MSc in Renewable energy systems &Environment

Cost-benefit analysis of Air source & ground source heat pumps

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Abstract

The need to combat the urgency for fulfilling the continuous demand and supply of energy is very much at its peak for which Renewable energy is to be brought on the forefront to tackle the energy issues which are being raised in the current times. With the increased level of carbon dioxide emissions in the buildings which is affecting the general household and also costing them twofold than required has ignited the means to adopt the micro generation technologies. It is a part of UK strategy to mitigate the carbon emissions and raise the energy efficiency for which heat pumps have become an important and potential carbon saving technology.

With the availability of different types and variable capacities of heat pump in the market, it becomes difficult for the consumer to come to a conclusion as to the selection of the system. This produces the upright need of overall analysis of heat pumps which is absolutely essential before the installation of the technology. Two different houses located in Glasgow & India are used as case studies for assessing the differences in the heat pump systems and to find which when suits the best. Here Climate is on deciding factor for which two regions of opposite nature are chosen. Performance of various models of ASHP & GSHP units were assessed for these dwellings using Retscreen, an Excel based energy modeling software .The feasibility check of the technology was done for both the houses in two different locations based on its varying capacity, Co-efficient of performance, type of fuel used, fuel costs and the reduction in carbon dioxide savings or the GHG emission factor.

The objective of this thesis is mainly to compare both Air source and Ground source heat pump systems for combined heating & cooling by using these variables, compiling the results and finally coming to the conclusion as to which system emerges as a winner in all circumstances.

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Chapter 1

Introduction

The widespread development and potential of heat pump systems is triggering the need for installation of these technologies to compete with the overall heating and cooling demand. Enhancement of energy efficiency and introduction of newer and more efficient space and water heating technologies in the UK domestic sector are essential if the UK is to achieve its ambitious target for 2050 of reducing greenhouse gas (GHG) emissions to less than 80% of 1990 levels. As the energy demand is increasing, models of various definitions are being made available in the domestic market.

Heat pump systems with variable capacities and better performance are penetrating the market which is ready to serve the purpose and are at the helm of tackling these issues. It is of utmost importance as heating accounts for the largest single proportion of the overall demand of the country. For a colder country like the UK, the demand for domestic heating is about two fifth. Similarly for warmer countries like India, the cooling demand is higher compared to the heating demand for which a best unit has to be put into practice to maintain the energy supply and demand with less or no side effects on the environment. Heat pumps are one such renewable system which are a proven technology in colder countries & have been used from decades, responsible enough and could help in reducing the carbon emissions by up to 6.5% by 2030 and up to 15% by 2050, Sweden being one of its pioneers in the domestic heat pump market.

Taking into consideration Ground source heat pumps and Air source heat pumps for two different houses in the UK & India the performance and the capability of the system was measured using an energy modeling software bearing in mind various factors like the climatic conditions, capacity, Co-efficient of Performance, the energy consumption & cost and the overall cost of the installation.
Air source heat pumps are considered better than Ground source heat pumps mainly due to its rapid development in the last years enabling the systems to perform better with its increasing efficiency under a wide range of temperatures and are rendered attractive in the domestic market because of its small size and the costs involved. This thesis is based upon the installations of various virtual units of ASHP and GSHP with the real data extracted from the database present in the

simulation software. Region-wise, the potentiality of the system was estimated to establish if ASHP are better than GSHP at all conditions. The analysis utilizes both acquired and simulated data, and the simulations were carried out to draw a comparison between the characteristics of systems. Various models of ASHP and GSHP were presented of which each manufacturer/model offered to have a different heating capacity and cooling capacity with their respective heating and cooling COP's which were more or less alike. As this thesis mainly focusses on residential heating and cooling, Retscreen helped a long way in getting the much – needed data required to bring about a comparative study and the case studies used gave a general idea about the load profiles of two kinds of houses in different periods in a year.

To prove the hypothesis of Air source heat pump being more capable and efficient than the Ground source heat pump, several factors were ran upon in the analysis part of this project which are explained further. Various measurement data and graphs were obtained from the two case studies of the residential properties located in Glasgow, UK and Pune, India ,using an excel based software Retscreen which is defined further in the Methodology section of this thesis.

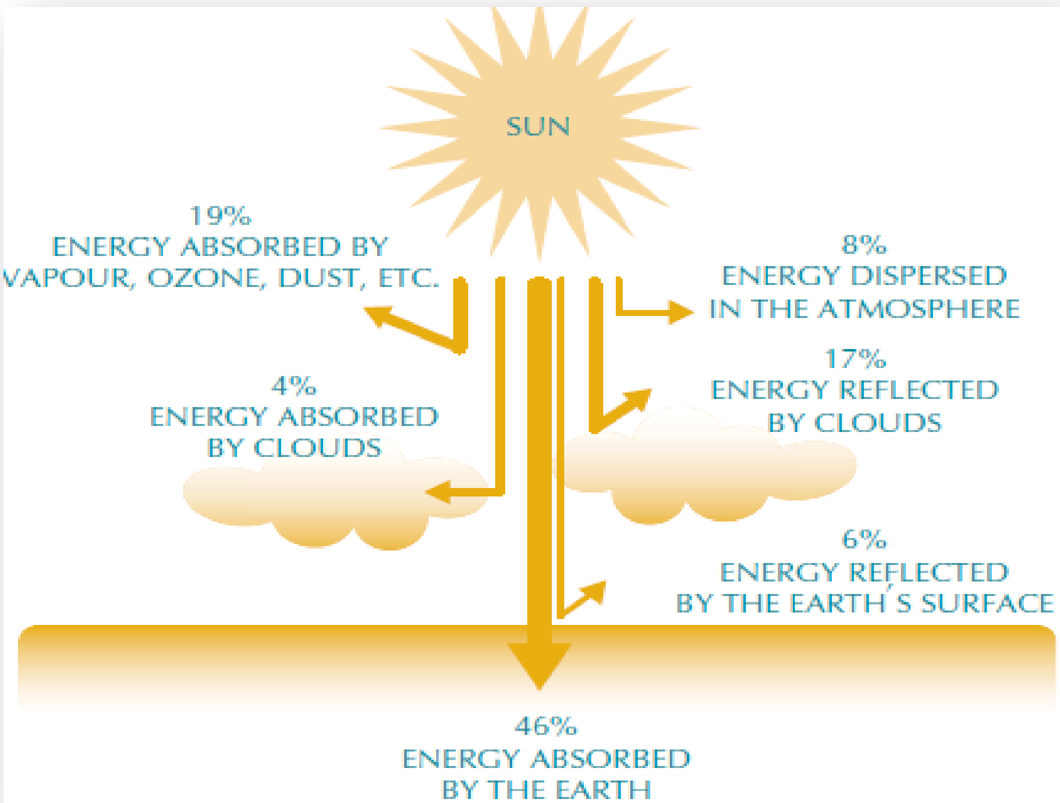
Chapter 2

Literature review

The first section looks at heat pump which is an outgrowing renewable technology in the UK .It covers the definition of heat pumps and its construction and the different types available in the domestic market.

With the advent of Renewable technologies with the increasing demand for heat and power, renewable sources have been brought in the forefront to tackle the issues that have cropped up in this era of excess energy consumption where almost everything demands high power (9). Due to the limitations in the usage of fossil fuels, the UK heat pump market has risen in order to fulfill the energy market demands and so is the case with other countries who are taking precautionary measures in reducing the energy consumption and opting for other Renewable sources of energy to maintain the energy balance (11).

Fig: 2.1.1 Solar energy distribution
Source: Clean energy project analysis, Ret screen engineering & cases textbook, 3rd edition



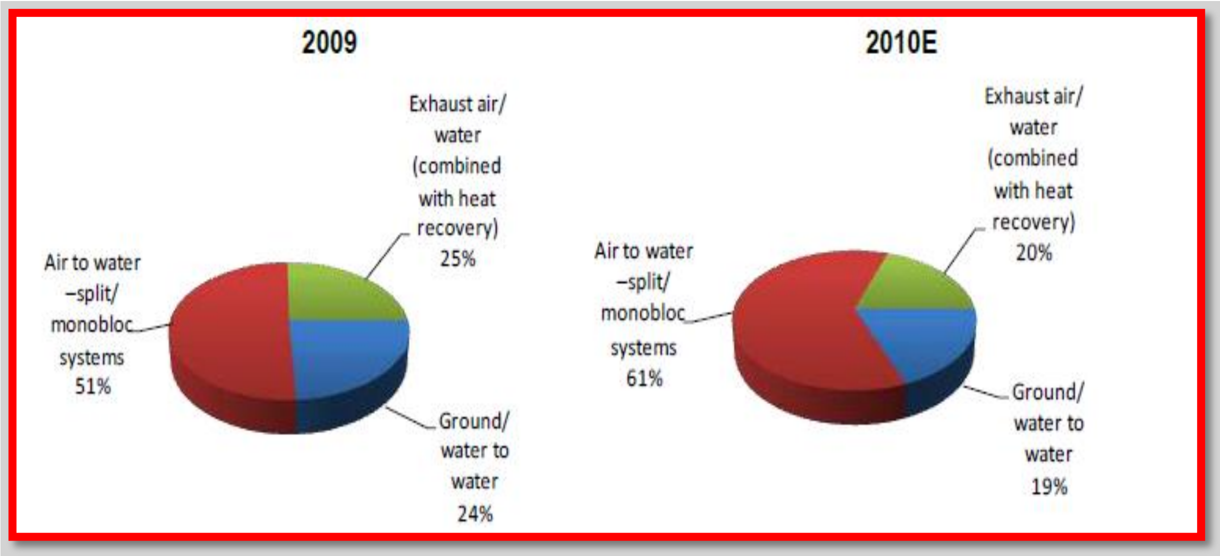
Heat Pumps are essentially tools or device to transfer heat energy from lower temperature source i.e. cold region to higher temperature source also referred to as hot region for domestic and industrial applications (36). In simple terms, heat pumps are renewable sources technology used to reduce the need of fossil fuels by extracting energy from natural sources like ground, air or water which themselves act as huge store of energy They are designed in such a way to move thermal energy opposite to the direction of spontaneous heat flow. Heat pumps have come a long way since 2010 and the percentage has kept adding with an overall rise in the market of heat pumps by 29% from the first half of the year .In recent years, energy efficiency has gained impetus particularly in the field of engineering of building services right from the start till the end phase of its construction. The main objectives of heat pump is to minimize the consumption of energy in residential buildings, houses or industrial spaces ,be it in the form of heat loss or heat gain to ensure comfortable ,economical and healthy living and a giant leap towards achieving the target of reduction in unwanted usage of fuels or energy.

