatures (ELT & LLT).
b) Configuration of boreholes
c) Annual net heat transfer to/from ground
d) Mathematical model used for designing
e) Arrangement of Ground heat exchanger

A number of mathematical models have been developed for heat conduction outside borehole. Some of these methods include:

a) Kelvin's line source model
b) Cylindrical source model
c) Finite line source model

Also, for heat exchange inside bore different models developed includes, one, two and quasi-three dimensional models (Gu et. al, 1998).

Guideline	Country	Type of Procedure	Year
American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)	USA	Analytical	2011
International Ground Source Heat Pump Association (IGSHPA)	USA	Analytical	2009
Verein Deutscher Ingenieure (VDI)	Germany	Simplified	2010
Microgeneration Certification Scheme (MCS)	UK	Simplified	2013

Table 2.1 Design Techniques for GSHP systems

To achieve better results, analytical techniques are preferred over simplified techniques. This is because of discrepancies often found in designs performed using simplified techniques because they do not include revaluation of design factors and parameters (Sailer et al., 2015). The primary distinction between ASHRAE and IGSHPA techniques is in the design procedure for estimating the long term temperature penalty in the ground. ASHRAE suggests that long term temperature be calculated through analytical techniques while IGSHPA uses a correction factor for long term temperature change.

2.9 Software:

Different design software are also available. The Lund program, this was developed by university of Lund Sweden. This software was based on Eskilson's finite line source model. It uses g-functions, whose values are dependent on the borehole separation distance and borehole depth.

A more user friendly software EED (earth energy designer) was developed on the same basis of Lund program. In EED anti-freeze temperature of GHE are calculated on the basis of monthly thermal loads and resistance of borehole.

2.9.1 GLHE pro:

The development of GLHE pro was chiefly for scheming vertical ground loop heat exchangers used in commercial/institutional buildings. The basis of this software is also eskilson's approach.

2.9.2 GeoStar program:

This software was developed by a group of researchers in China. It sizes the GHE according to values of minimum and maximum ELT to heat pump for the conditions defined like thermal properties of the ground, arrangement of boreholes, thermal loads of building and the conditions set for borehole operation.

2.9.3 GchpCalc program:

This program was developed on the basis of the concepts of Kavanaugh and Rafferty (ASHRAE, 1997). Calculation basis of this software are built on cylindrical source method presented by Carslaw and Jaegar. For calculation of required borehole length a steady-state equation for heat exchange was used. This takes into account three different temperature pulses. These pulses consider thermal disproportions in ground for long term, for monthly basis and for short term, for one day or for few hours. The base of solution

2.9.4 Limitation of design software:

One major limitation of most of these software and methods is that they do not take into account the influence of the groundwater flow around the borehole, on GSHP system efficiency. This is because thermal interference here is very crucial to sizing of ground heat exchanger.

2.10 Heating and Cooling Loads:

Calculating Building's heating and cooling loads is the first step of designing the geothermal system for heating and cooling of residential buildings. There are many techniques available for calculating heating and cooling loads such as MEP plugin of REVIT, TRNSYS software, ASHRAE design manuals and Hourly Analysis Program HAP. Heating and cooling load calculation process will govern the equipment selection as well as duct design for the design GSHP. The peak heating and cooling loads are calculated in Btu/h (Btu per hour). Liu and company suggest TRANSYS software for this purpose (Liu at al., 2015).

2.11 Critical Factors affecting heating and cooling loads:

For evaluating cooling loads, we have to take into account the unsteady state processes, since the peak cooling load occur during the day time and the outside conditions also change significantly throughout the day. Internal sources add to the cooling loads and hence cannot be neglected. Thus cooling load calculations are more complex as they involve solving unsteady equations with varying boundary conditions and internal heat sources.

The critical Factors that affect the heating and cooling loads of a building according to (Obuka et al., 2015) are discussed as follows.

2.11.1 Orientation of the Building:

Orientation of a building defines the location of the building with respect to wind and solar effects which have a major impact on the temperature of any building. The adjoining buildings and structures provided for shade also have an impact on the temperature of the building under consideration.

2.11.2 Building Type:

The type of the building (house, plaza, hospital, school, etc.) defines what kind of internal loads will affect the temperature of the building.

2.11.3 Design/Dimension of the Building:

Dimensions of a building include length, width and height. Physical dimensions such as these define the size of a building. The bigger the size of any enclosed space, larger will be its heating and cooling loads.

2.11.4 Characteristics of Building Enclosure:

Amongst these are insulations provided in the walls and ceilings, floor-to-floor height, window specifications and sizes, infiltration and ventilation levels and the like. These factors affect the heat-exchange process in buildings. Window specifications include thermal conductivity and solar heat gain coefficient.

2.11.5 Internal loads of a Building:

The number of occupants, their duration of occupancy, the nature of their occupancy, the lighting and appliances used in the building are the factors affecting the internal loads of a building. Occupants generate significant heat and so it is important to study these parameters involving them while calculating heating and cooling loads. Lighting loads are usually calculated in Watts. Appliances that generate significant heat are examined and their wattage is noted for calculating loads.

Assumptions for designing heating and cooling loads are as follows:

Design of outside conditions is selected from a long-term statistical database. The conditions will not necessarily represent any actual year, but are representative of the location of the building. The load on the building due to solar radiation is estimated for clear sky conditions. The building occupancy is assumed to be at full design capacity. All building equipment and appliances are considered to be operating at a reasonably representative capacity.

2.12 Heat Carrying Fluids

Heat carrying fluids are used in solution with water in Ground Heat Exchangers. An ideal heat carrying fluid has great thermal conductivity and is non-toxic, chemically stable, non-corrosive and cost effective. A fluid comprising of all the above characteristics is non-existent in nature (Karen Den Braven, 1998)). While speaking of efficiency, every heat carrying fluid has its own positive and negative aspects in relation to the location and conditions. Similarly, every heat carrying fluid will have its own environmental impacts (Everett W, et. al. 1995).

