بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering Department

Graduation Project

Design of Geothermal Heat Pump System

Project Team

Mahmood Al-Shakarna **Safwan Al-Khatib**

Project Supervisors

Eng. Mohammad Awad

Hebron-Palestine

June-2009

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According to the project supervisor and according to the agreement of the Testing committee members, this project is submitted to the Department of Mechanical Engineering at college of engineering and technology in partial fulfillment of the requirements of (B.SC) degree.

Supervisor Signature

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Examine community Signature

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Department Head Signature

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Dedication

We gift this graduation project
To my parents who raised me
To who carry candle of science
To light his avenue
Of live

To all students & who
Wish to look for
The future

To who love the knowledge &
Looking for all is new
In this world

Acknowledgement

Our thanks go first to our advisor Eng. Mohammad Awad . His guidance and support made this work possible. His constant encouragement, intuitive wisdom, and resolute Leadership were instrumental in completing this work.

We wish to thank Dr.Ishaq Sider and Eng. Kazem Osaily. We sincerely believe that our work would not exist without their inspiration

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ABSTRACT

Geothermal Heat pump is a new technology in A/C Systems in the world. The aim of this project is to describe the procedure of design and installation of a geothermal heat pump in Palestine. Heat pump has been changed and designed to a geothermal heat pump system for the first time in Palestine.

Local climate conditions and soil properties of Jerusalem, located at the Mid of Palestine, were used to design the geothermal coil. The coil was connected to the heat pump, and coefficient of performance (COP cooling) and (COP heating) are to be calculated and predicted for the local conditions available.

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CHAPTER ONE

Introduction

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Chapter One

Introduction

1.1 General Outlook of Geothermal Heat Pump

Maintaining a comfortable temperature inside a building can require a significant amount of energy. Separate heating and cooling systems are often used to maintain the desired air temperature, and the energy required to operate these systems generally comes from electricity, fossil fuels, or biomass. Considering that 46% of sun's energy is absorbed by the earth as shown in Figure 1.1, another option is to use this abundant energy to heat and cool a building. In contrast to many other sources of heating and cooling energy which need to be transported over long distances, Earth Energy is available on-site, and in massive quantities. [9]

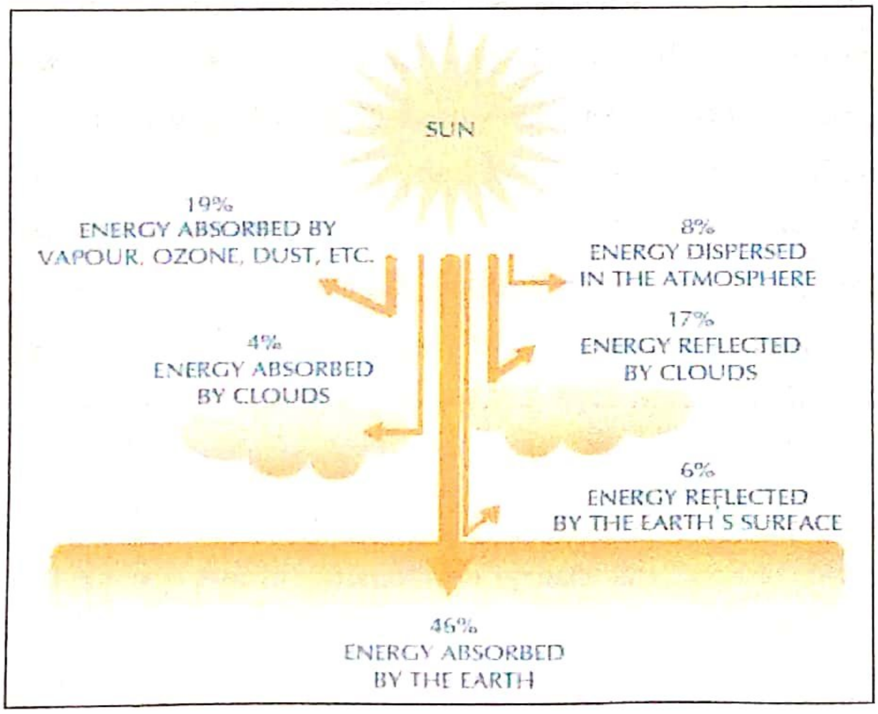

Figure 1.1: Solar Energy Distribution.

Because the ground transports heat slowly and has a high heat storage capacity, its temperature changes slowly—on the order of months or even years, depending on the depth of the measurement. As a consequence of this low thermal conductivity, the soil can transfer some heat from the cooling season to the heating season, heat absorbed by the earth during the summer effectively gets used in the winter .This yearly, continuous cycle between the air and the soil temperature results in a thermal energy potential that can be harnessed to help heat or cool a building. [9]

Another thermal characteristic of the ground is that a few meters of surface soil insulate the earth and groundwater below, minimizing the amplitude of the variation in soil temperature in comparison with the temperature in the air above the ground. This thermal resistivity fluctuations further helps in shifting the heating or cooling load to the season where it is needed. The earth is warmer than the ambient air in the winter and cooler than the ambient air in the summer.

This warm earth and groundwater below the surface provides a free renewable source of energy that can easily provide enough energy year-round to heat and cool an average suburban residential home, for example. A Ground-Source Heat Pump (GSHP) transforms this Earth Energy into useful energy to heat and cool buildings. It provides low temperature heat by extracting it from the ground or a body of water and provides cooling by reversing this process. Its principal application is space heating and cooling, though many also supply hot water, such as for domestic use. It can even be used to maintain the integrity of building foundations in permafrost conditions, by keeping them frozen through the summer. [9]

A heat pump is used to concentrate or upgrade this free heat energy from the ground before distributing it in a building through conventional ducts. It operates much as a refrigerator or conventional air conditioning system in that it relies on an external source of energy - typically electricity - to concentrate the heat and shift the temperature. Typically, each kilowatt (kW) of electricity used to operate a GHP system draws more than 3 kW of renewable energy from the ground. Heat pumps typically range from 3.5 to 35 kW in cooling capacity (about 1 to 10 refrigeration tons), and a single unit is generally sufficient for a house or a small commercial building. For larger commercial, institutional or industrial buildings, multiple heat pumps units will often be employed. [9]

Since a GSHP system does not directly create any combustion products and because it draws additional free energy from the ground (See Figure 1.2), it can actually produce more energy than it uses .Because of this, GHP efficiencies routinely average 200 to 500% over a season. GHP systems are more efficient than air-source heat pumps, which exchange heat with the outside air, due to the stable, moderate temperature of the ground. They are also more efficient than conventional heating and air-conditioning technologies, and typically have lower maintenance costs. They require less space, especially when a liquid building loop replaces voluminous air ducts, and are not prone to vandalism like conventional rooftop units. Peak electricity consumption during cooling season is lower than with conventional air-conditioning, so utility demand charges may be also reduced. [9]

For the above reasons, significant energy savings can be achieved through the use of GSHPs in place of conventional air-conditioning systems and air-source heat pumps .Reductions in energy consumption of 30% to 70% in the heating mode and 20% to 50% in the cooling mode can be obtained. Energy savings are even higher when compared with combustion or electrical resistance heating systems. This potential for significant energy savings has led to the use of GHPs in a variety of applications.

Figure 1.2: GHP System - The Horizontal Burial of an Earth Connection (Heat Exchanger).