The next few sections will cover the types of heat pumps and its physical and mechanical nature. Although this thesis is going to concentrate on Air source and Ground source heat pumps and analysis of both in terms of cost ,energy efficiency, performance, demand or uptake of heat pumps in the UK market.

2.1 Background

The history of heat pumps dates back to the history when modern refrigerants came in the limelight. The technology of heat pumps which is now regarded as a tool to fulfill the future energy demands was in picture long back and were been widely in Scandinavia and particularly in Sweden. In other words, Sweden is regarded as the pioneer for the technology as it has been involved in continuous working and improvement of heat pumps since the energy crisis in the 1970’s.Today heat pumps are used worldwide & have become a mainstream supplier of heat energy to millions of households and industrial units thus saving millions of pound.

Fig: 2.1.2 Heat pump market volume, units, 2009 & 2010E, United Kingdom
Source: BSRIA



2.2 Heat pumps

These are devices that transfer heat from energy a heat source to a heat sink against the change in temperature .Vapor compression heat pumps or commonly known as heat pumps undergo phase change through a cycle of evaporation and condensation and in the process they tend to transfer heat by circulating a substance which is phase changing agent called a refrigerant.
Refrigerant is nothing but a fluid which helps in storing the heat captured in the process and thereby transferring it to the domestic heating system (example: Antifreeze or brine)
The process is such in which the compressor pumps the refrigerant between the outdoor and indoor heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from a source of high temperature, then this gas refrigerant undergoes compression in another coil and thus there is an increase in the temperature, where it condenses at high pressure. Finally, this is the point when heat absorbed earlier in the cycle is released to the heat sink.

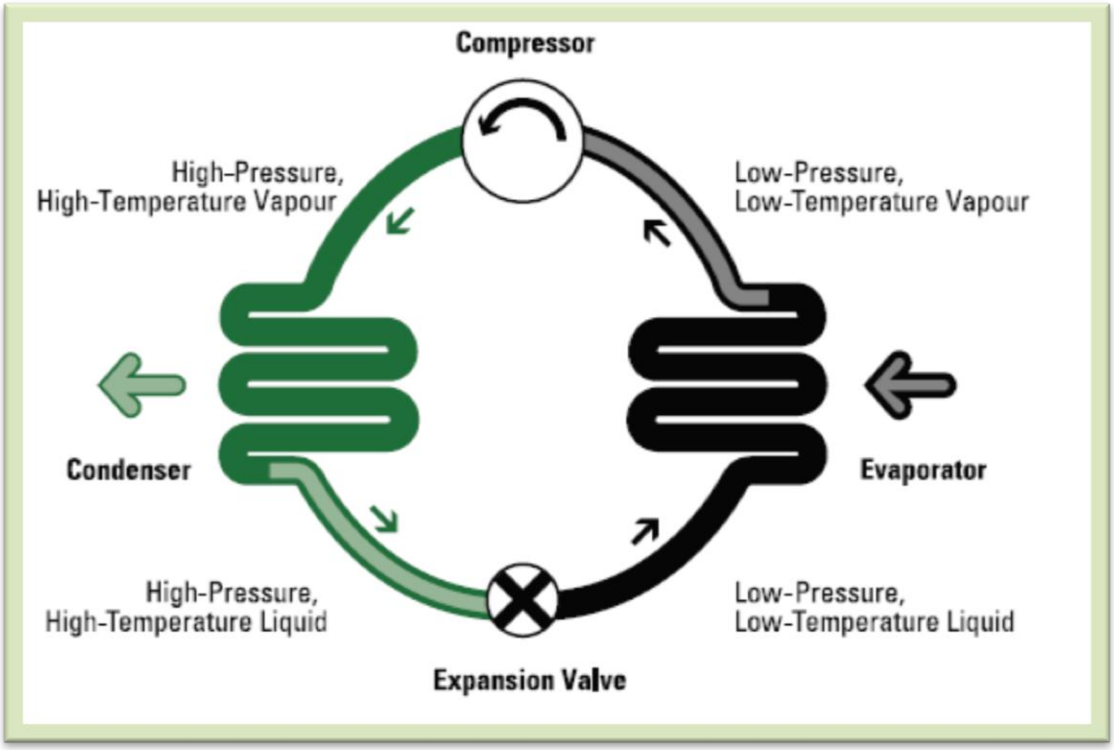


Fig: 2.1.3 Basic heat pump cycle
Source: Natural resources Canada's Office of energy efficiency, 2004

The performance of heat pump is greatly influenced by certain factors like the boundary and operating conditions namely the weather or the heat source temperature, outer-fluid temperature and the heating or cooling load of a specific dwelling or for that matter in this case any residential building (29). The energy efficiency of heat pumps and its performance factor is further discussed taking into account, the different types of heat pumps and the recent market trends.

2.2.1 Principles or the working cycle of heat pumps

Almost all the heat pumps currently in operation are based on two different principles or cycles.

The principles of these cycles are briefly discussed below.

a) Vapour compression cycle
b) Absorption cycle

a) Vapor Compression heat pumps

Majority of heat pumps work on the principle of Vapor compression cycle. The main components in such heat pump systems are the compressor, the expansion valve and the two heat exchangers which are the evaporator and the condenser. The components are formed to form a closed circuit, as shown in the figure above. A volatile liquid called the refrigerant circulates through the four components.

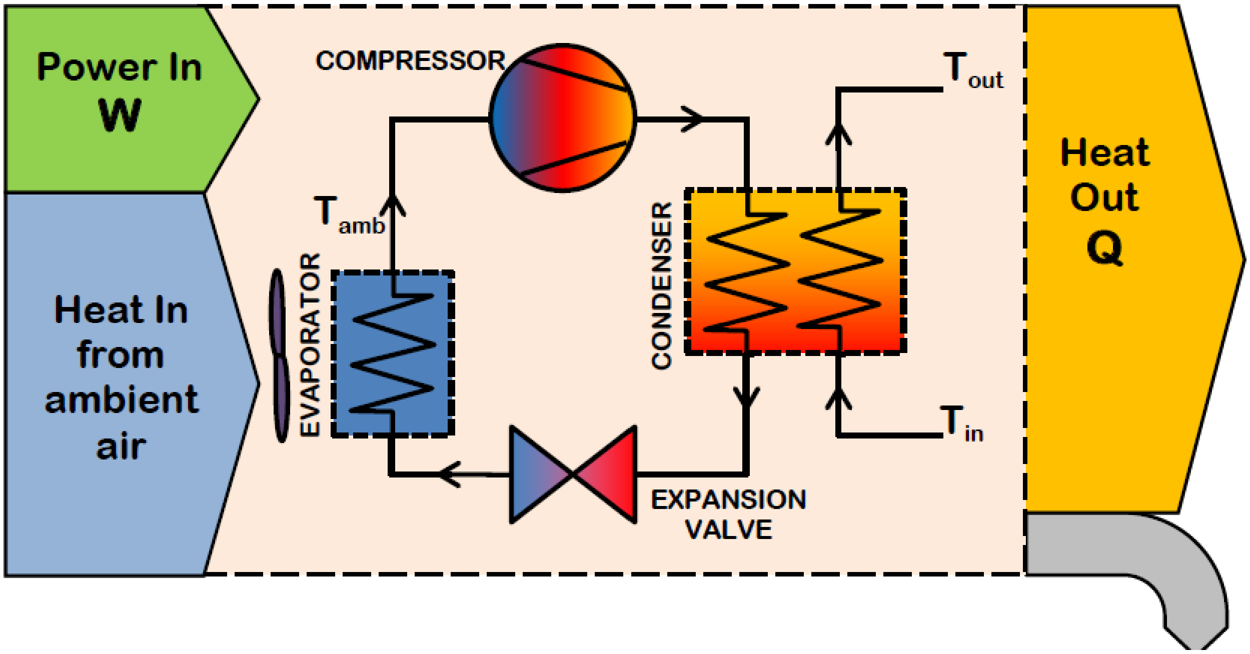


Fig: 2.1.4 Heat pump vapour compression cycle
Source: (Samuel Cooper, Geoffrey P.Hammond ,Marcelle C. McManus,2011)

In the evaporator, the temperature of the refrigerant is kept lower than the temperature of the heat source, directing the heat to flow from the heat source to the liquid or the refrigerant. This causes the liquid to evaporate. Now, this vapour from the evaporator is compressed at high temperature and pressure. The hot vapour then enters the condenser, where it condenses and releases heat (37).

Finally, the high pressure working liquid is expanded to the evaporator temperature and pressure once it enters the expansion valve. The refrigerant or the working fluid as it is normally called returns to its original state ready to repeat the same cycle producing useful heat overall again. The compressor is usually driven by an electric motor or sometimes by a combustion engine.

b) Absorption Heat pumps

These heat pumps are thermally driven unlike vapour compression pumps. In this type of system, compression of the refrigerant is achieved thermally in a solution circuit which consists of the absorber, a pump, a generator and an expansion valve as shown in the fig. above. The vapour which is at a low pressure in the evaporator is absorbed in the medium or the absorbent which produces heat. Now the solution is pumped to high pressure and then enters the generator where the temperature is generally high due to the presence of external heat supply and the working fluid heats up and vaporizes (37). This vaporized working fluid is now then condensed in the condenser while the transporting medium (absorbent) returns to the absorber via the expansion valve.

Absorption heat pumps utilize different energy sources like the biomass, Solar energy, waste heat etc. which are inexpensive and also their choice of environment friendly refrigerants have been adding to its popularity. The most widely used Absorption cooling system is the ammonia water system in which ammonia acts as a refrigerant and water as a carrier.
Other commonly used Absorption cooling systems (ACSs) include water-lithium chloride and water lithium bromide systems where water serves as the main working fluid or the refrigerant and lithium bromide or lithium chloride as the absorbent.

2.3 Types of Heat pumps

There are two types of heat pumps which are described below in detail:

2.3.1 Air source heat pump

Air source heat pumps are defined as renewable technologies which are considered more efficient than conventional boilers for domestic heating of water and spaces. ASHP’s are best and suitable for the UK climate as it can function in a temperature at low as -25 degrees.