CHAPTER 3

METHODOLOGY

3.1 Digging of boreholes:

In order to Study the subsurface conditions, we dug boreholes at 4 different locations in National University of Sciences and Technology. This was to study the effect of surface conditions on the temperature variation between surface and sub-surface layers of the soil. Earth profiles at these locations was also collected and studied for thermal properties. Digging of 6 bore holes was necessary because of three reasons.

a) To incorporate change in soil properties.
b) To check the effect of soil on subsurface soil temperature and thermal Properties.
c) To cover major portion of the university campus.

Auger, available in the Geotech lab of the department, was used to dig boreholes in the campus. The bore diameter of the auger that was used in this study is 6 inches.

3.2 Temperature Data Logging:

Due to unavailability of subsoil temperature data in the respective region, we designed a temperature data logging system. Such system is shown in figure 3.1. The temperature data at different depths in the bore holes was continuously recorded over the project tenure. This is done by installing high precision temperature sensors at different depth in the bore holes. The bore holes were back filled with soil. Daily mean temperature value was calculated to study the behavior of variation of temperature in the area under observation.

This system is cost effective, efficient and easy to assemble. It enables us to Log the temperature data of each day in a separate file along with time of data input. This system, like any other system, carry out 3 processes; Input, Processing and output.

3.2.1 Input

This data logging system takes input from Real time clock and Temperature sensor.

Real Time clock:

Real Time Clock (RTC DS1307) is a serial time clock, low powered and full binary coded decimal clock calendar. Address and data are transferred through an I2C, bidirectional bus. It provides seconds, minutes, hours, day, date, month, and year information, with an automatic adjustment to leap years.

RTCs use a crystal oscillator. The frequency of the oscillator is 32.768 kHz. Quartz clocks and watches use the same frequency.

Temperature Sensors

There are wide Range of Analog Temperature sensors available in the market of different ranges and characteristics. We used two sensors LM35 and Negative Temperature Coefficient Thermistor. The Characteristics of both the sensors are tabulated below in table 3.1.

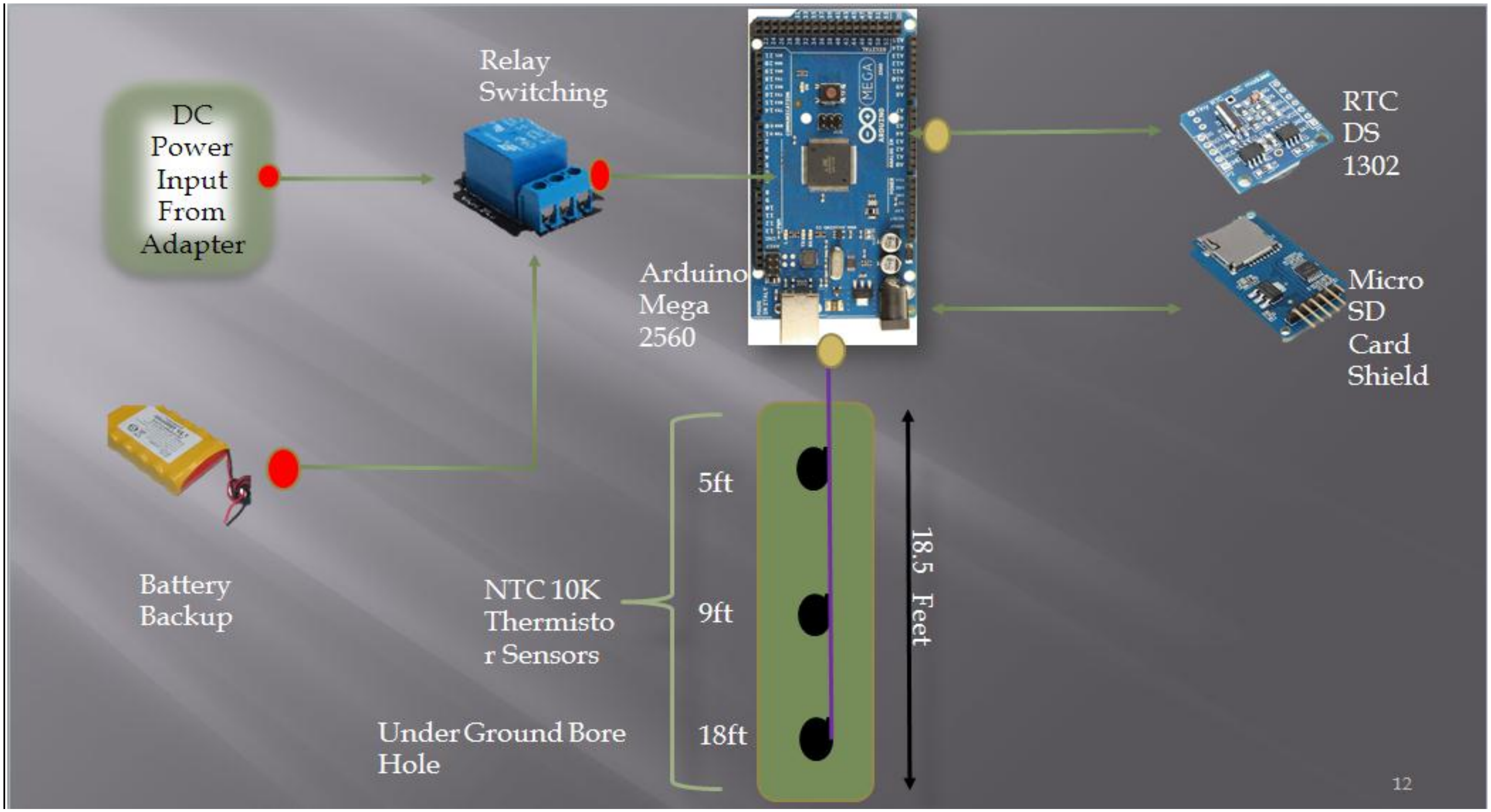


Figure 3.1: ground temperature data loging system

Property	LM 35	NTC 10KΩ
Calibration	^oC	^oC
Accuracy	±0.5^oC	± 1^oC
Cost	HIGH	LOW
Voltage	5 volts	No specific range
Working Pins	3	2
Wires required per sensor	3	2
Stability	LOW	HIGH
Response Time	LOW	HIGH
Power Requirement	HIGH	LOW
Temperature Range	LOW	HIGH

Table 3.1: Comparison of two temperature sensors on basis of various properties.