Today, GSHP systems are one of the fastest growing applications of renewable energy in the world, with most of this growth happening in USA and Europe, but also in other countries such as Japan and Turkey. By the end of 2004, the worldwide installed capacity was estimated at almost 12 GWh with an annual energy use of 20 TWh. Today, around one million GSHP system units have been installed worldwide, and annual increases of 10% have occurred in about 30 countries over the past 10 years. [9]

In the USA alone, over 50,000 GSHP units are sold each year, with a majority of these for residential applications. It is estimated that a half million units are installed, with 85% closed-loop earth connections (46% vertical, 38% horizontal) and 15% open loop systems (groundwater) . [9]

1.2 Project Outline

The project is divided up in 5 chapters; the chapters follow each other logically to get the complete idea about the project. Chapter 1; Provides an introduction about the project and some historical information about the Geothermal Heat Pump, Chapter 2; It talks about normal heat pump air source heat pump. Chapter 3; It talks about geothermal energy. Chapter 4; It talks about geothermal heat pump system. And Chapter 5: Design and calculations.

1.3 The Objectives and Scope

This study ~~deals~~ with the modeling of vertical closed-loop, geothermal heat ~~pump~~ systems. ~~The~~ challenges associated with the design of these systems were discussed in the previous section. A considerable amount of research in the past decade has been geared toward optimizing the performance of these types of systems and this study is part of those efforts.

1.4 History of Geothermal Heat Pump

Ground source heat pump technology is the wave of the future, but the concept isn't new at all. In fact, Lord Kelvin developed the concept of the heat pump in 1852. In the late 1940's, Robert C. Webber, a cellar inventor, was experimenting with his deep freezer. He dropped the temperature in the freezer and touched the outlet pipe and almost burned his hand. He realized heat was being thrown away, so he ran outlets from his freezer to his boilers and provided his family with more hot water than they could use! There was still wasted heat, so he piped hot water through a coil and used a small fan to distribute heat through the house to save coal. Mr.

Webber was so pleased with the results that he decided to build a full size heat pump to generate heat for the entire home. Mr. Webber also came up with the idea to pump heat from underground, where the temperature doesn't vary much throughout the year. Copper tubing was placed in the ground and Freon gas ran through the tubing to gather the ground heat. The gas was condensed in the cellar, gave off its heat and forced the expanded gas to go through the ground coil to pick up another load. Air was moved by a fan and distributed into the home. The next year, Mr. Webber sold his old coal furnace.

In the forties, the heat pump was known for its superior efficiency. The efficiency was especially useful in the seventies. The Arab oil embargo awakened conservation awareness and launched interest in energy conservation despite cheap energy prices. That is when Dr. James Bose, professor at Oklahoma State University, came across the heat pump concept in an old engineering text. Dr. Bose used the ideas to help a homeowner whose heat pump was dumping scalding water into his pool. Dr. Bose fashioned the heat pump to circulate the water through the pipes instead of dumping the water into the pool. This was the beginning of the new era in geothermal systems. Dr. Bose returned to Oklahoma State University and began to develop his idea. Since then, Oklahoma has become the center of ground source heat pump research and development. The International Ground Source Heat Pump Association was formed in Oklahoma, and is based on the campus of Oklahoma State University, where Dr. Bose severs as executive director.

1.5 Time Table

The time of the introduction to project is scheduled over 18 week; table 1.2 shows how the work scheduled over these weeks:

Table 1.1 Project time-schedule for first semester

process	Week																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Identification of the project	🟧	🟧																
Writing ch1			🟧	🟧														
Writing ch2					🟧	🟧												
Writing ch3							🟧	🟧										
Writing ch4									🟧	🟧								
Writing ch5											🟧	🟧	🟧	🟧				
Printing and finishing									🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧		
The preparatin of discussion and Printing Project																	🟧	🟧

Table 1.2 Project times- Schedule in the second semester

process	Week															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Calculate heating and cooling lodes for the balding	▨	▨	▨	▨	▨	▨										
Design the GHP system							▨	▨	▨	▨						
Examination of results								▨	▨	▨	▨					
Writing Documentation											▨	▨				
Printing the final copy of the project Document													▨	▨	▨	▨

1.6 Budget

The budget of the project includes printing costs and local study and survey. The following table shows the estimated cost of each one.

Table (3.1) Budget

Equipment	**Cost(NIS)**	**Total (NIS)**
Using the internet	100	=
Transportation	400	=
Printing papers	150	=
Printing the final copy of chapters	350	=
		1000

CHAPTER TWO

Heat Pump

2.1 Introduction
2.2 What Is A Heat Pump And How Dose It Work?
2.3 Heat Pump Components
2.4 How Does an Air-Source Heat Pump Work?
2.5Other Terms
2.6 Maintenance
2.7 Life Expectancy and Warranties
2.8 Operating Costs

Chapter Two

Heat Pump

2.1 Introduction

If you are exploring the heating and cooling options for a new house or looking for ways to reduce your energy bills, you may be considering a heat pump. A heat pump can provide year-round climate control for your home by supplying heat to it in the winter and cooling it in the summer. Some types can also provide supplementary hot water heating.

In general, using a heat pump alone to meet all your heating needs will not be economical. However, used in conjunction with a supplementary form of heating, such as an oil, gas, or electric furnace, a heat pump can provide reliable and economic heating in winter and cooling in summer. If you already have an oil or electric heating system, installing a heat pump may be an effective way to reduce your energy costs. [11]

Nevertheless, it is important to consider all the benefits and costs before purchasing a heat pump. While heat pumps may have lower fuel costs in comparison with conventional heating systems, they are more expensive to buy. It is important to carefully weigh your anticipated fuel savings against the initial cost. It is also important to realize that heat pumps will be most economical when used all year round. Investing in a heat pump will make more sense if you are interested in both summer cooling and winter heating. [11]

2.2 What Is A Heat Pump And How Dose It Work?

A heat pump is an electrical device that extracts heat from one place and transfers it to another. The heat pump is not a new technology; it has been used in Palestine and around the world for decades. Refrigerators and air conditioners are both common examples of heat pumps. [9]

Heat pumps transfer heat by circulating a substance called a refrigerant through a cycle of alternating evaporation and condensation (see Figure 2.1). A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed en route to the other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle. [9]