The primary aim of an ASHP is to extract the heat from the surrounding or outside air and pass it through a heat exchanger where its temperature is elevated to a certain extent and moves the heat from the air to a hot water supply.

i) It is further divided into two sub-types, where two different sources of energy are used to extract or move the heat from outdoor to indoor and vice-versa.

a) **Air to air heat pump**

In this type, heat is extracted from the air by the system and then the heat is transferred outside or inside depending on the season. It is the most common type of heat pump used.

b) **Air to water heat pump**

This type of heat pump is mainly used in homes with hydronic heat distribution systems. During the winters, the heat pump takes the heat from the surrounding outside air and then transfers it to the water in the hydronic distribution system. When the weather is too hot and humid, the entire process is reversed. The heat pump extracts heat from the water stored in the home's distribution system and pumps it outside in order to provide cooling to the house, thereby making the environment indoors comfortable for the occupants. The availability and use of air to water type of system is very scarce due to its nature of ineffective cooling during the days when it is hot and humid or not able to provide cooling at all leaves it as a last choice for the buyers

Therefore, in this thesis we are going to focus mainly on the air to air heat pumps as they are widely used due to their satisfactory performance.

ii) Components of ASHP: ASHP are no different in physical appearance or in its structure from an air conditioning unit or refrigerator. It is bit larger than the domestic washing machine.

The main components of an ASHP are:

a) A fan which is used to force the outside air over the heat exchanger which is nothing but a copper coil filled with refrigerant to extract heat from the ambient air.

b) Evaporator: As the name suggests the main function of the Evaporator is to evaporate or heat the liquid refrigerant passing through the outside heat exchanger .In the evaporator, heat energy from the outside air has been absorbed and stored in the refrigerant as latent heat

c) Compressor: The gas or the liquid refrigerant which was transformed into vapour is now compressed using electric pump. This reduces the volume of the gas and increases the temperature to levels of 75 to 125 degrees. The gas is then fed into the heat exchangers.

   The indoor heat exchanger: Inside the building, the gas passes through a pressure valve into heat exchanger coils. There, the hot refrigerant now condenses back to liquid and transfers the stored latent heat to the indoor air or domestic hot water system. This indoor air or hot heating water is pumped across the heat exchanger with the help of an electric pump commonly known as fan. The cool liquid refrigerant is ready to pass through the outdoor heat exchanger coils and repeat a new cycle.

d) Expansion Valve: Last but not the least is the Expansion valve which is an important part to complete the closed circuit of Air source heat pump. Its main objective is to reduce the pressure of the condensed liquid which is now ready to enter a new cycle of producing indoor heat and hot water.

2.3.2 Ground source heat pumps

Ground source heat pumps are just like any other heat pumps capable of heating or cooling the house. It extracts all the heat or thermal energy stored in the mother earth by circulating a fluid an anti-freeze mix through a closed loop of underground pipes. This fluid absorbs the heat from the earth and is transported to the heat pump attached to the building .The heat pump extracts the heat from the fluid via the refrigerant flowing through a heat exchanger and then gets distributed to radiators or under floor heating and utilizes this energy in heating or cooling the houses GSHP have been in use from couple of decades and is one of the most efficient technologies in capturing and transporting heat. Ground being its main source of energy, makes this technology more self-sufficient & thus viable (18).

I: Types of Ground source heat pump

i) Open systems: As the name suggests, there is not such barrier like evaporator between the rock/soil, the source and the system. Hence it is open in nature.

ii) Closed systems: In this type of system ,heat exchangers are present or located in the underground either horizontally, vertically or oblique manner and a heat carrier medium is circulated within the heat exchangers which are principally bound to transfer heat from the source i.e. ground to the heat pump system or in the reverse fashion.

iii) In closed loop systems, the heat carrying fluid or the refrigerant is separated from the rock/soil and groundwater by the wall of the heat exchanger unlike open systems.

II: Closed loop systems are further sub-divided into two types,

a) Horizontal loop systems

This type is easy to install. Individual pipes or loops are laid down in a relatively dense pattern in a horizontal position connected either in series or parallel. The main reason for this is the restrictions in the availability of area, in the Western and central Europe. For such dense pattern of pipe works, usually the top layer of earth is completely evacuated. Then the pipes are laid and soil is dispensed back over the layer of loops (13). The laying of pipes in the trenches varies widely from place to place. Some special ground heat exchangers have been developed to save some surface area with ground heat collectors. The main thermal recharge for all horizontal systems is mainly provided by the solar radiations which is available freely on the earth's surface. For its effective functioning as a heat store, it is important not to cover the surface area above the heat collector in case it is placed under a building. The omission of one heat exchange process improves the chances of system to perform more efficiently. These systems are more widely accepted in areas where there is ample land area with high water table. A horizontal loop system of 11-12 KW capacity would cost around £1480/KW.

b) Vertical loop systems

From the measurements analyzed dating back to the 17th century, the ground temperature below a certain depth remains constant throughout the year. Based on this fact and the need to install sufficient heat exchange capacity under a confined surface area, it favors vertical ground heat exchanger. Vertical loops are generally preferred when there is land surface available. Wells are bored to depths that typically are 75 to 300 feet deep. The closed pipes are then inserted into the vertical borehole. Soil and ground temperature conditions determine the piping requirements and also the capacity of the system which can be installed on a specific land. Different climatic conditions affect the measurements of the multiple wells whose main aim is to achieve the heat transfer requirements.
Vertical systems cost less than horizontal loop system, say about £900/KW.

There are three types of Vertical system, heat exchangers: U-tube, divided –tube and concentric tube system configurations.

Fig: 2.2.4 Vertical loop system

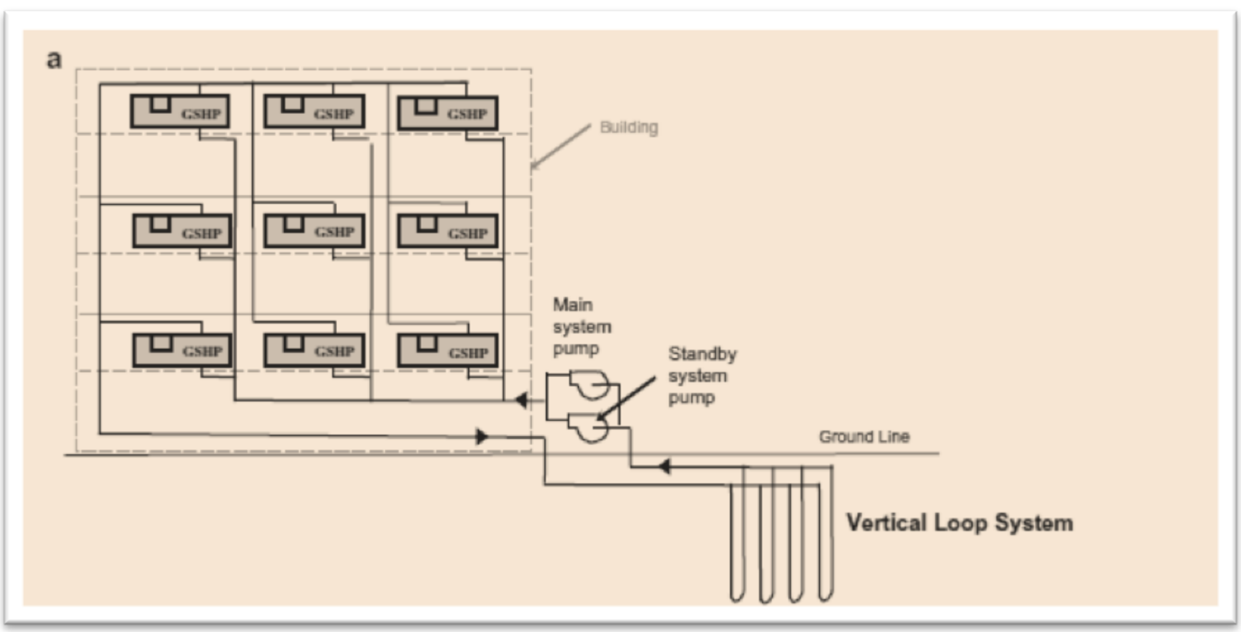
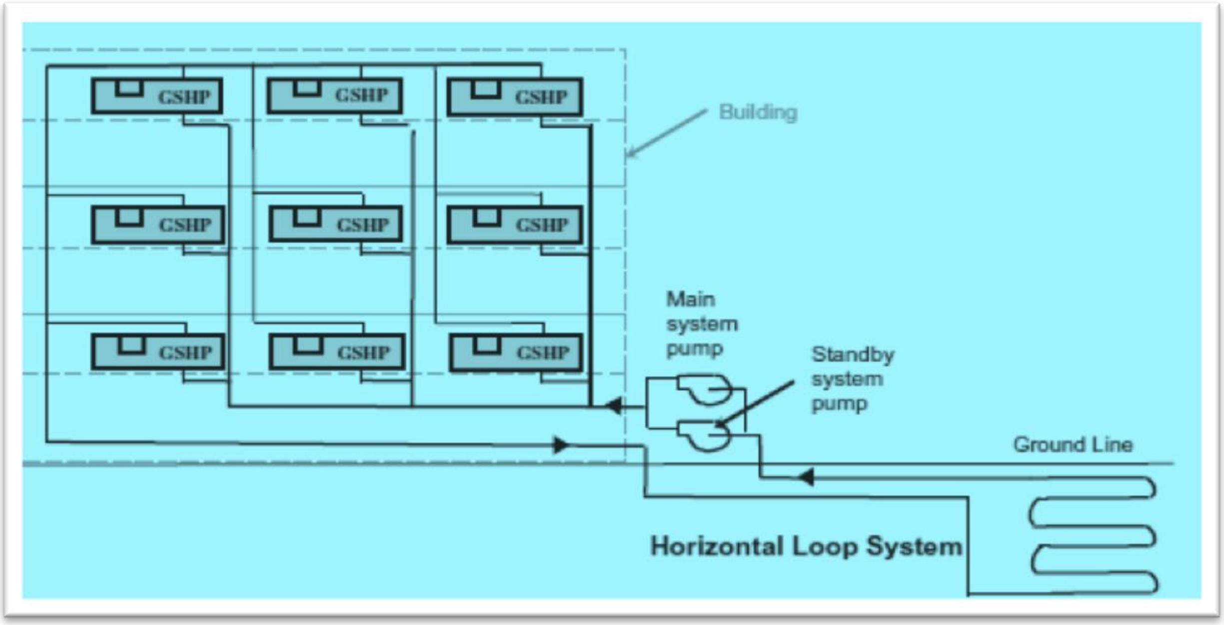