NTC Thermistor was preferred over the LM 35 analog sensor because NTC thermistor:

a) Is more stable as compared to LM 35
b) Has less power consumption.
c) Requires only 2 wires per sensor in comparison to LM 35, which need 3 wires per sensor which reduces Cost.
d) Is cost effective.
e) Is encapsulated in copper capsule which is water proof and hence reduces chances of short Circuiting.

3.2.2 Processing:

All the processing is done by Arduino Mega 2560 board, a micro controller kit for building and controlling digital projects. This controller is basically a complete package of microcontroller and it's supporting electrical components.

The main function of Arduino board in data logging system is to take input from the temperature sensors and RTC, sorting the input and writing it in a txt file with a comma "," with in between the values. This is called comma separated files. The extensions of such txt files can be changed from ".txt" to ".csv" in order to open it in the Microsoft Excel program.

The Logical steps of the Software program are as following, these steps are performed again and again in an infinite loop.

a) Arduino takes input of date and month from RTC in the form of variable.
b) A file is created in the name of the respective date.
c) If the file already exists the Arduino just appends the file.
d) Arduino then takes time input from RTC and temperature inputs.
e) Arduino writes these values to the file in order and saves the file in micro SD card.

The original program is attached in Appendix A.

3.2.3 Output:

Output of the system is in the form of text files, stored in a micro SD card. These files contain time stamps and temperature values. This can be converted easily into CSV file. This CSV file can be analyzed worked on and graphed in Microsoft excel. The data was logged at 10 second intervals over the tenure of the project.

These files were processed in Microsoft excel and averages of temperatures were calculated. These averages were plotted on two time scales vs. temperature.

a) Daily
b) Monthly

The graphs were analyzed and results and conclusions were drawn. The design temperature for our ground heat exchanger was also output of these graphs which was 21^{o}C.

Furthermore the process is explained by the figure 3.1.

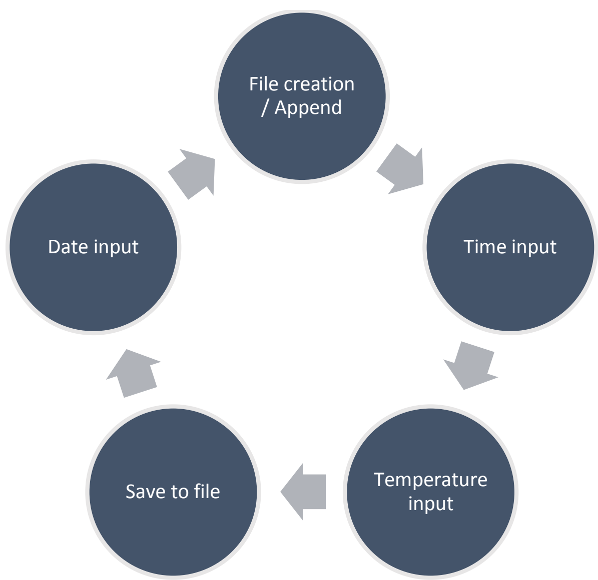


Figure 3.1(a): Process of data logging.

3.3 Soil Properties:

We needed a complete profile of the subsurface rock or soil layers, as different materials have different properties depending upon their composition, density and water content. Soil type plays a major role in estimating the feasibility of Ground Loop Systems. Local reports showed that the most commonly occurring soil type in Islamabad region is Shale followed by Sandstone which is decomposed into silt stone in some areas. These reports were acquired from a local Geotechnical research institute. Thus design of GHE was based on Ground Parameters of Shale. The undisturbed ground temperature was acquired from the borehole data logging system as discussed in section 3.2 of this report.

This helped us in assessing thermal properties of soil which in turn enabled us to calculate the heat transfer capacity of soil. Moreover superficial and bed rock strength helped us estimating cost of drilling cost and deciding whether we have to install our system horizontally or vertically.

Properties of shale and Sand stone are given in the table 3.2.

Soil Type	Thermal Conductivity (k) Btu/h·ft·°F	Thermal Diffusivity (α) ft^2/day	Specific Heat (c_p) Btu/lb·°F	Density (ρ) lb/ft^3	Undisturbed Ground Temperature °C
Shale	1.8	0.55	0.21	150	21

Table 3.2: Thermo-physical Properties of Shale

3.4. Heating and Cooling load estimation:

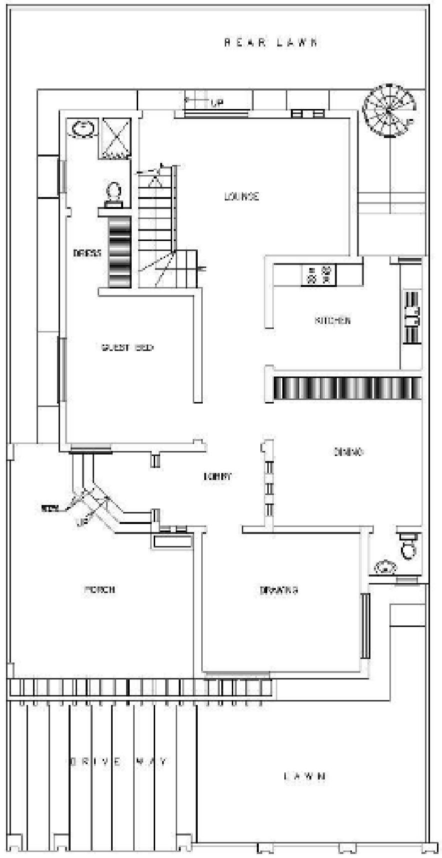
We chose to calculate heating and cooling loads using MEP plugin of Autodesk Revit 2015. Details of design input parameters for estimation of heating and cooling loads is further explained in this section.