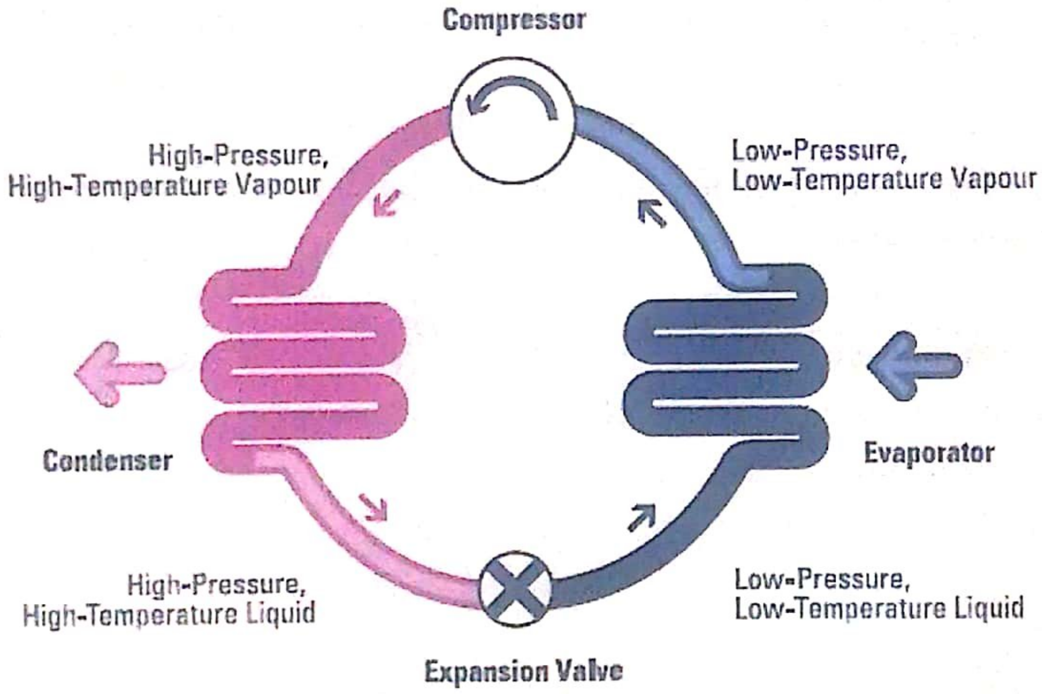

Figure 2.1: Basic Heat Pump Cycle

Refrigerators and air conditioners are both examples of heat pumps operating only in the cooling mode. A refrigerator is essentially an insulated box with a heat pump system connected to it. The evaporator coil is located inside the box, usually in the freezer compartment. Heat is absorbed from this location and transferred outside, usually behind or underneath the unit where the condenser coil is located. Similarly, an air conditioner transfers heat from inside a house to the outdoors. [9]

The air-source heat pump absorbs heat from the outdoor air in winter and rejects heat into outdoor air in summer.

2.3 Heat Pump Components

- The **Refrigerant** is the substance which circulates through the heat pump, alternately absorbing, transporting, and releasing heat.

- The **Reversing Valve** controls the direction of flow of the refrigerant in the heat pump.

- A **Coil** is a loop, or loops, of tubing where heat transfer takes place. The tubing may have fins to increase the surface area available for heat exchange.

- The **Evaporator** is a coil in which the refrigerant absorbs heat from its surroundings and boils to become a low temperature vapour. As the refrigerant passes from the reversing valve to the compressor, the **accumulator** collects any excess liquid that didn't vaporize into a gas. Not all heat pumps, however, have an accumulator.

- The **Compressor** squeezes the molecules of the refrigerant gas together, increasing the temperature of the refrigerant.

- The **Condenser** is a coil in which the refrigerant gives off heat to its surroundings and becomes a liquid.

- The **Expansion Device** releases the pressure created by the compressor. This causes the temperature to drop, and the refrigerant becomes a low-temperature vapor/liquid mixture.

- The **Plenum** is an air compartment which forms part of the system for distributing heated or cooled air through the house. It is generally a large compartment immediately above the heat exchanger.

2.4 How Does an Air-Source Heat Pump Work?

The air-source heat pump has three cycles: the heating cycle, the cooling cycle, and the defrost cycle.

2.4.1 The Heating Cycle

During the heating cycle, heat is extracted from outdoor air and pumped indoors (see Figure 2.2).

- First, the liquid refrigerant passes through the expansion device, changing to a low-pressure liquid/vapor mixture. It then goes to the outdoor coil, which acts as the evaporator coil. The liquid refrigerant absorbs heat from the outdoor air and boils, becoming a low-temperature vapor. [9]

- The reversing valve sends this vapor to the accumulator, which collects any remaining liquid before the vapor passes to the compressor. The vapor is then compressed, reducing its volume and causing it to heat up. [9]

- Finally, the reversing valve sends the gas, which is now hot, to the indoor coil, which acts as the condenser. The heat from the hot gas is transferred to the indoor air, causing the refrigerant to condense into a liquid. This liquid returns to the expansion device and the cycle is repeated. [9]

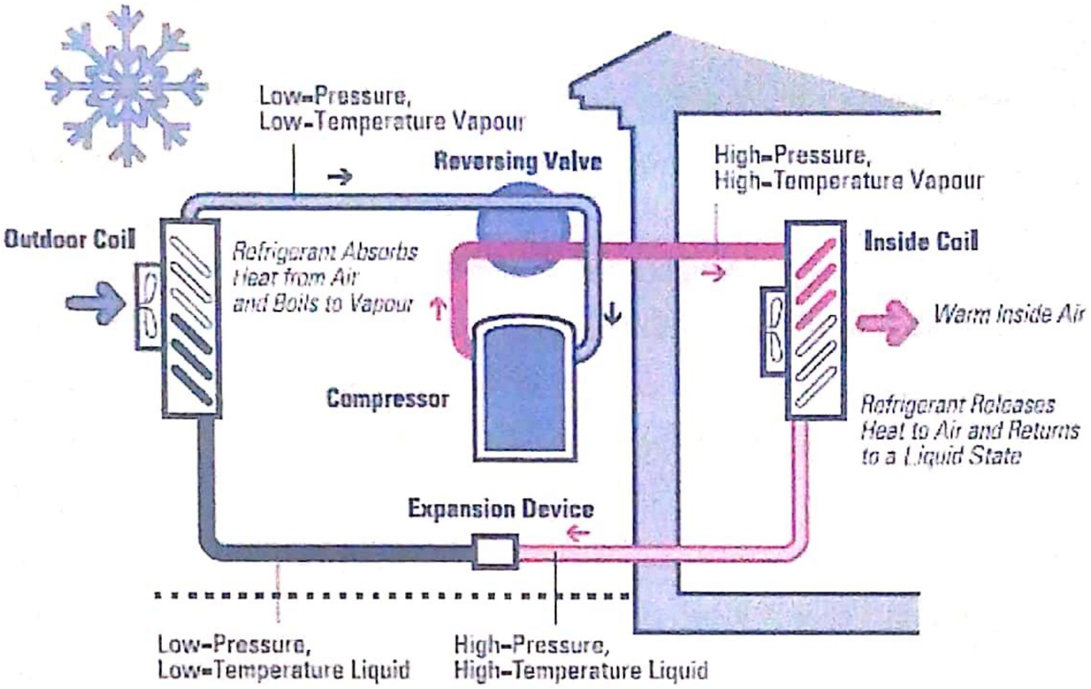

Figure 2.2: Components of an Air-source Heat Pump (Heating Cycle)

The ability of the heat pump to transfer heat from the outside air to the house depends on the outdoor temperature. As this temperature drops, so does the ability of the heat pump to absorb heat (the unit's capacity)?

At the outdoor ambient balance point temperature, the heat pump's capacity is ~~equal~~ to the heat ~~loss~~ of the house. Below this outdoor ambient temperature, the heat pump cannot supply all the heat required to keep the living space comfortable, and supplementary heaters must be used. [12]

When the heat pump is operating in the heating mode without any supplementary heat, the air leaving it will be cooler than air leaving a furnace. Furnaces generally deliver air to the living space at between 55°C and 60°C. Heat pumps provide air in larger quantities at about 29°C to 43°C.

2.4.2 The Cooling Cycle

The cycle described above is reversed to cool the house during the summer. The unit takes heat out of the indoor air and dumps it outside (see Figure 2.3).