Fig: 2.2.5 Horizontal loop system



III: Components of Ground source heat pump

A ground source heat pump consists of three major components: A heat pump, an earth connection and an interior heating or cooling distribution system.

a) Heat pump:

The heat pump transfers the heat between the distribution system (heating/cooling) and the earth connection. It is the basic building block of the GSHP system. The heat pump system removes heat from the refrigerant or the circulating fluid, concentrates it and then is transferred to the building for space or water heating. For cooling purpose, the process is reversed.

b) The second component i.e. the earth connection subsystem
It is usually a closed loop of pipes which is buried deep in the ground either in horizontal or vertical position. A fluid is circulated through those closed loops allowing heat to be transferred from the building to the ground. This circulating fluid is nothing but a antifreeze or brine solution which is referred as Refrigerant. It plays a very important role in maintaining the COP of the system. There is open

loop type of system in which the earth connection system includes open loop of pipes which is connected to a water body that directly transfers water between the heat exchanger and the water body. This is very less commonly used.

c) The heat distribution system

As its name suggests is used to distribute heating or cooling to the building depending on the demand of the house. According to the US department of Energy, more than 40% of electricity is consumed by the residential and commercial buildings for the heating and cooling purpose. The US environmental Protection agencies (USEPA) have estimated that ground source heat humps can go a long way in reducing the percentage of energy consumption.

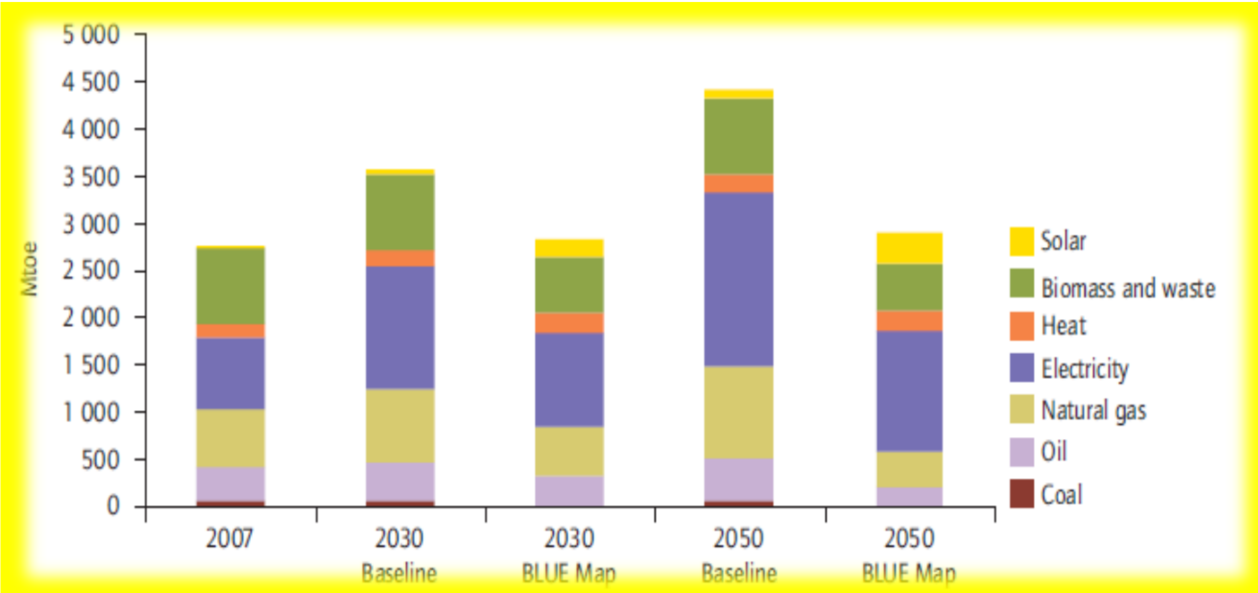
There are three types of Vertical system, heat exchangers: U-tube, divided –tube and concentric tube system configurations.

2.4 Factors affecting the uptake of Heat pump

There are several factors that affect the consumer behavior when it comes to adoption of renewable technologies, in this case heat pump for domestic purposes. Though it does effectively suffice the need of Space & water heating and cooling purposes without causing much harm to the environment unlike the conventional technologies, it also possesses its share of nature that affects the heat pump market.

1) The climate plays a very important role in the suitability and hence performance of the system –Annual heating & cooling demand
2) Varying Capacity and COP of the heat pump
3) Fuel type
4) Fuel cost
5) Heat pump costs

Fig: 2.2.6 Timely gap & different fuels used.
Source: Technology roadmap-Energy efficient buildings: heating & cooling equipment



Chapter 3

Objectives & Methodology

Based on the facts, between the two different types of heat pump, we are going to assess the energy efficiency & performance of both air source heat pump and Ground source heat pump .A modeling tool used here is clean energy project software called the RETScreen.

3.1 Objectives

The main objective of this thesis is to investigate the performances of heat pumps both Air-source and Ground source with respect to different climates, different capacities and COP's, the type of fuel used and its cost in terms of heating and cooling load. It is a kind of cost benefit analysis to come to conclusion which one is better in all circumstances.

Certain variables which are important in the making or functioning of the system and which affects the overall efficiency of the pump have been used from the RETScreen database to make a point about respective heat pump

3.2 Methodology

RETScreen is a leading tool which particularly aims at facilitating pre-feasibility and feasibility analysis of clean energy technologies. This tool can be used world-wide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various renewable energy technologies .It is easily accessible and suitable for use to individuals and companies not necessarily having prior knowledge about the software. Retscreen is available in two different versions of which Retscreen 4 is being used here for modeling and monitoring of heat pumps installed in the residential building. It is an Excel-based clean energy project analysis software modeling tool that helps the decision makers quickly and inexpensively to determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects. Each model includes a wide array of renewable technologies with a large database of the climate, location, manufacturers, its model, capacity etc. required to measure the performance of the technology. There are five standard steps to be followed in order to evaluate the energy efficiency of any building.

Thus, RETScreen is perhaps considered as the quickest and easiest energy modeling tool for computing the costs and benefits or say to evaluate how energy efficient a particular technology is. The analysis allows for the minimum input of effort and time to understand the advantages of a particular technology further probing into it based on its merits. RETScreen assesses the risk factors associated with the financial matters beforehand to make the entire project cost-effective. Thus, it is very flexible, leaving it at the helm of the user to concentrate on those aspects that are of particular interest to the user.

Chapter 4

Analysis of heat pumps in different climatic conditions & load profiles

4.1 Case study 1: Residential building in Glasgow, UK

4.2 Case study 2: Residential building in Pune, India

There are several factors that affect the performance of heat pumps but this thesis will concentrate mainly on the variables discussed below.

It is with the help of RETScreen, Excel-based energy simulation software, it became possible and a desk based work to assess the performance of the heat pump system in two different geographical locations with the availability of the information needed.

The factors taken into consideration are discussed below with the help of information absorbed from two different case studies:

1) Climate

2) Varying Capacity and COP of the heat pump

3) Fuel type

4) Fuel cost

5) Heat pump costs

4.1 Case study 1: Residential building in Glasgow, UK

Type of heat pump: Air source heat pump/Ground source heat pump

Heat source system: Ambient air/ground

This house which is situated in the Dennistoun district of Glasgow area is a 110 year old dwelling which is now a converted flat. It comprises of a ground floor conversion contained in a former two-storey with basement end-terraced building, which has been sub-divided into three separate dwelling flats. The one taken into account is only the ground floor flat which consists of two bedrooms, a living room/Kitchen and a bathroom and has a gross internal floor area of 71m²

Currently it runs on electric condensing boiler to suffice its need of space heating/ cooling & water heating as per the changes in the weather and the comfort level of the occupants.

Table 4.1.1: Characteristics of the dwelling in the UK

Country	United Kingdom
City	Glasgow
Client name	Rajesh Pathak
Application area	Building sector
Building type	Residential
Year of Construction	1900
Property type	Converted flat
Installation	ASHP/GSHP
Purpose	Space & water heating
Weather	Cold with high winds & heavy rain

In order to assess the performance of heat pumps in this house, RETScreen is been used to evaluate the differences in the conditions of the variables in cold weather zone. Apparently, the heating and cooling loads vary on a large extent in a cold climate as that of the UK.

Site reference conditions obtained from RET Screen's climate database are represented in the table below:

Latitude: 55.9 º North

Longitude: 4.4 º east

Table 4.1.2: Climate data location: Glasgow

Geographical factors	Measured units	Source
Elevation	8 m	Ground
Heating design temperature	-3.9 ºC	Ground
Cooling design temperature	21.6 ºC	Ground
Earth temperature amplitude	13 ºC	NASA
Annual air temperature	9.1 ºC	Ground
Relative humidity	80.9 %	Ground
Daily solar radiation-horizontal KWh/m²/d	2.67	Ground
Atmospheric pressure	99.7 KPa	Ground measured at m
Wind speed	4.5 m/s	Ground at 10 m
Earth temperature	8.5 ºC	NASA
Heating degree days	3,265 ºC –d	Ground
Cooling degree days	490ºC –d	Ground

The main objective of this thesis is to analyze the factors affecting the heat pump and prove the demand and performance of one heat pump over the other.

Four different configurations of ASHP and GSHP systems were installed with making necessary changes in certain factors like the heat pump capacity and COP, fuel type , fuel costs, heat pump costs and of course the climate. This was monitored by keeping one variable constant and changing the other. This thesis mainly concentrates on the cost-effective behavior of the two heat pumps which is later represented in the form of graphs for different factors.

I) Capacity and its co-efficient of performance

In the first method, four different models of Amana manufactured Air source heat pumps were virtually installed in the house, making use of the real data available from the database present in the Retscreen 4.
The table 4.1.3 shows ASHP units of different capacities and COP keeping the heating and cooling load of the house constant. In this case, the fuel used to run the system is taken as Electricity and therefore the fuel costs for the functioning of each of the air source heat pumps will remain the same throughout. In the UK, the

standard price of electricity was quoted to be 12.6 pence/unit therefore the running costs for each season remains the same with a slight variation on the usage depending on the occupancy level. .For each of the ASHP unit, the Heating and cooling COP is noted down. It was observed that the COP varies with the capacity and also with the number of units installed to meet the heating or cooling demand.