3.4.1 Location of the building:

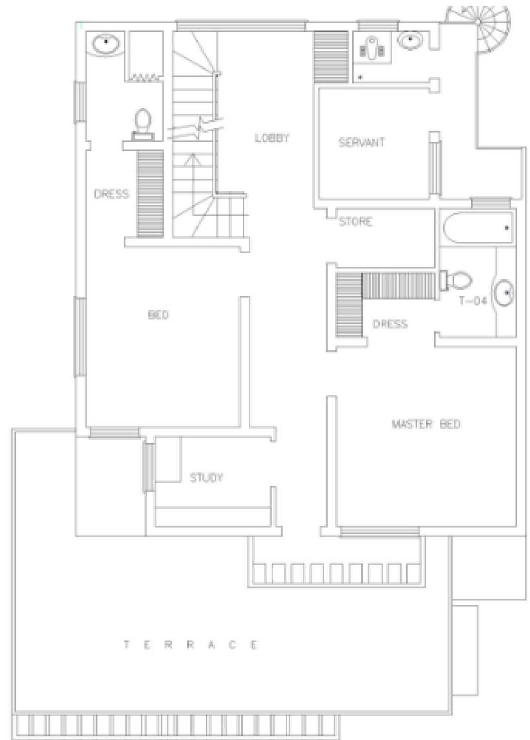
A two story building situated in H-12, Islamabad, Pakistan was selected for heating and cooling load calculation. Humid sub-tropical local climatic conditions imply hot summers and mild to cold winters in Islamabad. Outdoor temperature of the building ranges from a low of 0.5°C to a high of 45°

3.5Building Enclosure:

Covered area of the selected building was 3200 ft² and enclosed floor area was 2613 ft². The Figures of the building plans are shown below.



GROUND FLOOR PLAN



FIRST FLOOR PLAN

Figure 3.2:Floor Plans of the Selected Residential Building

3.5 Energy Transfer Capacity:

Using the soil thermal properties and temperature difference we will be calculating the capacity of the soil to dissipate or gain energy.

3.6 Selection of Design Techniques

As discussed in literature review, analytical techniques are generally preferred over simplified techniques because they include a more efficient and systematic use of parameters involved. ASHRAE procedure is selected because it reinforces the importance of long term temperature change in the design whereas IGSHPA suggests the use of a correction factor for this purpose. Importance of long term temperature change is stressed upon because our building is situated in a region where there is bound to be significant annual heat imbalance in the ground due to relatively longer summers.

3.7 Selection of Heat Pumps

Selecting a suitable heat pump is of vital importance in ensuring that an acceptable degree of efficiency is achieved by the GSHP system. This selection is based on the calculated heating and cooling loads. Any heat pump of decent rated power can be selected. However for efficient operation of the system, a heat pump which meets the building loads requirement. Heating and cooling loads of the building were matched against nominal heating and cooling capacities of the heat pumps. These nominal capacities were then matched against their respective required rated powers in WATTs. Rated power was 3411Watts for cooling mode and 4079Watts for heating mode. These rated powers resulted in specific coefficient of performances for both heating and cooling mode.

Operational Mode	Net Output Required Btu/hr.	Power Required Watts	Net Output Rated Btu/hr.
Cooling	57011	3411	59572
Heating	36901	4079	45735

Table 3.3: Heat Pump Operations

3.8 Selection of Grouting Material

After selecting piping material, the next step is to select suitable material for grouting the borehole. Grout fills the void between pipe and the soil. Criteria for selecting material for grouting are similar to that of piping material. Since pipes are enclosed by grout, so grout material should have thermal conductivity which compliments the thermal conductivity of pipe material. This ensures efficient heat transfer in the ground loop because of enhanced thermal conductivity of Ground Heat Exchanger.

The most commonly used materials for grouting in Ground Heat Exchanger are Sodium Bentonite recipes with Silica Sand and Cement recipes with Graphite. Thermal conductivities of both Bentonite and Graphite grouts vary with change in proportions. Bentonite grouts are generally preferred over Graphite grouts for residential systems owing to their relatively lower costs and generally comparable thermal conductivities. A comparison of different grout material recipes is listed in table 3.4.

Grout Recipe	Thermal Conductivity Btu/h·ft·°F	Density lb/ft^3
Bentonite 1:2 Sand	0.70	89.76
Bentonite 1:4 Sand	0.9	93.50
Bentonite 1:8 Sand	1.2	112.98
Cement 47:100 Sand	1.2	136.1455
Cement 10:3 Graphite	1.4	83.78

Table 3.4 Thermal Properties of different Grouts

Sodium Bentonite recipe with 1 part Bentonite and 8 parts Silica Sand was selected for our Ground Loop Design. It has a thermal conductivity of 1.2 Btu/h•ft•°F and density of 112.98 lb/ft^3. This thermal conductivity value is mutually compatible with thermal conductivity of selected HDPE pipe, ensuring efficient heat transfer from ground to pipes.

3.9: Selection of Heat-Carrying Fluids:

After selecting materials for piping and grouting, we had to select a suitable heat-carrying fluid for circulation inside the pipe. Factors that influence the selection again revolve around thermal conductivity and cost. Aside from these two major factors, there are other considerations as well which measure the effect of fluid on long term efficiency of the Ground Heat Exchanger. These secondary factors also take into account the environmental impact of the fluid. Numerous antifreezes are recommended for this purpose with varying balance between efficient heat transfer and Ground loop long-term efficiency. Antifreeze solutions are often preferred to avoid losses due to freezing as the temperatures inside the heat pump may fall below 0oC.

Long term efficiency of ground heat exchanger is strongly related to some physical properties of the antifreeze solution. These include toxicity, flammability, stability and corrosiveness. The behavior of antifreeze upon interacting with the pipe material, or with grout material and surrounding soil in the case where there is any occurrence of leakage. Moreover, the possibility of contamination of groundwater should be considered and catered for by selecting antifreeze that is chemically stable and non-toxic in nature. Another consideration is the behavior of viscosity of the fluid with varying temperature as change in viscosity will hinder in maintaining a steady flow through the ground loop. A comparison among different antifreeze solutions commonly used in Ground Loop Heat Exchangers is shown in table 3.5.