- As in the heating cycle, the liquid refrigerant passes through the expansion device, changing to a low pressure liquid/vapor mixture. It then goes to the indoor coil, which acts as the evaporator. The liquid refrigerant absorbs heat from the indoor air and boils, becoming a low-temperature vapor. [9]

- The reversing valve sends this vapor to the accumulator, which collects any remaining liquid, and then to the compressor. The vapor is then compressed, reducing its volume and causing it to heat up. [9]

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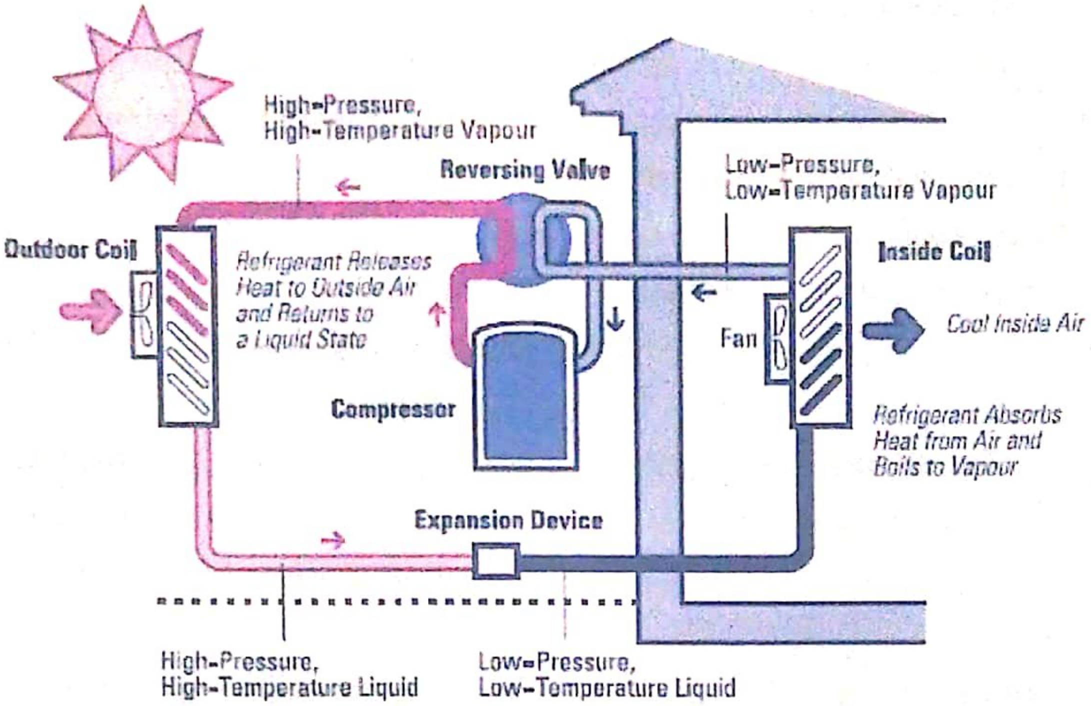

Figure2.3: Components of an Air-source Heat Pump (Cooling Cycle)

During the cooling cycle, the heat pump also dehumidifies the indoor air. Moisture in the air passing over the indoor coil condenses on the coil's surface and is collected in a pan at the bottom of the coil. A condensate drain connects this pan to the house drain.

2.4.3 The Defrost Cycle

If the outdoor temperature falls to near or below freezing when the heat pump is operating in the heating mode, moisture in the air passing over the outside coil will condense and freeze on it. The amount of frost build-up depends on the outdoor temperature and the amount of moisture in the air. [11]

This frost build-up decreases the efficiency of the coil by reducing its ability to transfer heat to the refrigerant. At some point, the frost must be removed. To do this, the heat pump will switch into the defrost mode. [12]

- First, the reversing valve switches the device to the cooling mode. This sends hot gas to the outdoor coil to melt the frost. At the same time the outdoor fan, which normally blows cold air over the coil, is shut off in order to reduce the amount of heat needed to melt the frost. [9]

- While this is happening, the heat pump is dumping cool air into the house. The supplementary heating system can be used to warm this air before it is distributed throughout the house. [9]

One of two methods is used to determine when the unit goes into defrost mode:

1- **Demand-frost** controls monitor airflow, refrigerant pressure, air or coil temperature, and pressure differential across the outdoor coil to detect frost accumulation on the outdoor coil. [9]

2- **Time-temperature Defrost** is started and ended by a preset interval timer or a temperature sensor located on the outside coil. The cycle can be initiated every 30, 60, or 90 minutes depending on the climate and the design of the system. [9]

Unnecessary defrost cycles reduce the seasonal performance of the heat pump. As a result, the demand-frost method is generally more efficient since it starts the defrost cycle only when it is required. [11]

If the heat pump is all-electric, supplementary heat will be supplied by a series of resistance heaters located in the main air-circulation space or plenum downstream of the heat pump indoor coil. If the heat pump is an add-on unit (see

Figure 2.4), the supplementary heat will be supplied by a furnace . The furnace may be electric, oil, natural gas, or propane. The indoor coil of the heat pump is located in the air plenum, usually just above the furnace. [11]

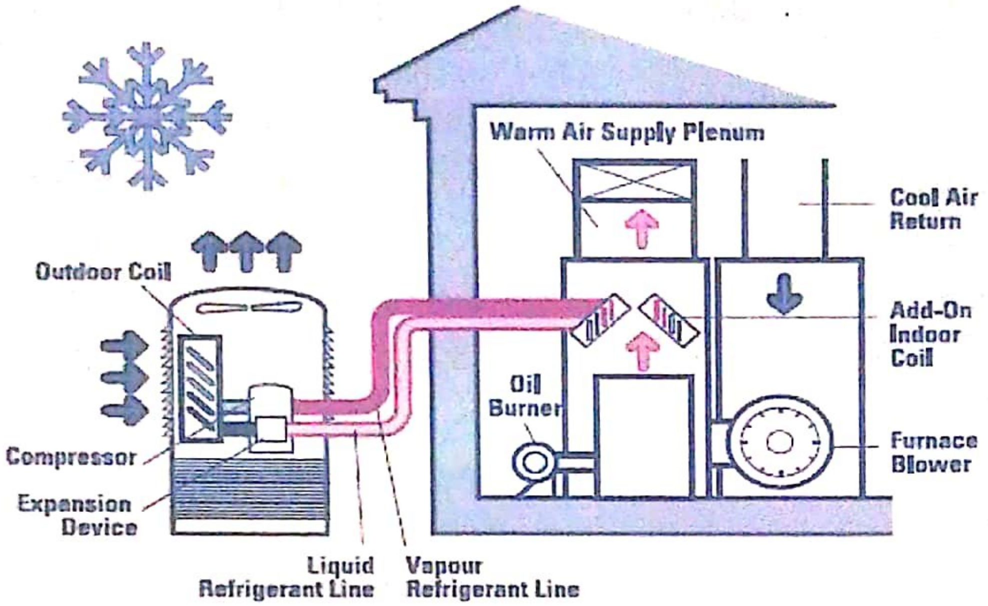

Figure 2.4: Add-On Heat Pump

2.5 Other Terms

There are several relative terms which help in more understanding and analyzing the heating and cooling systems from among is:

- A **Btu/h,** or British thermal unit per hour, A heat unit equal to the amount of heat required to raise one pound of water one degree Fahrenheit. [8]

- Heating **Degree Days** are a measure of the severity of the weather. One degree day is counted for every degree that the average daily temperature is below the base temperature of 18°C. For example, if the average temperature on a particular day was 12°C, six degree days would be credited to that day. The annual total is calculated by simply adding the daily totals. [9]