Glasgow which is a region of high winds and rainfall, the temperature throughout the year remains low with only increase in the temperature to about 25 -26ºC in the Summer which lasts for three months i.e June, July & August. The heating load is more for this house as it falls in this region and with different models of ASHP the graph was obtained where it was evident that with the increase in the capacity of the system, the heating and cooling performance also increased or decreased accordingly.

Type of pump-ASHP (Glasgow)

Manufacturer: AMANA

Table 4.1.3: Different models of ASHP units installed in case study-1

Model	Capacity (in KW)		COP	
	Heating	Cooling	Heating	Cooling
PHD24C02F1	6.9	7	3.24	3.82
PHD30C02F1	8.59	8.6	3.22	3.82
PHD42C02F1	9.6	9.9	3.25	3.82
PHD36C02F2	12	12	3.17	3.52

The temperature throughout the year in the UK remains low so the demand for heating is higher for which more heating energy is delivered.

Fuel type: Electricity

Fuel cost: 0.126 £/KWh

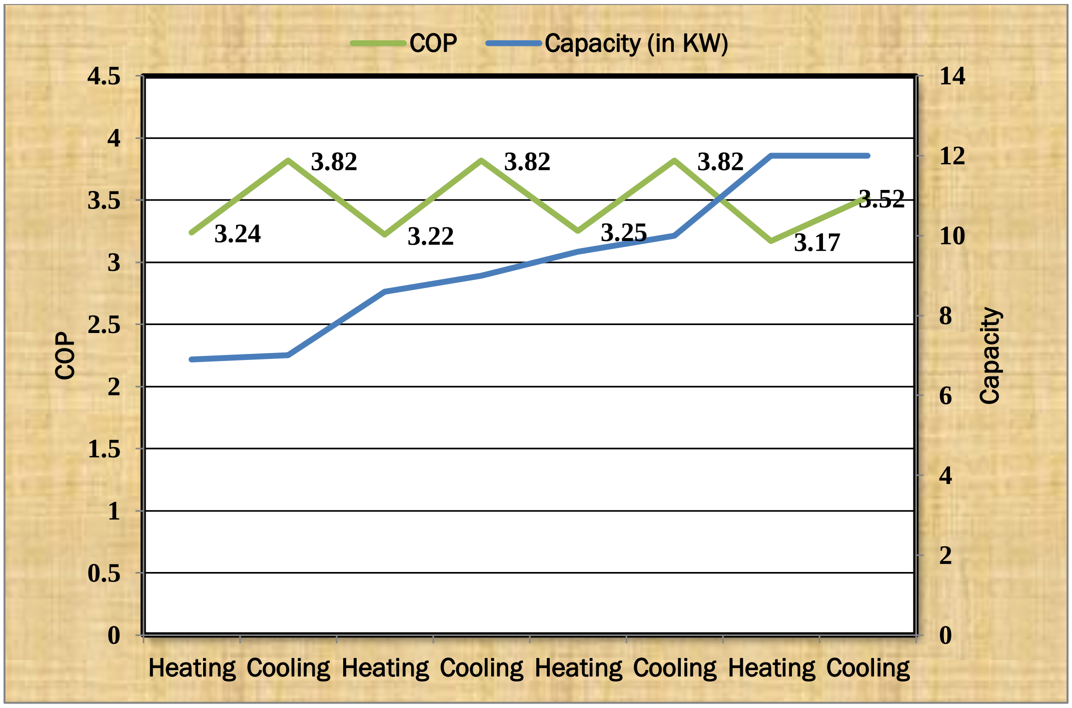


Fig 4.1: ASHP Heating & cooling Capacity against its COP in cold region

Similar tests were carried out by adding extra units to the same system to check if there was any change in the heating and cooling performance of the ASHP system.

Table 4.1.4: Unchanged COP's for different capacities of similar ASHP models.

Model	Number of units	Capacity	Heating COP	Cooling COP
PHD24C02F1	1	7.1	3.24	3.82
PHD24C02F1	2	14.2	3.24	3.82
PHD24C02F1	3	21	3.24	3.82
PHD24C02F1	4	28	3.24	3.82
PHD24C02F1	5	35	3.24	3.82
PHD24C02F1	6	42	3.24	3.82
PHD24C02F1	7	49	3.24	3.82

What if the capacity of the system is kept constant and the COP changed for each of those, it is definite that the seasonal performance factor of the system would change making it more efficient. But in reality, the COP of the system remains constant even if several units of heat pump are added to supply energy to the dwelling. For example, an air source heat pump system of capacity 7KW will give a heating & cooling COP of 3.82 & 3.24 respectively. Addition or increase in the number of units will only increase the capacity and not have any effect on the COP. Increase in the capacity will lead to increase in the ability to command the heating or cooling load for a house.

Now, four different units of GSHP were installed and monitored in the same house. So we could say that as the ambient temperature goes down the heating capacity of the unit increases and it gives high heating COP compared to its capability of cooling. But it is otherwise in much warmer or humid environment.

Type of pump-Ground Source Heat Pump (Glasgow)

Manufacturer: Enertran

Fuel type: Electricity

Fuel cost: 0.126 £/KWh

Table 4.1.5: Different models of GSHP units installed in case study-1

Model	Capacity (in KW)		COP	
	Heating	Cooling	Heating	Cooling
GT310WA	12.4	12	3.1	4.19
GT410WA	13	15	3.1	4.19
GT150WA	15	18	3.3	4.16
GTE2X410WA	29	25	3.1	4.13

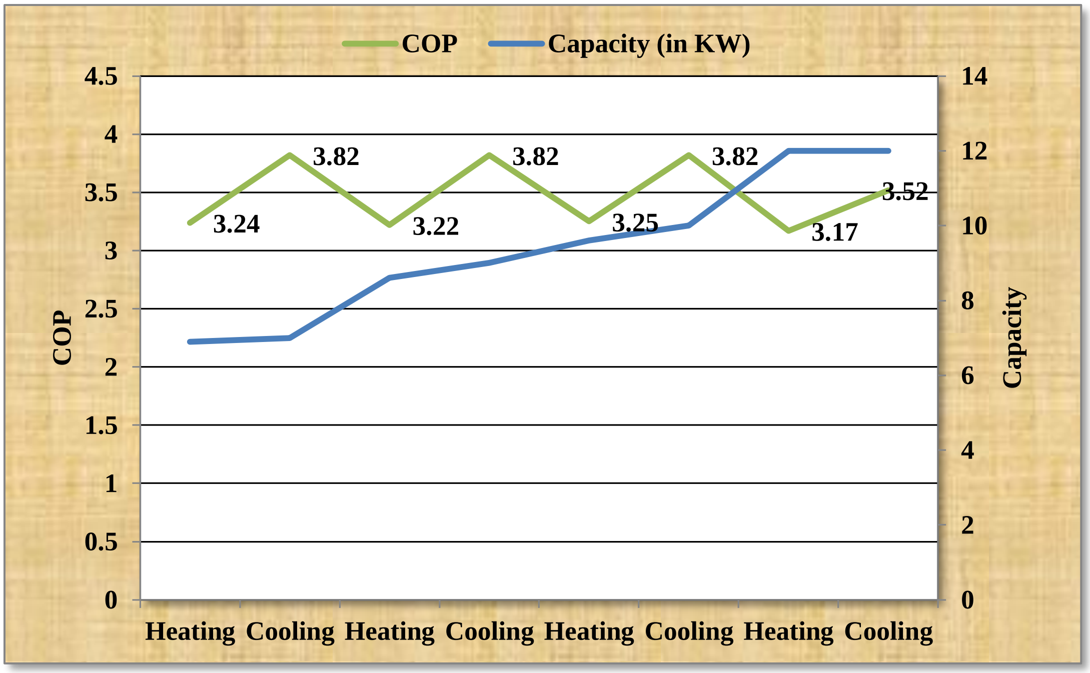


Fig 4.2: GSHP Heating & cooling Capacity against its COP in cold region

Similar models of GSHP will give same heating and cooling COP even if the one or several units are added to the system thereby increasing the capacity.

Table 4.1.6: Unchanged COP's for different capacities of same GSHP model.

Model	Number of units	Capacity	Heating COP	Cooling COP
CFO24V	1	7.2	3.5	4.5
CFO24V	2	14.4	3.5	4.5
CFO24V	3	21.6	3.5	4.5
CFO24V	4	28.8	3.5	4.5
CFO24V	5	36.0	3.5	4.5
CFO24V	6	43.2	3.5	4.5
CFO24V	7	50.4	3.5	4.5

Therefore the heating or cooling load of the house can be accommodated by increasing the capacity of the GSHP system and there would no need for a supplementary system or a backup in times of peak demand.

Case study 2: Residential building in Pune, India

Type of heat pump: Air source heat pump/Ground source heat pump

Heat source system: Ambient air or ground

Table 4.1.7: Characteristics of the dwelling in India

Country	India
City	Pune
Client name	Ashok Kumar V
Application area	Building sector
Building type	Residential
Year of Construction	2008
Property type	Detached house
Installation	ASHP/GSHP
Purpose	Space & water heating
Weather	Warm & mild

In order to assess the performance of heat pumps in this house, RETScreen is been used to evaluate the differences in the conditions of the variables in warm & humid weather zone. Apparently, the heating and cooling loads vary on a large extent in a warm or hot climate as that of the India.