Antifreeze Solution	**Freezing Point**	**Temperature (°C)**	**Viscosity (cp)**	**Flow Type**
20% Propylene glycol	-7.2°C	0	4.07	Transitional
		10	2.37	Transitional
		30	1.52	Turbulent

Table 3.5: Thermal Behavior of Antifreeze Solutions

20% Propylene glycol is best-suited for our purpose given its comparatively smoother variation of Flow with change in temperature. It can be inferred from table 3.4, 25% Methanol and 30% Propylene Glycol show high variation in flow when subject to similar temperature change. 30% Propylene glycol provides a relatively better freezing point. However, our heat pump requirements for fluid freezing point are easily met by its 20% counterpart.

3.10 Pipe Material Selection for GLHE

When designing a Ground Loop Heat Exchanger, particular attention must to be paid to maintaining balance of heat exchange between different components of the Heat Exchanger. This requires that the heat exchanger materials which include piping material and grout material have mutually compatible thermo-physical properties i.e. they must have thermal conductivities that lie within range of each other.

There are various options for piping material for Ground Heat Exchangers. Each having its own pros and cons. Polyethylene pipes are most commonly used in Ground Loops because of their cost effectiveness with decent thermal conductivity and their compatibility with a range of heat-carrier fluids. Moreover they have very low repair frequency aside from being strong and highly durable. Other available piping options include copper pipes and stainless steel pipes which have very high thermal conductivities but are also very expensive. Copper pipes having high thermal conductivities is often counterproductive since their high thermal conductivities are not compatible with grouts having relatively low thermal conductivities as it results in inefficient heat transfer.

High density Polyethylene (HDPE) pipes are corrosion resistant, lightweight and much cheaper as compared to copper and stainless steel pipes. Moreover their thermal conductivities lie perfectly within range of most commonly used grout materials. Other advantages of HDPE pipes include less fittings required due to pipe flexibility and excellent durability. A comparison of copper and HDPE pipes is shown in table.

Pipe Material	**Copper**	**HDPE Pipe**
Life	20 years	70 years
Flexibility	Non-flexible	Flexible
Thermal Conductivity	Very high (232.42 Btu/h.ft.°F)	Moderate (0.26 Btu/h.ft.°F)
Plumbing	Requires fittings	Requires less fittings
Cost	Very expensive	Cheap
Durability	Highly corrosive	Non-corrosive

Table 3.6: Pipe material properties

So 1 inch, double U tube DR11 HDPE pipes having thermal conductivity of 0.26 Btu/h.ft.°F and density of 58.68 lb/ft^3 were selected.

3.11 Borehole Thermal Resistance

Borehole thermal resistance is the resistance between the antifreeze liquid and the outer borehole wall. Significance of borehole thermal resistance can be inferred from the fact that low borehole thermal resistance can lead to more favorable temperatures of antifreeze entering the heat pump which in turn can help in maintaining better heat pump performance. Temperature difference between the circulating antifreeze solution and the borehole outer wall can have an adverse effect on heat pump performance (AA Koenig, 2015). Reduction in borehole thermal resistance can lead to less drilling costs because of reduction in required bore length. In our case, the use of a thermally enhanced grout is advantageous because increased thermal conductance can limit the value of borehole thermal resistance.

Borehole thermal resistance was calculated using ASHRAE recommended analytical method. It takes into account the thermal resistances of pipe and grout.

$$R_b = R_p + R_{gt}$$

Where Rb is borehole thermal resistance, Rp is pipe resistance and Rg is grout resistance. Pipe and Grout resistances were estimated using ASHRAE tabulated values for different piping and grouting materials. Following equations can also be used to get values of Rp and Rgt.

$$R_p = [(1/ (\pi d_i h_{conv}) + \ln(d_o/d_i) /2 \pi k_p)]/4$$

Here di and do are inner and outer diameters of pipe respectively and k_p is thermal conductivity of the pipe material.

$$R_{gt} = [\beta_o (d_b/d_o)^{\beta 1} \text{ x } k_{grt}]^{-1}$$

Here d_b is borehole diameter and kgrt is thermal conductivity of grout material. Values of β_o and β_1 have been estimated for different configurations of pipe arrangements. Our selected arrangement falls under C type configuration i.e. double U tubes inserted with spacers implying β_o=21.97 and β_1= -0.3795.

3.12 Ground Heat Exchanger length

Considering all the discussed parameters, the GHE length was calculated by the formula proposed by Kavanough and Rafferti.

$$L = \frac{q_a R_{ga} + Q_{cond}(R_b + PLF_m R_{gm} + F_{sc} R_{gst})}{T_g - \frac{ELT + LLT}{2} + T_p}$$

Where q_a is the net annual heat imbalance, Q_{cond} is the rate at which heat pump condenser is rejecting heat to the ground, R_b is the thermal resistance of the borehole, PLF_m is the part load factor for the design month, R_{ga} ,R_{gm} and R_{gst} are the effectives thermal resistances of the ground for annual, monthly and short-term heat pulses respectively, ELT is entering liquid temperature to heat pump on sink side, LLT is liquid temperature leaving the heat pump Q_{evp} is the rate at which the heat pump evaporator is taking heat from ground.

This formula is applicable to calculate both the required cooling and heating lengths by just changing Q_{cond} to Q_{evp} for calculating heating length and the selected design length should be the greater of the two lengths.

3.13 Long Term Temperature Correction

Long term temperature change results from imbalance between heat discharged to the ground in cooling mode and heat removed from the ground in heating mode. Long term temperature change typically relates to net annual heat transfer. This temperature change is measured in terms of a correction factor for bore length called Temperature Penalty (t_p). It is calculated using the formula stated in ASHRAE guidelines:

$$t_p = Q/ (\rho c_p S^2_{bore} L_b)$$

Here Q is a measure of design-specific annual heat transfer, c_p is specific heat of the ground, S_b is bore separation and L_b is required bore length. From the equation it is clear that long term temperature change is dependent on spacing between boreholes and the net annual heat transfer. ASHRAE recommends that this long term temperature penalty must be less than 5^{o}F or 2.5^{o}C. If it exceeds the stated limits, then the required borehole length should be re-calculated by incorporating temperature penalty.