- A **Ton Refrigeration** is a measure of heat pump capacity. One Ton Refrigeration is equivalent to 3.5 kW or 12 000 Btu/h. [9]

- The **coefficient of performance (COP)** is a measure of a heat pump's efficiency. It is determined by dividing the energy output of the heat pump by the electrical energy needed to run the heat pump, at a specific temperature. The higher the COP, the more efficient the heat pump. This number is comparable to the steady-state efficiency of oil and gas-fired furnaces. [11]

- The **heating seasonal performance factor (HSPF)** is a measure of the total heat output in Btu of a heat pump over the entire heating season divided by the total energy in watt hours it uses during that time. This number is similar to the seasonal efficiency of a fuel-fired heating system and includes energy for supplementary heating. Weather data characteristic of long-term climatic conditions are used to represent the heating season. [9]

- The **energy efficiency ratio (EER)** measures the steady state cooling efficiency of a heat pump. It is determined by dividing the cooling capacity of the heat pump in Btu/h by the electrical energy input in watts at a specific temperature. The higher the EER, the more efficient the unit. [9]

- The **seasonal energy efficiency ratio (SEER)** is a measurement of the cooling efficiency of the heat pump over the entire cooling season. It is determined by dividing the total cooling provided over the cooling season in Btu by the total energy used by the heat pump during that time in watt hours. The SEER is based on a climate with an average summer temperature of 28°C. [9]

- The **balance point** is the temperature at which the amount of heating provided by the heat pump equals the amount of heat lost from the house. This is the point at which the heat pump meets the full heating needs of the house. Below this point, supplementary heat is required. [11]
- The **economic balance point** is the temperature at which the cost of heat energy supplied by the heat pump equals the cost of heat supplied by a supplementary heating system. [9]

2.6 Maintenance

Proper maintenance is critical to ensure that your heat pump operates efficiently and has a long service life. You can do some of the simple maintenance yourself, but you may also want to have a competent service contractor do an annual inspection of your unit. The best time to service your unit is at the end of the cooling season, prior to the start of the next heating season.

- **Filter** and **Coil** maintenance has a dramatic impact on system performance and service life. Dirty filters, coils, and fans reduce air flow through the system. This reduces system performance, and can lead to compressor damage if it continues for extended periods of time. [9]

Filters should be inspected monthly and cleaned or replaced as required by the manufacturer's instructions. The coils should be vacuumed or brushed clean at regular intervals as indicated in the manufacturer's instruction booklet. The outdoor coil may be cleaned using a garden hose. [9]

- The **Fan** should be cleaned and the fan motor should be lubricated annually to ensure that it provides the airflow required for proper operation. The fan speed should be checked at the same time. Incorrect pulley settings, loose fan belts, or incorrect motor speeds can all contribute to poor performance. [9]

- **Ductwork** should be inspected and cleaned as required to ensure that air flow is not restricted by loose insulation, abnormal buildup of dust, or any other obstacles which occasionally find their way through the grilles.

- Be sure that **Vents** and **Registers** are not blocked by furniture, carpets, or other items that can block airflow. As noted earlier, extended periods of inadequate airflow can lead to compressor damage.

You will need to hire a competent service contractor to do more difficult maintenance such as checking the refrigerant level, and making electrical or mechanical adjustments.

Service contracts are similar to those for oil and gas furnaces. But heat pumps are more sophisticated than conventional equipment and, therefore, can have higher average service costs. [9]

2.7 Life Expectancy and Warranties

Air-source heat pumps have a service life of between 15 and 20 years. The compressor is the critical component of the system. [9]

Most heat pumps are covered by a one-year warranty on parts and labour, and an additional five-year warranty on the compressor (for parts only). However, warranties vary between manufacturers, so be sure to check the fine print.

2.8 Operating Costs

The energy costs of a heat pump can be lower than those of other heating systems, particularly of an electric system. However, the relative savings will depend on whether you are currently using electricity, oil, propane, or natural gas, and on the relative costs of different energy sources in your area. By running a heat pump, you will use less gas or oil, but more electricity. If you live in an area where electricity is expensive, or fuel is relatively inexpensive, your operating costs may be higher. Depending on these factors, the payback period for investment in an air-source heat pump could be anywhere from a few years to a decade or more. [9]

Later in this project, heating energy cost comparisons between air-source and ground-source heat pumps.

CHAPTER THREE

Geothermal Energy

Content:

Chapter Three

Geothermal Energy

3.1 What Is Geothermal Energy?

The word geothermal comes from the Greek words geo (earth) and thermal (heat). So, geothermal energy is heat from within the earth. We can use the steam and hot water produced inside the earth to heat buildings or generate electricity. Geothermal energy is a renewable energy source because the water is replenished by rainfall and the heat is continuously produced inside the earth.

3.2 How Have People Used Geothermal Energy In The Past?

From earliest times, people have used geothermal water that flowed freely from the earth's surface as hot springs. The oldest and most common use was, of course, just relaxing in the comforting warm waters. But eventually, this "magic water" was used (and still is) in other creative ways. The Romans for example, used geothermal water to treat eye and skin disease and, at Pompeii, to heat buildings. As early as 10,000 years ago, Native Americans used hot springs water for cooking and medicine. For centuries the Maoris of New Zealand have cooked "geothermally," and, since the 1960s, France has been heating up to 200,000 homes using geothermal water. [14]

3.3 Uses of Geothermal Energy

Some applications of geothermal energy use the earth's temperatures near the surface, while others require drilling miles into the earth. The three main uses of geothermal energy are:

1) Direct Use and District Heating Systems: which use hot water from springs or reservoirs near the surface.

2) Electricity generation: in a power plant requires water or steam at very high temperature (300 to 700 degrees Fahrenheit). Geothermal power plants are generally built where geothermal reservoirs are located within a mile or two of the surface.

3) Geothermal heat pumps: use stable ground or water temperatures near the earth's surface to control building temperatures above ground.

3.3.1 Direct Use of Geothermal Energy

The direct use of hot water as an energy source has been happening since ancient times. The Romans, Chinese, and Native Americans used hot mineral springs for bathing, cooking and heating. Today, many hot springs are still used for bathing, and many people believe the hot, mineral-rich waters have natural healing powers.

After bathing, the most common direct use of geothermal energy is for heating buildings through district heating systems. Hot water near the earth's surface can be piped directly into buildings and industries for heat. A district heating system provides heat for 95 percent of the buildings in Reykjavik, Iceland. Examples of other direct uses include: growing crops, and drying lumber, fruits, and vegetables.

3.3.2 Geothermal Power Plants

Geothermal power plants use hydrothermal resources which have two common ingredients: water (hydro) and heat (thermal). Geothermal plants require high temperature (300 to 700 degrees Fahrenheit) hydrothermal resources that may come from either dry steam wells or hot water wells. We can use these resources by drilling wells into the earth and piping the steam or hot water to the surface. Geothermal wells are one to two miles deep. [15]

There are three basic types of geothermal power plants:

- Dry steam plants - use steam piped directly from a geothermal reservoir to turn the generator turbines. The first geothermal power plant was built in 1904 in Tuscany, Italy at a place where natural steam was erupting from the earth. [16]

- Flash steam plants - take high-pressure hot water from deep inside the earth and convert it to steam to drive the generator turbines. When the steam cools, it condenses to water and is injected back into the ground to be used over and over again. Most geothermal power plants are flash plants. [16]

- Binary power plants - transfer the heat from geothermal hot water to another liquid. The heat causes the second liquid to turn to steam which is used to drive a generator turbine. [16]

3.3.3 Geothermal Heat Pumps

Animals have always known to burrow into the earth, where the temperature is relatively stable compared to the air temperature, to get shelter from winter's cold and summer's heat. People, too, have sought relief from bad weather in earth's caves. Today, with geothermal heat pumps (GHP's), we take advantage of this stable earth temperature - about 45 - 58 degrees F just a few feet below the surface - to help keep our indoor temperatures comfortable. GHP's circulate water or other liquids through pipes buried in a continuous loop (either horizontally or vertically) next to a building. Depending on the weather, the system is used for heating or cooling. [14]

Geothermal heat pumps use the Earth's constant temperatures to heat and cool buildings. They transfer heat from the ground (or water) into buildings in winter and reverse the process in the summer.