Site reference conditions obtained from RETScreen's climate database are represented in the table below:

Latitude: 18.5 ºNorth

Longitude: 73.9 ºEast

Table 4.1.8: Climate data location: Pune, India

Geographical factors	Measured units	Source
Elevation	559 m	Ground
Heating design temperature	10.9 ºC	Ground
Cooling design temperature	37.1 ºC	Ground
Earth temperature amplitude	14.5 ºC	NASA
Annual air temperature	24.7 ºC	Ground
Relative Humidity	64.4 %	Ground
Daily solar radiation-horizontal	5.52 KWh/ m^2/d	Ground
Atmospheric pressure	94.3 KPa	Ground measured at m
Wind speed	1.8 m/s	Ground-10 m
Earth temperature	27.7 ºC	NASA
Heating degree days	0 ºC –d	Ground
Cooling degree days	5,369 ºC –d	Ground

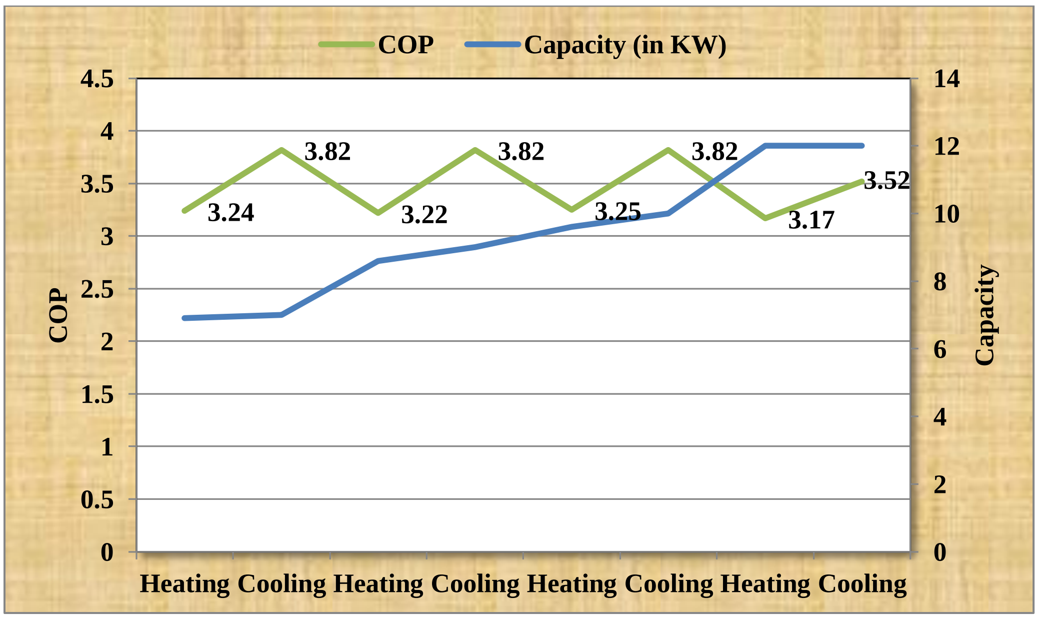
The detached house which is taken into consideration consists of three bedrooms, Living room, a kitchen, 2 bathrooms and open space area making a total floor area of 1500 ft^2. It is a complete concrete/brick, sand construction and is well insulated. Water requirements are fulfilled with the two tanks present in the premises of the house. The total electricity consumption of the house is 1500 KWh/month. The main factor that influences the load profile of the house is the climate. It does not need heating for most part of the year as the house is already located in a country which possess hot climate reducing the need for heating. On the contrary the cooling loads are comparatively high than the minimal requirement for space/water heating. This large variation in the energy usage and the performance of heat pumps are inter-related which is discussed in the next section.

Similarly, four different models of ASHP and GSHP are installed in this house to check the performance factor of this technology in altogether different climate.

Table 4.1.9: Different models of ASHP units installed in case study-2

Type of system	Model	Heating Capacity (KW)	Cooling Capacity (KW)	Heating COP	Cooling COP
ASHP	PHD24C02F1	6.9	7	3.24	3.82
ASHP	PHD30C02F1	8.6	9	3.22	3.82
ASHP	PHD36C02F1	9.6	10	3.25	3.82
ASHP	PHD42C02F1	12	12	3.17	3.52

Fig 4.3: ASHP Heating & cooling Capacity against its COP in warm region



Now, four different units of GSHP were installed and monitored in the same detached house in India. Manufacturer Type/Model: Enertran

Type of pump-Ground Source Heat Pump (India)

Manufacturer: Enertran

Fuel type: Electricity

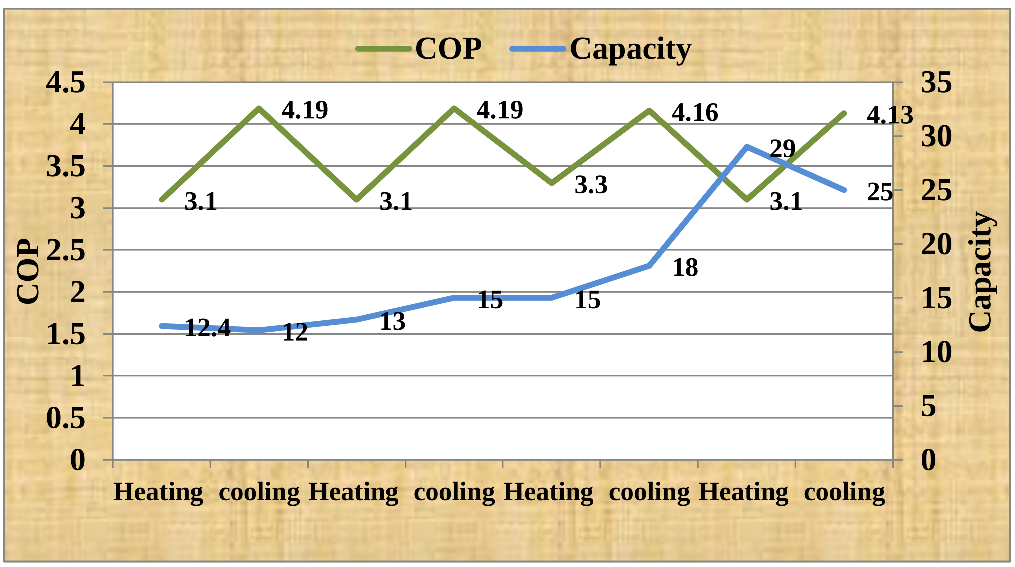
Fuel cost: Rs.5/KWh

Table 4.2.0: Different models of GSHP units installed in case study-2

Model	Capacity (in KW)		COP	
	Heating	Cooling	Heating	Cooling
GT310WA	12.4	12	3.1	4.19
GT410WA	13	15	3.1	4.19
GT150WA	15	18	3.3	4.16
GTE2X410WA	29	25	3.1	4.13

From the above table it was concluded that as the capacity of the system changes, so does its ability to perform better and also there is less probability for the usage of any extra system to fulfill the demands of the house. GSHP works well in the warm weather as the ground source remains constant all throughout the year and the heat exchangers are not affected by cold winds or heavy rainfall unlike Air source heat pumps. The following graph was obtained from the table 4.2.0

Fig 4.4: GSHP Heating & cooling Capacity against its COP in warm region



The analysis of the case study was also based on the type of fuel used. The main fuel that is used to drive the heat pumps is Electricity but in order to have a better understanding about the efficiency and the related costs simulation were run to check if other fuels made any difference. At the same time, GHG emission from the fuels was one such factor which had to be kept in check. It is explained further in the next section.

When we compare both ASHP and GSHP in terms of weather conditions and geological location, we come to a point where ASHP seems to perform better and does not require any feasibility study with regards to soil due to the nature of the source being used. ASHP can be conveniently used without carrying out many geological surveys or investigation onto the soil conditions of the location whereas for Ground source heat pumps number of preliminary aspects have to be considered like the quality of the soil, thickness and the nature of any superficial or chemical deposits, depth & the strength of weathered bedrock geology or for that matter any other site conditions. All these tests and methods have to be put into action before finally installing the system in order to make the project financially feasible. Still the overall cost and time consumed in the installation of GSHP is a lengthy process in comparison to the small units of ASHP which takes 1 to 2 days for the entire installation.

Also this is one reason why more and more people opt for Air source heat pump rather than ground source heat pump. The COP and the heating Capacity of the system are measured against the Outdoor temperature. The house in case study one is a building located in a zone where the climate remains cold and with high winds for most part of the year with an exception in summer when the temperature increases up to as high as 25ºC.

First different capacities of ASHP models were analyzed in the temperature of Glasgow which droops down to as low as -10ºC.Different capacities will favor different co-efficient of performance with the outdoor temperature playing an important role in the functioning of the system.

Now, from the RETScreen database ten different models of ASHP were chosen of varying capacities and COP to check the performance of the system in cold climates when the outdoor temperature drops or rises subsequently. Heating capacity has been taken into account as heating is more into use as compared to cooling for a climate of the UK. Cooling requirement is minimal in these areas.

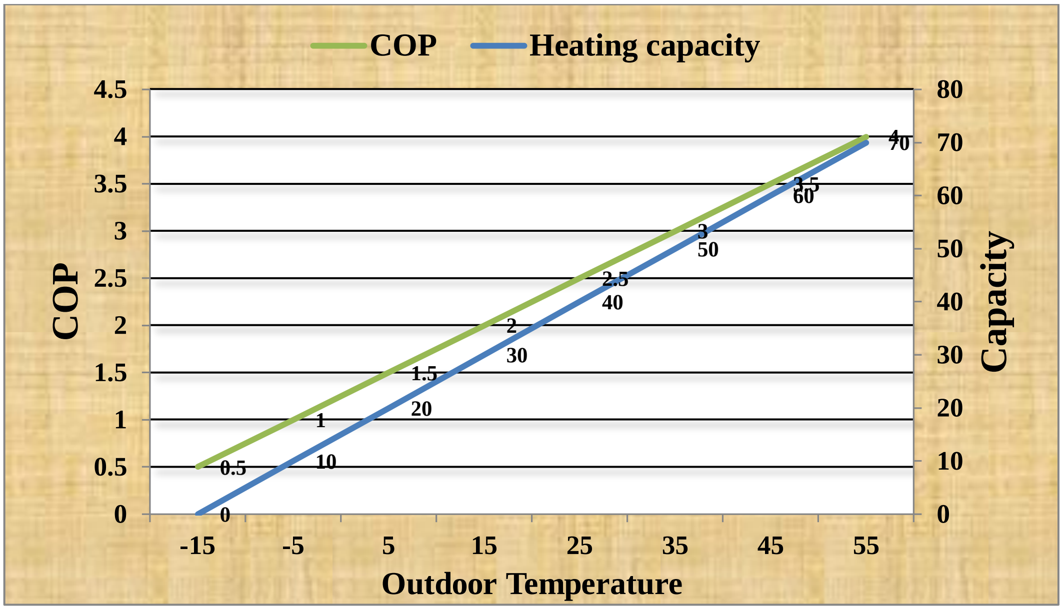
A graph has been presented by using these variables and the performance is assessed for air source heat pumps first keeping in mind the fluctuation the temperature outdoors.