3.14 Energy Consumption Calculations

Energy consumption of both conventional and GSHP systems for heating and cooling of buildings will be calculated. Determining how much electricity our systems conventional and modified, use, will help us understand how much the system is costing us on the basis of operational cost.

3.15 Economic Study

Economic decision will be carried out on the basis of the following key points:

1. Energy Efficiency
2. Budgeting for Upgrades
3. Guaranteed Energy Savings
4. Environmental Impacts
5. Payback Time

CHAPTER 4

RESULTS AND CONCLUSIONS

4.1 Temperature Graphs:

The recorded data was plotted on two scales that are daily and monthly means. Following points were observed when the data was pondered on.

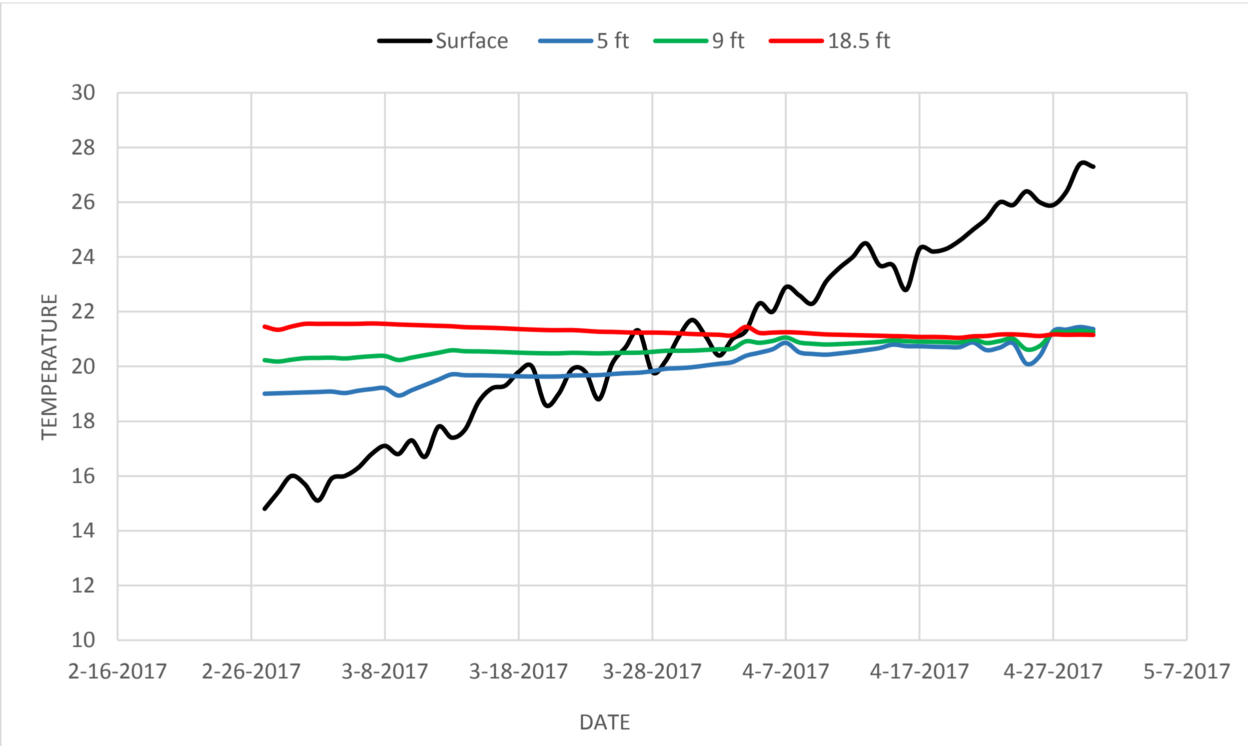


Figure 4.1: Temperature behavior at various depths

1- The temperature variation at ground surface is very high and is continuously increasing over the period of observation, which is February to April. As we can see from the graph that the average temperature at the end of February is approximately 15ºC while in the month of April it rises above 24ºC.

2- There are sudden drops in the surface temperature curve causes of which include rainfall that reduced the temperature of the surface of earth.

3- Ability of the soil to gain and loose temperature is lower than the atmosphere because of the heat energy retaining capacity of the earth. When sun rises the temperature of atmosphere rises more quickly compared to earth surface and similarly the temperature change at sunset is high in the atmosphere compared to ground.

4- The short term rise and fall of the temperature at surface does affects the shallower sub surface level but the magnitude of variation minimizes as the depth decreases and we reach out to deeper soil layers.

5- From the above points we can conclude that the temperature of the earth does not change drastically or can be said that it is more stable than the surface temperature.

6- As we go down further and as the depth of the soil layer increases the effect of the surface soil temperature decreases drastically.

7- The decrease in temperature variation is directly proportional to the depth of the soil layer but the relation is nonlinear.

8- At 18.5 feet depth we get minimum variation in the temperature and as we can observe from the graph that a very stable line is obtained throughout the tenure of data recording.

9- This forces us to ponder on that the rise and fall of temperature at 18.5 feet is negligible and we can observe that at the end of February 2017, it was recorded that the difference between the surface temperature and temperature at 18.5 feet is -6.7^{o}C and in the month of May the temperature difference between the same points was 6.2^{o}C.

10- This gives us space and opportunity to harvest this temperature difference and utilize it for heating and cooling purposes.

11- By shrinking the time scale of the graph to monthly level we can get a crystal clear picture of the scenario which helps us understand the phenomenon more easily.

12- As we can see that the gradient of the temperature curve at surface is quite high, while the gradient of temperature behavior at 5ft, 9ft and 18.5ft is low, lower and lowest respectively.

13- In the month of March the surface temperature recorded was low which rises with a very high gradient to 24^{o}C in April, from 18^{o}C. While the average temperature at the depth remains constant at 21^{o}C.

14- More over these graphs gives us the major input design perimeter of Ground Heat Exchanger which is 21^{o}C.

Other information that this graph gives us is that in order to install Horizontal Heat Exchanger we need to dig at least 10 feet into the earth. This is the minimum depth at which the subsurface temperature conditions are not affected by surface temperature variation. This minimum depth is known as frost line

4.2 Design Results:

In the light of the studies conducted on the residential building located in Islamabad for the GSHP system following the procedure discussed in the methodology, following components were considered as the most feasible options.