Heating: Earth's heat (the difference between the earth's temperature and the colder temperature of the air) is transferred through the buried pipes into the circulating liquid and then transferred again into the building.

Cooling: During hot weather, the continually circulating fluid in the pipes 'picks up' heat from the building - thus helping to cool it - and transfers it into the earth.

GHP's use very little electricity and are very easy on the environment.

In the U.S., the temperature inside over 300,000 homes, schools and offices is kept comfortable by these energy saving systems, and hundreds of thousands more are used worldwide. The U.S. Environmental Protection Agency has rated GHP's as among the most efficient of heating and cooling technologies. [15]

According to the U.S. Environmental Protection Agency (EPA), geothermal heat pumps are the most energy-efficient, environmentally clean, and cost-effective systems for temperature control. Although, most homes still use traditional furnaces and air conditioners, geothermal heat pumps are becoming more popular. In recent years, the U.S. Department of Energy along with the EPA have partnered with industry to promote the use of geothermal heat pumps. [15]

3.4 What Parts Of The World Have Geothermal Energy?

- **For electricity and direct use:** Geothermal reservoirs that are close enough to the surface to be reached by drilling can occur in places where geologic processes have allowed magma to rise up through the crust, near to the surface, or where it flows out as lava. The crust of the Earth is made up of huge plates, which are in constant but very slow motion relative to one another. Magma can reach near the surface in three main geologic areas:

1- where Earth's large oceanic and crustal plates collide and one slides beneath another, called a subduction zone The best example of these hot regions around plate margins is the Ring of Fire -- the areas bordering the Pacific Ocean: the South American Andes, Central America, Mexico, the Cascade Range of the U.S. and Canada, the Aleutian Range of Alaska, the Kamchatka Peninsula of Russia, Japan, the Philippines, Indonesia and New Zealand. [16]

2- spreading centers, where these plates are sliding apart, (such as Iceland, the rift valleys of Africa, the mid-Atlantic Ridge and the Basin and Range Province in the U.S.). [16]

3- Places called hot spots-- fixed points in the mantle that continually produce magma to the surface. Because the plate is continually moving across the hot spot, strings of volcanoes are formed, such as the chain of Hawaiian Islands. The countries currently producing the most electricity from geothermal reservoirs are the United States, New Zealand, Italy, Iceland, Mexico, the Philippines, Indonesia and Japan, but geothermal energy is also being used in many other countries. [16]

- **For geothermal heat pumps**, use can be almost world-wide. The earth's temperature a few feet below the ground surface is relatively constant everywhere in the world (about 45 - 58 degrees F), while the air temperature can change from summer to winter extremes. Unlike other kinds of geothermal heat, shallow ground temperatures are not dependent upon tectonic plate activity or other unique geologic processes. Thus geothermal heat pumps can be used to help heat and cool homes anywhere.[14]

CHAPTER FOUR

Geothermal Heat Pump System

Chapter Four

Geothermal Heat Pump System

4.1 Introduction

Geothermal heat pumps use the earth as a heat source or sink by means of a circulating water loop. Mean earth temperatures are approximately 17.3°C in Jerusalem City, resulting in excellent coefficients of performance. Since the heat pump supplies both heating and cooling, only one appliance is needed to satisfy both conditioning needs. No exterior equipment such as cooling towers or condensing units is needed, nor is heating plants. Each heat pump unit can heat or cool at any time, zoning is easy to accomplish and the part load performance is excellent. Maintenance is simple and less costly than conventional fossil fuel and cooling tower systems. [5]

Geothermal heat pumps are available from all major manufacturers and are configured as water-to-air, water-to-water, and split equipment.

A geothermal heat pump moves heat into or out of the earth using water wells or a network of high-density polyethylene pipes buried in horizontal trenches or vertical boreholes.

The pipes carry a heat transfer fluid usually comprised of water and antifreeze, which is pumped through the ground loop and the circulated pump units within the building. The heat transfer fluid extracts heat (heating mode) from the earth surrounding the ground loop.

The refrigeration system in the geothermal heat pump unit upgrades the heat, which is then distributed throughout the building by way of ductwork or a hydronic (hot water space heating) system. In a heat pump, the refrigeration system can also work in reverse and provide cooling.

4.2 Benefits of Geothermal Heat Pump Systems

Geothermal heat pump systems allow for design flexibility and can be installed in both new and retrofit situations. Because the hardware requires less space than that needed by conventional HVAC systems, the equipment rooms can be greatly scaled down in size, freeing space for productive use. GHP systems also provide excellent "zone" space conditioning, allowing different parts of your home to be heated or cooled to different temperatures.

Because GHP systems have relatively few moving parts, and because those parts are sheltered inside a building, they are durable and highly reliable. The underground piping often carries warranties of 25–50 years, and the heat pumps often last 20 years or more. Since they usually have no outdoor compressors, GHPs are not susceptible to vandalism. On the other hand, the components in the living space are easily accessible, which increases the convenience factor and helps ensure that the upkeep is done on a timely basis. [6]

Because they have no outside condensing units like air conditioners, there's no concern about noise outside the home. A two-speed GHP system is so quiet inside a house that users do not know it is operating: there are no tell-tale blasts of cold or hot air.

4.3 Geothermal Heat Pump System Components

A geothermal heat pump system requires the following three components to provide heating and cooling for your building (see figure 4.1): a ground loop (buried piping system); heat pump furnace units (inside the building); and a heating and cooling distribution system.

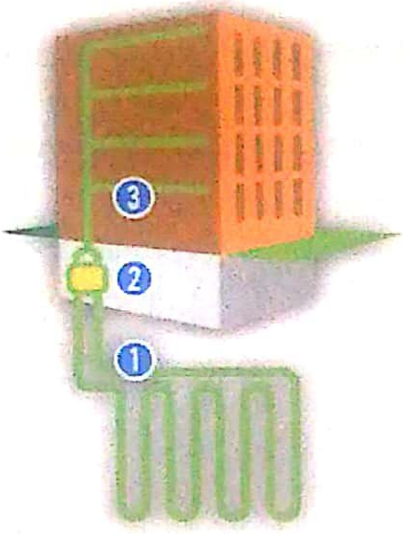

Figure 4.1: Main Components Geothermal Heat Pump System

1. An electric pump circulates a heat transfer fluid through a system of pipes, and picks up heat from the earth (heating mode) or releases heat to it (cooling mode). This process brings the heat transfer fluid to its required temperature as it enters the heat pump unit to ensure the system will work as designed and achieve the desired efficiency.

2. The heat transfer fluid is circulated through the heat pump unit where the refrigeration system extracts or rejects heat from the fluid and delivers it to a fan coil.