Table 4.2.1: Assessment of ASHP Heating capacity & COP against the outdoor temperature for case study 1-Glasgow (UK)-cold climate

Manufacturer	Model	Heating Capacity	COP
Amana	PHD36C02F1	9.64	3.25
Armstrong	SHP10C36A-C2E,U2E436NB	10.52	2.23
Carrier	38YDB048CK5A/CK5BA048	12.41	2.68
Goettl	HP482E5	13.87	2.94
Heat controller	HRC1060-1	15.77	3.0
Luxaire	BA-06	20.16	3.2
Lennox	LHA090H2B	26.29	3.3
Shandong Lark central AC	LAAHCP 30	31.4	2.98
Trane	TWA120A3	35.63	3.2
Luxaire	BA-12	41.48	3.1

As seen the table above, the outdoor temperature ranges from -15 to 35ºC.Heating capacities are given in Kilowatts and the heating COP has been noted down for each of these ASHP unit models.

Fig 4.5: Heating capacities & COP for cold climate versus Outdoor temperature for Case study 1: Glasgow.



Also the cooling capacities and COP for each of the models used above were noted. Heating capacity is of more importance in this case, due to the behavior and performance of the system in the house located in a cold region.

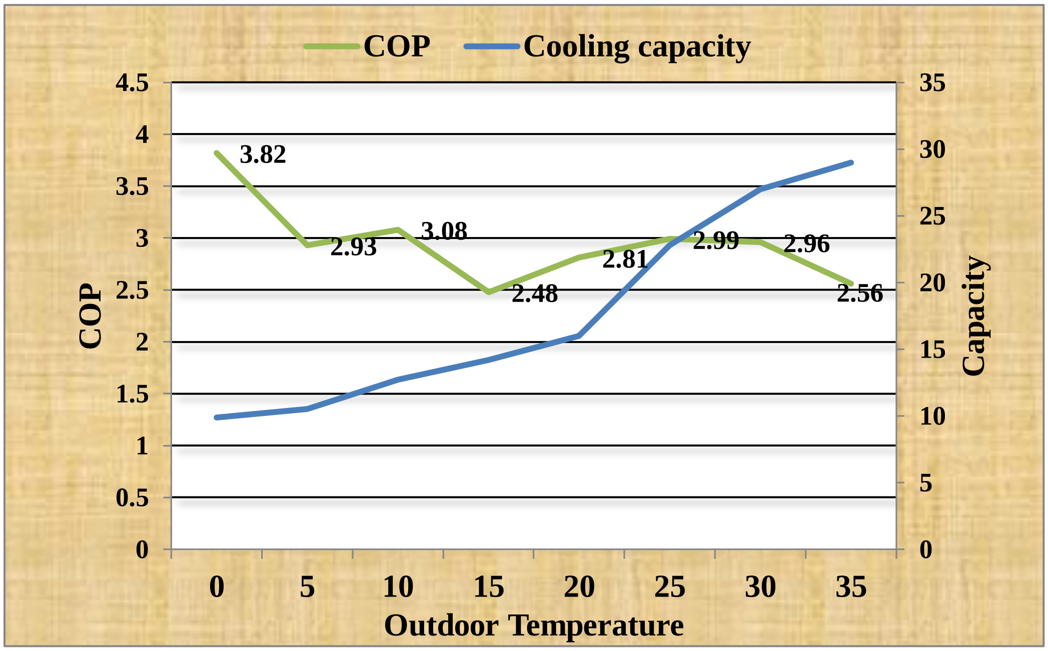
Similarly these ASHP models were tested in the warmer region of India (case study-2) where the graph was obtained for the cooling capacities & COP of the system against the outdoor temperature .The outdoor temperature in Pune, India varies from season to season. Pune experiences both hot and cold climates in a year with the minimum outdoor temperature falling down to 10ºC in winters which is characterized by humidity of a medium level and warm cool weather to the maximum of 42ºC in peak summer days. Both winters and summer lasts for four month each increasing the need equally for both heating and cooling with domestic water heating required all through the year. However, the need for cooling persists for most parts of the year. Despite the cool but humid nature of the environment, the necessity for cooling does not fade away. So the performance of the system is estimated on the basis of their cooling capacities & COP with respect to the outdoor temperature. Outdoor temperature ranges from 0ºC to 50ºC

Table 4.2.2: Assessment of ASHP Cooling capacity & COP against the outdoor temperature for case study 2-Pune (India)-warm climate

Manufacturer	Model	Cooling Capacity	COP
Amana	PHD36C02F1	9.9	3.82
Armstrong	SHP10C36A-C2E,U2E436NB	10.5	2.93
Carrier	38YDB048CK5A/CK5BA048	12.7	3.08
Goettl	HP482E5	14.2	2.48
Heat controller	HRC1060-1	16.0	2.81
Luxaire	BA-06	22.8	2.99
Lennox	LHA090H2B	27.0	2.96
Shandong Lark central AC	LAAHCP 30	29.0	2.56
Trane	TWA120A3	35.0	3.25
Luxaire	BA-12	42	2.73

Cooling capacities for each of the ASHP unit is given in Kilowatt and their COP’s are noted down.

Fig 4.6: Cooling capacities & COP's for Warm climate versus the outdoor temperature for case-study-1, Pune.



Similar analysis is carried out with the help of RETScreen for Ground source heat pumps. Using the database for Ground source heat pump, different models, their heating and cooling capacities are matched with the corresponding heating & cooling COP's to find out the efficiency of GSHP in both the climates.

Table 4.2.3: Assessment of GSHP heating capacity & COP against the outdoor temperature for case study 1-Glasgow (UK)-cold climate

Manufacturer	Model	Heating Capacity	COP
Addison	DWPG017	3.37	3.1
American Geothermal	DXG-240A	7.59	4.43
Bard	WPV48C	10.55	2.7
Carrier	50RVS/RHS0705	15.65	3.6
ClimateMaster	HE 096	21.39	2.8
Enertran	GTE2X500WA	29.25	3.2
GeoSmart Energy	Eco Z-ZS 070 (ECM2.3 motor)	15.12	3.5
Hydro Delta	03-068-WTAR-HE	14.59	3.2
Hydron module	CS-HA120	33.4	3.2
Mammoth	F054VLH	12.16	3.3

Table 4.2.4: Assessment of GSHP cooling capacity & COP against the outdoor temperature for case study 2-Pune (India)-warm climate

Manufacturer	Model	Cooling	COP
Addison	DWPG017	4.8	4.25
American Geothermal	DXG-240A	8.1	5.04
Bard	WPV48C	13.9	3.37
Carrier	50RVS/RHS0705	19.7	3.9
ClimateMaster	HE 096	28	3.1
Enertran	GTE2X500WA	34	4.16
GeoSmart Energy	Eco Z-ZS 070 (ECM2.3 motor)	20.1	4.72
Hydro Delta	03-068-WTAR-HE	20.1	3.7
Hydron module	CS-HA120	38	4
Mammoth	F054VLH	15.23	4.1

Costs associated with heat pumps

Air source heat pumps are said to be cheaper than the Ground source heat pumps. Hindrance in the market penetration of Ground source heat pumps has been their high initial cost which is twice the cost of a conventional boiler or central heating systems used in the residential applications. Also heat pumps work well and efficiently in climates where there is a need for both heating and cooling and is preferred more compared to the ones requiring only one or the other.

From the above two case studies we can assess the costs involved in both the systems and claim one to be better than the other.

Out of the many scenarios, there were two cases which helped in analyzing the financial side of the technology.

a) Fuel type

b) Fuel costs

These are two factors which are briefly discussed as part of the results in order to have a better idea as to which is a good technology in terms of both performance and cost in different climates.

Mostly electrically driven heat pumps are available in the market but there are several other sources of fuel which can help bring down the costs of Air and Ground source heat pumps.

From the above results it is seen that GSHP works better in both the climates of that in the UK and India. Preferably in India as it is used throughout the year for both heating & cooling purpose. Water heating is a domestic need on daily basis so it serves the purpose well. In a cold place like that of Glasgow, there can be severe wind and rainfall which can affect the outside unit of the Air source heat pump which is not the case with Ground source heat pump. Also the large ambient temperature variation in UK is one of the main problems which cannot be ignored. Sometimes due to harsh weather conditions there might be a disruption in the functioning of the air source heat pump and also it may decrease the amount of energy or heat delivered.

Climate brings about a substantial difference in the load profile of the house. In Glasgow, the heating and cooling load is impacted due to lot of outside air being carried in the conditioned space due to ventilation and infiltration. The peak operational efficiency and effectiveness can be attained only if the system runs for a longer time to meet the house loads. This was observed by making use of different models & capacities of heat pump of both ASHP & GSHP .An evaluation was carried out by keeping the capacity of the technology constant and changing other important factors which was fuel type and cost which adds to the incremental cost of the system and also the environment indoors. The types of fuel used to run both the systems were Electricity, Biomass, Natural gas, Oil and LPG.

A comparison was drawn between the costs associated with the respective fuels in both the countries. The amount of fuel consumed throughout the year was also a deciding factor in the choice of fuel.

Table 4.2.5: Different fuel types and their costs for the UK are been reflected in the table below

Fuel type	Fuel cost (£/KWh)
Electricity	0.145
Biomass	0.03
Natural gas	0.048
Oil	0.06
LPG	0.076

Electricity is expensive source of fuel compared to the other fuel types and is widely used in the UK for running many systems.

Table 4.2.6: Different fuel types and their costs for India are been reflected in the table below

Fuel type	Fuel cost (Rs/KWh)
Electricity	5.00
Biomass	4.00
Natural gas	6.00
Oil	3.00
LPG	2.50

An air source heat pump and a Ground source heat pump with similar capacities were installed in both the houses and the performance of the heating and cooling system was assessed keeping in mind the fuel and its costs. In the UK, Electricity was found out to be the best source but it is expensive and twice the price of gas which is used as a conventional source of heating in the boilers.