Various different options for heat pump selection by manufacturer were available. Once all the requirements are known the choice of heat pump selection is totally up to the consumer/buyer. The selected heat pump was a W-type water to water heat pump of 5 ton capacity by NORDIC.

The calculated coefficient of performance for selected heat pump was 4.2 in cooling mode and 3.28 in heating mode. The difference in these two COP's is because the system is optimized for cooling demand.

To get a perfect match for the optimized system, grouting material with different thermal conductivities and boreholes of different diameters were evaluated. The best combination of grout and borehole diameter was of bentonite: sand (1:8) and a 6 inch diameter borehole with a double U-tube of HDPE pipes inserted in it.

This combination gave us a borehole thermal resistance of 0.10 h.ft.°F/Btu.

For calculation of the required borehole heat exchanger length different schemes were employed varying in number of boreholes, separation distance of boreholes and arrangement of boreholes. And the effect of all these 3 parameters on the long-term ground temperature change in the vicinity of the boreholes for a period of 20 years was studied. The available plot size was another important parameter.

Different schemes that were used include:

- 3x3 Grid Pattern with borehole separation of 20 feet.
- 3x3 Grid Patter with bore hole separation of 25 feet.
- 4x2 Grid Patter with bore hole separation of 20 feet.
- 4x2 Grid Patter with bore hole separation of 25 feet.

3x3 Grid Pattern			
Separation Distance (ft)	**Total Required Length (ft)**	**ΔT_p (°C)**	**Required Length/Borehole (ft)**
20	1494	1.26	166
25	1430	0.71	159

Table 4.1: 3X3 Grid pattern

4x2 Grid Pattern			
Separation Distance (ft)	**Total Required Length (ft)**	**ΔT_P (°C)**	**Required Length/Borehole (ft)**
20	1510	3.72	189
25	1510	2.68	189

Table 4.2: 4X2 Grid pattern

The temperature penalty calculated in all the above mentioned schemes was positive because the annual inflow of heat to the ground is much higher than the outflow of heat from the ground.
The 4x2 grid pattern with a borehole separation of 20 feet was totally unacceptable because the temperature penalty (**ΔT_P**) was exceeding the recommended limit which is 5 °F or 2.7 °C. This excessively high, long term temperature change lowers the efficiency of the GHP since the temperature of the anti-freeze moving through the closed loop of the GHE is affected by this ground temperature change. As inlet temperature to the heat pump changes, its efficiency increases or decreases accordingly.
The best scheme was a 3x3 pattern with a separation distance of 25 feet because the minimum temperature penalty of 0.71°C. But the selected pattern was a 3x3 gird with a borehole separation distance of 20 feet because of the limitation of the plot size.

4.3 COST BENEFIT ANALYSIS

For the cost benefit analysis of Ground source heat pump system designed for the selected building it was compared with the conventional system installed in the building.

There are different conventional methods used for heating and cooling like natural gas heaters, electric heaters, water geysers for domestic heating of water, air conditioners etc. In Pakistan the most commonly used appliances for cooling in summers are air conditioners and for heating purpose in winter are electric heaters or natural gas heaters.

Analysis for the two systems was based on:

- Capital costs comparison
- Annual operational costs comparison

4.4 GROUND SOURCE HEAT PUMP SYSTEM CAPITAL COST

As discussed in previous sections, GSHP system comprises of various components. A component-wise breakdown the GSHP capital cost is shown in table X.Y.

Sr. No	Component	Cost (lac rupees)
1	Heat Pump	6.5-7.5
2	Ground Heat Exchanger(Piping Material)	2.2
3	Drilling	7-7.7
4	Antifreeze Solution	0.8
5	Grouting	1.3
6	Installation	2.1
7	Circulator Pump	0.7
8	Miscellaneous Costs	0.55
9	**TOTAL**	21.15-22.85

Table 4.3: GSHP Capital Cost

Major influential costs are the geothermal heat pump cost and the vertical borehole drilling costs which were estimated to be Rs.7.5 lacs and Rs.8.1 lacs respectively. Similarly, cost for other components were calculated which totaled to a sum of Rs.22.85 lacs.

Cost for internal distribution system which was an underfloor heating and cooling system was calculated and came out to be:

Cost/Unit	Covered Area	Total Cost
Rs.180-210/ft^2	2613 ft^2	Rs.470,340 – 548,730

Table 4.4: Distribution System Cost

So the total cost of the ground source heat pump system with distribution system lies between Rs.25.87 - 28.33 lacs. This cost includes a 10% contingency, the shipment costs were also incorporated as ground source heat pumps are not available in Pakistan and need to be imported.

4.4.1 Conventional System Capital Cost

As gas heaters and geysers are providing energy for required heating loads and air-conditioning units are providing energy for required cooling loads. The capital cost for this conventional system was Rs.3.9 – 4.1 lacs which includes the 6 x 1 ton air-conditioning units and a 50 gallon gas geyser along with gas heaters.

4.4.2 GSHP System Annual Operational Cost

Operational costs for heating and cooling mode were calculated separately for the whole season.

Cost for Heating

In heating mode the system was fulfilling the required heating energy demand and was also providing 42 gallons of hot water. Total electrical energy consumed by GSHP was 1890 kWh for a total of 950 hours of heating season, the costs come out to be;

Cost = 20,790 PKR

Cost for Cooling

In cooling mode the GSHP has to be operated for 2100 hours per annum. Total number of electrical units consumed were 4200 kWh and the total cost come out to be;

Cost = 46,200 PKR

Hence the total operating cost per annum for a GSHP system is Rs.46, 200 PKR.