3. A distribution system is required throughout the building. In a forced air system, a fan in the heat pump unit blows air over a fan coil and the heated or cooled air is distributed through your ductwork to regulate the temperature in your building. In a hydronic system, hot water is circulated through radiators or a system of in-floor pipes to provide heat.

4.3.1 How does a Geothermal Heat Pump (GHP) system work?

A Geothermal Heat Pump system can work in heating only, cooling only and heating/cooling configurations with providing domestic hot water as an option.

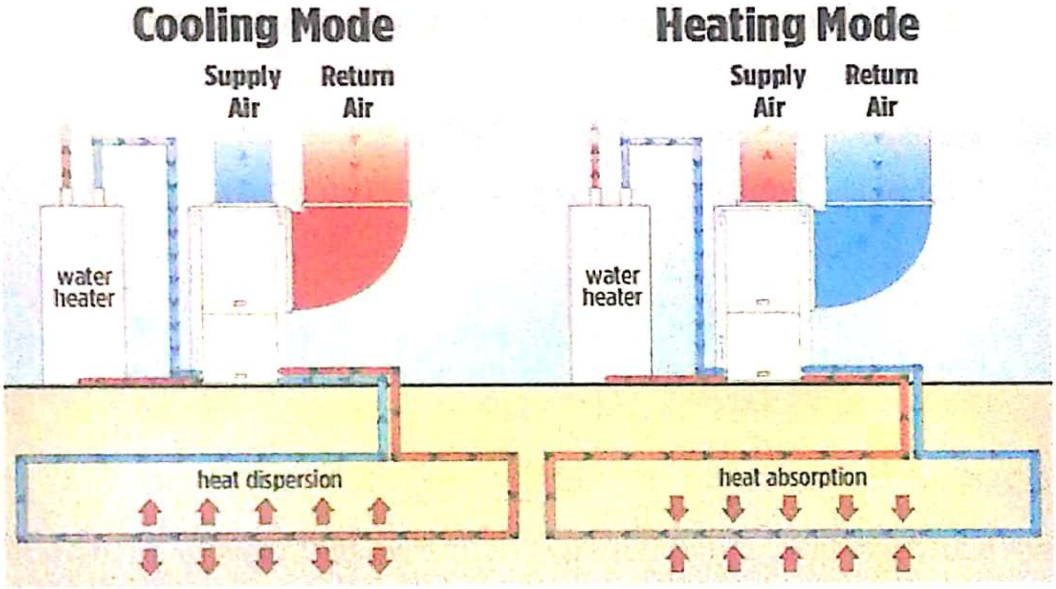

Figure 4.2: Geothermal Heat Pump cycle

4.3.1.1 Heating cycle

In the heating cycle, the heat collected from the ground is transferred to the evaporator (see Figure 2) in which refrigerant boils to become a low-temperature vapor. The reversing valve directs the refrigerant vapor to the compressor. The vapor is then compressed, which reduces its volume and causes it to heat up. And, the reversing valve directs the now-hot gas to the condenser coil, where it gives up its heat to the distribution system which delivers the heat to the home. Having given up its heat, the refrigerant passes through the expansion device, where its temperature and pressure are dropped further before it returns to the evaporator to begin the cycle again.

4.3.1.2 Cooling cycle

The cooling cycle is basically the reverse of the heating cycle. The direction of the refrigerant flow is changed by the reversing valve. The refrigerant picks up heat from the house air and transfers it directly to the antifreeze or groundwater. The heat is then pumped outside through the underground loop.

4.3.1.3 Domestic hot water

In some Geothermal Heat Pump systems, an additional heat exchanger, sometimes called a "desuperheater", takes heat from the hot refrigerant after it leaves the compressor. Water from the home's water heater is pumped through a coil ahead of the condenser coil, in order that some of the heat that would have been dissipated at the condenser is used to heat water. Excess heat is always available in the summer cooling mode, and is also available in the heating mode during mild weather when the heat pump is above the balance point and not working to full capacity. Other Geothermal Heat Pump systems provide domestic hot water on demand: the whole machine switches to providing domestic hot water when it is required.

4.4 Advantage and disadvantage of Geothermal Heat Pump

4.4.1 The advantage of a Geothermal Heat Pump (GHP) system over a conventional Air Source heat pump system

A conventional air source heat pump system absorbs heat from the outdoor air in winter and "dumps house" heat into outdoor air in summer. However, a Geothermal Heat Pump system uses the earth or ground water or both as the sources of heat in the winter, and as the "sink" for heat removed from the home in the summer. Therefore, a Geothermal Heat Pump system would exceed a conventional air source counterpart in respect of followings:

4.4.1.1 Durable & Reliable

A Geothermal Heat Pump is housed indoor and protected from harsh elements and vandalism. Moreover, the earth loop, if installed properly, can be expected to perform well for 50 years or more, and few moving parts like compressor can last about 15 years or more.

4.4.1.2 Quiet

Because the completely self-contained, indoor equipment does not need noisy, unsightly outside condensing unit, there's no concern about noise outside the home

4.4.2 The advantage of a Geothermal Heat Pump (GHP) system over those conventional heating systems such as fossil fuel furnace and electric heating systems

4.4.2.1 Environmentally Friendly

Geothermal Heat Pump systems eliminate the combustion of fossil fuels on site and dramatically lower the need to generate power - reducing the emission of greenhouse gas and minimizing the environmental impact associated with nonrenewable resource extraction.

4.4.2.2 Comfortable

Compared with conventional heating and cooling systems, a Geothermal Heat Pump system warms or cools air in smaller temperature rises and with a much more uniform level of heat. As a result, homeowners notice a stable level of heat with no peaks or troughs, less drafts, etc.

4.4.2.3 Safe

Because heat pumps do not burn fossil fuels, there is no flame, no flue, no odors and no risk of accumulations of the “silent killer”– carbon monoxide.

4.4.3 The Disadvantage of a Geothermal Heat Pump (GHP) System

The only disadvantage of a Geothermal Heat Pump system is the high cost of initial installation, including the cost of human resource, machine and other parts of the system. However, the capital cost of the installation can be offset by the energy savings.

4.5 Types of Geothermal Heat Pump Systems

There are four basic types of ground loop systems. Three of the horizontal, vertical, and pond/lake are closed-loop systems. The fourth type of system is the open-loop option. Which one of these is best depends on the climate, soil conditions, available land, and local installation costs at the site. All of these approaches can be used for residential and commercial building applications.

4.5.1 Closed-Loop Systems

4.5.1.1 Horizontal

This type of installation is generally most cost-effective for residential installations, particularly for new construction where sufficient land is available (see Fig: 4.3). It requires trenches at least four feet deep. The most common layouts either use two pipes, one buried at six feet, and the other at four feet, or two pipes placed side-by-side at five feet in the ground in a two-foot wide trench. The Slinky™ method of looping pipe allows more pipe in a shorter trench, which cuts down on installation costs and makes horizontal installation possible in areas it would not be with conventional horizontal applications.