Biomass fuels are predominantly used in India from decades in the rural households for basic heating like cooking and water heating. Wood fuels contribute to about 56 % of total biomass energy but consumption of lot of wood or Biomass energy also leads to deforestation which is another problem in India. It makes the environment more dry and arid. LPG is expensive but is used mainly for cooking and is safe and reliable. Not much of space heating is required in India in comparison to UK.

Number of fuels can be used to drive the heat pump but the most common and best fuel is electricity as it gives a better COP. But here four other fuels are brought into picture to analyze the effect it would have on the heat pump and the costs associated with it. Biomass energy cost is highly variable, depending upon the source and geographical location. Delivered cost of coal also varies depending upon the costs of extraction and logistic costs which vary with the distance from the mine. Biomass offers most promising future carbon mitigation options. Significant social and environmental benefits make biomass a deserving alternative for support from governments committed to sustainable development. If oil is made use of, it might be a cheaper source for both the systems but the efficiency of the heat pump might reduce to a very low level. Both in UK & India, the cost of Electricity is more compared to other fuels but it is a preferred source of fuel due to its nature of improving the shelf life of the system by performing better. Running cost is proportional to the amount of fuel used and not to forget the type of fuel. For a heat pump, one unit of electricity is consumed to give three units of heat and also the carbon emissions associated with electric heating are high.

GHG emission: Annual heating period for a colder region like Glasgow is almost throughout the year with the exception of three months of summer when there is less requirement of space heating if not water heating. So the total days of heating comes about 275 days indicating a need for substantial amount of energy consumption and thereby releasing large amounts of greenhouse gases or carbon dioxide in the atmosphere (dwelling) diminishing the comfort level of the house. Also the choice of fuel to run the heat pump system affects the environment.

Table 4.2.7: Different fuels and the GHG emissions are listed in the table below:

GHG emission factors tCO2/MWh					
Country	Natural gas	Coal	Oil(#6)	Other	All types
India	0.410	1.207	0.815	0.00	0.993
United Kingdom	0.376	0.896	0.446	0.00	0.497

Chapter 5

Results & Discussions

The capacity of the building's heating equipment typically depends on the heating design temperature (obtained from Retscreen).Hence the equipment needs to be sized to keep the building comfortable under the coldest conditions. Heating design temperature is used to determine the peak heating load and to size the heating system accordingly.

Similarly for hot weathers, the building's cooling equipment depends on the cooling design temperature as the system needs to be sized to maintain the comfort level of the occupants when it gets warm and humid. Annual heating and cooling demand and maximum peak loads are dependent on the climate. It increases or decreases depending on the nature of the local weather conditions. Average Annual heating period for UK is 275days indicating a need for significant amount of energy consumption and even greater amount of carbon dioxide emission.

Heating load and cooling load of the building are calculated in advance by the manufacturers to get a clear idea of the exact system capacity. Changes can be implemented at that stage and is more convenient.

As we take into consideration the climate of UK, the monthly heating loads remains consistent throughout the year and is required for both space and water heating. It was seen that the ASHP and GSHP units give higher heating COP compared to the cooling COP in the cold weather of Glasgow. Typical seasonal efficiency of heating systems for ASHP and GSHP are 130-200% and 250-350% respectively whereas for cooling systems, the seasonal efficiency varies a bit for GSHP. It is more efficient and is about 300-350%.

Table 4.1.1 & 4.1.2 reflects the characteristics of the dwelling which is located in the UK and its climate which is cold and damp throughout the year. From the analysis that was carried out by installing both different models of GSHP & ASHP it was seen that there are certain factors which are the deciding factor decide the productivity of heat pump in different countries. Fig.4.1 produced a graph which shows that with the percentage of change in the capacity the, heating and cooling COP also changes. This decrease or increase in the COP of the heat pump is the deciding factor for the type of heat pump to be installed in a certain region or climate. Cooling COP is expected to be higher in warmer regions as compared to cooler ones. Similarly, the heating COP of the heat pump in a region of hot climate is apparently going to be maximum.

Table 4.1.4 explains and gives results for heat pumps of different capacities and the resultant value for each of those models of heat pump does not show any change in its co-efficient of performance. Different models of ASHP and GSHP installed in the buildings taken into consideration gives a similar type of graph for case study -1.This dictates the fact that the heating and cooling COP's for different models of ASHP and GSHP units will instigate the nature of heating in the cold region or vice-versa.

Table 4.1.6 denotes the capability of variable capacity heat pumps and its potential to perform or meet the peak demands mitigates the need for another supplementary back up system. So the heating and cooling load of the house can be met with one single system of higher capacity.

Table 4.1.7 & 4.1.8 represents the characteristics of the house located in India and its geographical factors respectively. Like the previous models of heat pump used for case study -1, the analysis for case-study -2 is also carried out in similar manner and two different graphs are obtained from the values calculated for models of both ASHP & GSHP in the fig 4.3 &4.4.The graph suggests that the electrically driven heat pump are more energy efficient and the COP is the main force in predicting the nature of the system. Table 4.2.1 & 4.2.2 depicts the ASHP heating & cooling capacity and the COP required for serving the purpose in a cold & warm climate respectively against different outdoor temperatures which is further interpreted in the fig 4.5 & 4.6.It displays the fact about the outdoor temperature conditions which is a crucial factor in determining the loads. Based on this, its potential requirement of a suitable heat pump can be assessed.

Similarly, in table 4.2.3 & 4.2.4 the GSHP heating & cooling capacities are taken into account with respect to the outdoor temperature levels for the two case studies.

It helps in establishing the fact that the decrease in the surrounding temperature brings about a significant change in the performance of the heat pumps. However, the performance of GSHP remains less affected due to the nature of its source whose temperature remains stable throughout in comparison to ASHP.

Table 4.2.5 & 4.2.6 attempts to evaluate the difference in the types of fuels and their respective costs for both the countries. Huge thrust is placed on the economic behavior and the capital cost for each of the fuels represented in the table which impacts the conventional usage or choice of fuels. This in turn influences the decision making of the consumer and the qualified heat pump market. Also the GHG emission per fuel type is listed in the table 4.2.7 which was obtained from Ret screen.

Chapter 6

Conclusion

Scope of technology improvement

The technology is well-proven and used widely in the colder countries where there is need for substantial heating all throughout the year. In order to encourage the usage of these renewable technologies in the market, the government is putting its step forward by contributing towards its initiation and participation. For any heat pump, the most important factor to be looked at is it Seasonal performance factor. Also best practice methods in the installation design of the system and operation is essential.

Well insulated heat pumps and moreover a properly insulated house adds to the effective functioning of the system. It needs to be designed and sized in a way that would suit the conditions of the environment in the best possible manner to provide comfort cooling and heating as the demand arises. Also the way the heat pumps are put into use is of utmost importance. The shelf life of the system can be maintained or improved by balancing the usage of the system.

Table 6.1.1: Cost and performance goals for heating and cooling technologies, 2030 and 2050, Source: Technology Roadmaps (35)

Heat pumps	Space/water heating	Cooling	Space/water heating	Cooling
Installed cost	20% to -30%	-5% to -15%	-30% to -40%	-5% to -20%
Coefficient of performance	30% to 50% improvement	20% to 40% improvement	40%to 60% improvement	30% to 50% improvement
Delivered energy cost	-20% to -30%	-10% to -20%	-30% to -40%	-15% to -25%

There are certain factors which can increase the scope of heating and cooling by heat pumps by researching and working for the development of improved and efficient system components to fulfill both the demands of meeting the heating and cooling loads at the same time .The co-efficient of performance of the systems must be enhanced and made better to reduce the usage of electricity or for that matter any other fuel source in order to provide more heating or cooling with reduced consumption of energy .There is a scope of improvement in this area by 20% by 2020 and 50% by 2030.

The costs related to Ground source heat pumps is one area which can be looked onto, especially when it comes to the installation or uptake of the system for the domestic purpose. Though the maintenance and operation costs of the GSHP are not higher compared to the conventional boilers the initial investment cost limits their penetration where domestic consumers are concerned. But with the ASHP, there is no such issue with its cost as they are not very expensive and within the reach of a common man. Reduction in the installation costs could help occupy the domestic market better. Improving the components and system of existing technologies and design the systems as per the requirement of heating and cooling loads will help maximize the COP. Increase in the COP will automatically result in the reduction of Carbon emissions. In order to widen the potential market, factors like climates and operator behavior has to be taken care of before installing the system. Hybrid systems are also available in the market but running two systems adds to cost of the fuel, depending on the usage. Nevertheless, it makes it highly efficient for days when it is extreme cold or warm. Focus should be laid on reducing the system cost by introducing less expensive but efficient components and at the same time making the system more reliable and energy efficient.

The system components including the heat exchangers, compressors, expansion valves, heat pump cycles, defrosting strategies smart controls needs to be researched upon in depth to gain better values or performance. For extreme cold climates, advanced system design (big-sized heat exchangers) is essential in order to give out optimum heating .Also having remote control systems would help in operating the system better as per the need and this would further optimize the annual performance of the system making it more energy efficient. The user should also keep good knowledge about the functioning of the system so as to not hamper the productivity or the life of the system .Different methods should be adopted for the better maintenance of the system especially for Air source heat pumps which suffer from defrosting when the ambient temperature goes down. ASHP requires supplemental heating during extreme low temperatures outside unlike GSHP.GSHP use less refrigerant and are in simple in design and less maintenance as GSHP's are not exposed to weathering.

The performance of the system also depends on the design of the building so it has to be taken into account prior to the installation for better operating efficiency. Renewable heat incentive scheme is one such scheme which was introduced to the world for the first time in the UK. It is a first long term financial support programme for Renewable heat which was launched in November 2011.Utility companies and Electricity & gas regulators like the Ofgem have come up with various incentive schemes in the past to subsidize the residential market for renewable technologies. These financial incentives are provided to encourage the participation of consumers in the development & adoption of renewable heating systems primarily to bring about reduction in the Carbon dioxide emissions to make the environment free from toxic gases thereby achieving the target set by the UK government. Also its agenda is to partially reduce the cost of developing heat pump projects. Heat pumps are a part of this scheme and the proposed tariff for residential installation in July 2013 for ASHP and GSHP has been set as 7.3 pence/KWh and 18.8 pence/KWh respectively.

Therefore, it is important to consider all the factors discussed and the user behavior to come to a concrete conclusion of which one performs better or which system is financially viable as the climate and economies of the respective countries vary widely and have a different story to tell.

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