Operational Mode	Consumed Energy	Cost
Heating	1890 kWh	Rs.20,790
Cooling	4200 kWh	Rs.46,200
Total	6090 kWh	Rs.66,990

Table 4.5: GSHP System's Operational Cost

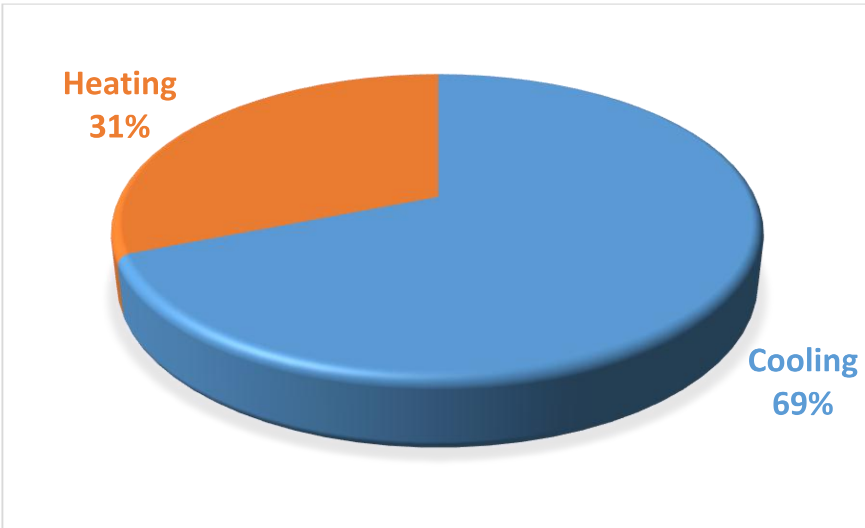


Figure 4.2: Heating Cooling Cost Distribution

Conventional system annual operational cost

Similarly for conventional systems, operational costs for heating and cooling mode were estimated separately for the whole season.

Cost for heating

The utility company (Sui Northern Gas Supply Company) charges at Rs.80/kWh. The total cost for domestic hot water heating and that of the house was Rs.45, 600.

Cost for cooling

The utility company (Islamabad Electric Supply Company) charges at Rs.11/kWh for more than 300 kW consumed per month. Total cooling cost for air-conditioning of the house was Rs.254, 100.

Operational Mode	Consumed Energy	Cost
Heating	570 therms	Rs.45,600
Cooling	23100 kWh	Rs.254,100
Total	-	Rs.299,700

Table 4.5: Conventional System's Operational Cost

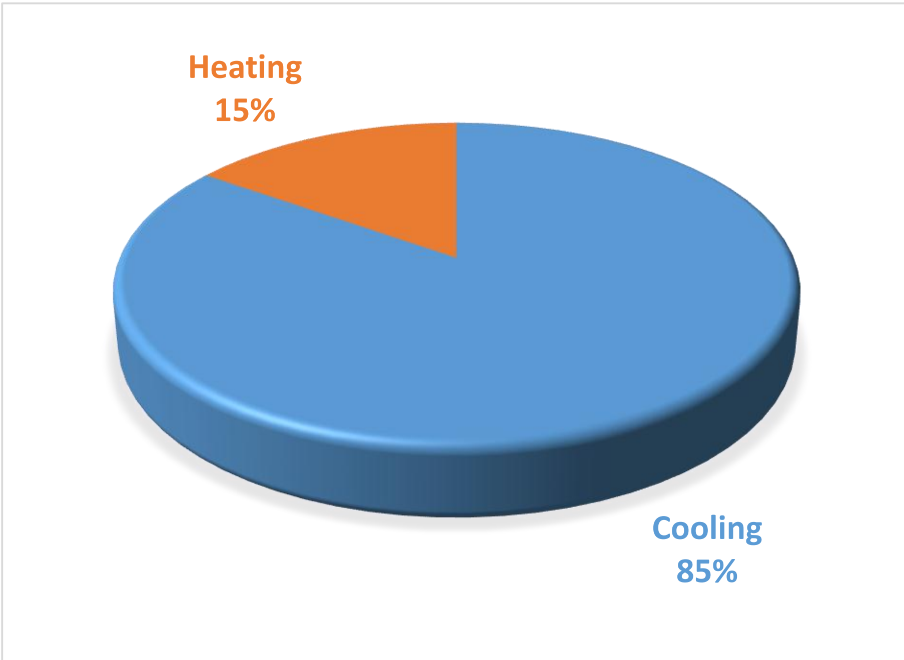


Figure 4.3: Heating cooling cost distribution for conventional system

4.5 Inference from Cost and Benefit Analysis

After performing Cost and Benefit analysis it became clear that the Capital Cost of GSHP system is quite high when compared to that of the Conventional systems. However, it can also be inferred that a rather high initial investment can result in annual savings in operational costs of up to Rs.234, 000 for the potential lifetime of the GSHP system. This implies that the initial capital cost will be repaid in the form of savings in operational costs in around 7-8 years. Future savings after this payback time can be benefitted from as savings of up to Rs.250, 000 will result for the rest of the actual lifetime period of the GSHP system. The significance of this saving lies not only in terms of money but also in terms of energy. An environmental benefit can also be extracted from this lesser consumption of energy and fuel as it will result in relatively fewer Carbon and CFCs emissions into the environment.

4.6 Conclusions

- Using the underground temperature data logging system, it was indicated that the frost line of Islamabad lies at a depth of 10-11 feet under the ground. This is because the temperature at this depth tends to become constant and is not affected by the external atmospheric temperature variations.
- The life of the project was considered to be 20 years. The payback time was calculated as 7-8 years. The annual saving per annum comes out to be Rs.232, 710/-. The ground source heat pump system enables us to save this amount for 12-13 years.
- This system works totally on electricity and the annual operational cost comparison indicates that the GSHP system utilizes 4.5 times less than the conventional system making it highly energy efficient. As the burden on energy consumption has reduced this means that the carbon emissions have reduced as well making GSHP system environment friendly.

4.7 Recommendations

- The results from annual operational costs are were promising and they suggest that this system is highly recommended in Pakistan. This will help Pakistan face its current electricity shortfalls and environmental problems.
- The capital cost is very high but here is where the government can play its part. Like the governments of all the developing countries of the world, our government can provide incentives and subsidies for this system to promote it.
- As this system is not locally available in Pakistan, the government can go for mass production of this system locally and by doing so the cost are surely to scale down drastically.

CHAPTER 5

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