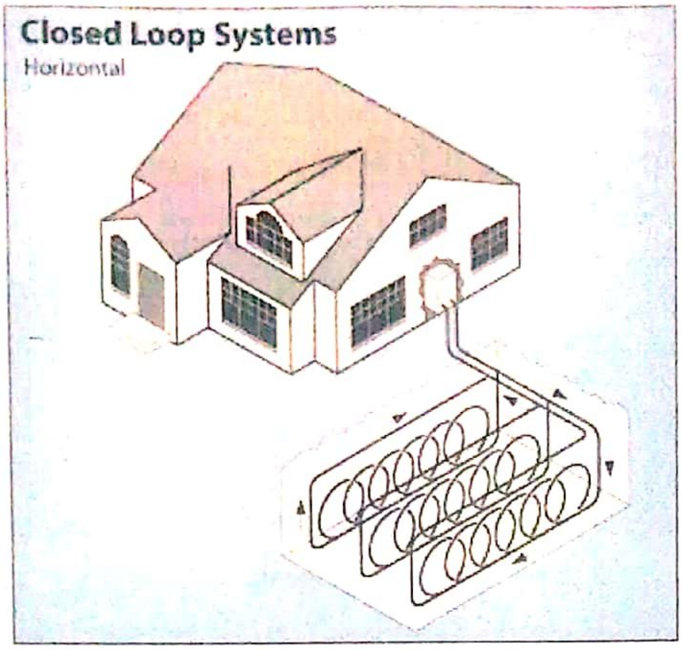

Figure 4.3: closed loop system Horizontal

4.5.1.2 Vertical

~~Large~~ ~~commercial buildings~~ and schools often use vertical systems because the land area required for horizontal loops would be prohibitive (see Figure 4.4). Vertical loops are also used where the soil is too shallow for trenching, and they minimize the disturbance to existing landscaping. For a vertical system, holes (approximately four inches in diameter) are drilled about 20 feet apart and 100–400 feet deep. Into these holes go two pipes that are connected at the bottom with a U-bend to form a loop. The vertical loops are connected with horizontal pipe, placed in trenches, and connected to the heat pump in the building.

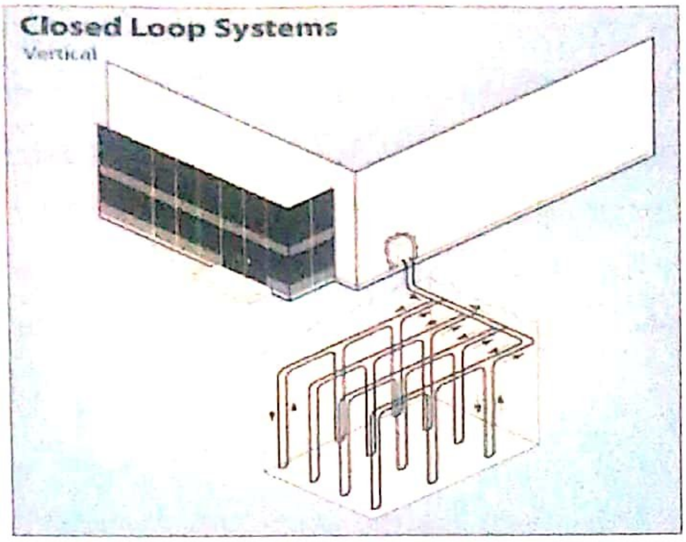

Figure 4.4: Closed loop system vertical

4.5.1.3 Pond/Lake

If the site has an adequate water body, this may be the lowest cost option (see Figure 4.5). A supply line pipe is run underground from the building to the water and coiled into circles at least eight feet under the surface to prevent freezing. The coils should only be placed in a water source that meets minimum volume, depth, and quality criteria.

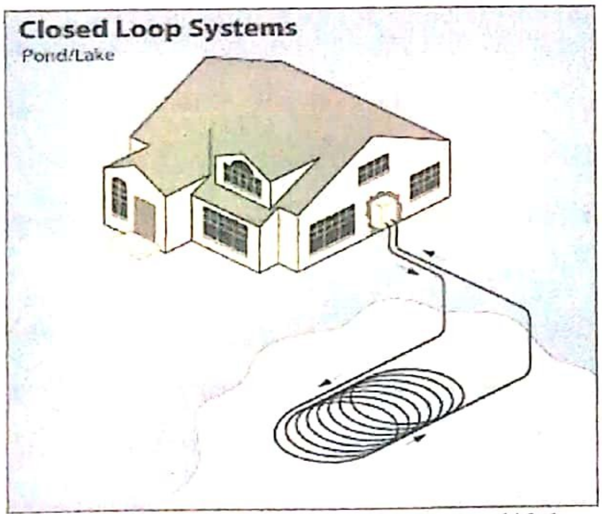

Figure 4.5: closed loop system Pond/ lake

4.5.2 Open-Loop System

This type of system uses well or surface body water as the heat exchange fluid that circulates directly through the GHP system (see Figure 4.6). Once it has circulated through the system, the water returns to the ground through the well, a recharge well, or surface discharge. This option is obviously practical only where there is an adequate supply of relatively clean water, and all local codes and regulations regarding groundwater discharge are met.

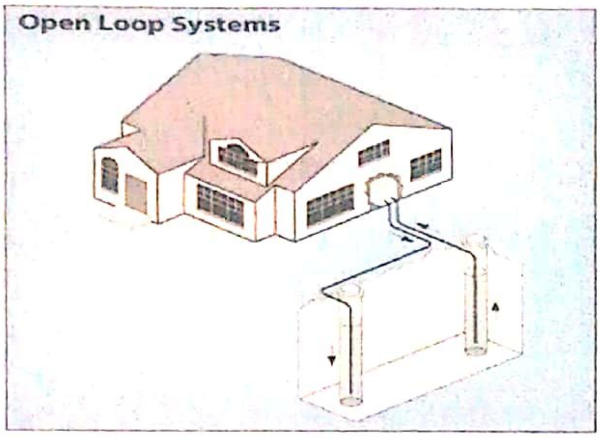

Figure 4.6: Open loop system

In this project we have to design the vertical lope system because we haven't large area in Palestine.

4.6 Inside the Building

- Geothermal Heat Pump systems are a distributed system rather than a central system.
- Energy is moved around the building efficiently with water rather than air.

The distributed nature of the Geothermal Heat Pump system contributes to its overall efficiency. Thermal energy is primarily transported throughout the building with a water loop. A heat pump in each space (zone) rejects or extracts heat from the loop to maintain the desired temperature.

Other systems circulate large volumes of air to provide space conditioning. A central system may supply cooled air to all spaces, with individual spaces reheating the air to maintain the desired temperature. Geothermal Heat Pump systems often save on fan energy as they use many smaller fans to blow air through short ducts at low pressure (e.g. typical fan energy use rate of 0.3 W/cfm). Other systems use extensive duct systems that transport air greater distances at a higher pressure (e.g. energy use rate of 1.0 W/cfm).

In the schematic of a standard chiller/boiler variable air volume (VAV) system, each room or zone can be heated or cooled independently. Cold air is distributed throughout the building to each room. When room temperature is too warm, a damper allows more cold air into the space.

When room temperature is too cold, the damper closes to its minimum position. If the space is still too cold, a heating coil reheats the air supplied to the room. When room temperature is at the desired level, some cold air is still introduced to provide ventilation since the dampers are at the minimal position. As less air is required in more rooms, the central fan slows to reduce the amount of energy used.

In an effort to reduce the amount of reheat at the zones, control systems often increase the supply air temperature so the damper in at least one zone is almost fully open, or the supply air temperature is reduced with lower outdoor temperature. The supply air temperature reset reduces reheat energy use at the expense of additional fan energy.

It is imperative that all the dampers operate well. Stuck dampers can drive the entire system into using excessive amounts of both fan energy and reheat energy.
The VAV system supplies hot water to each room or zone, and provides chilled water to each central air handler (see Figure 4.7). Cold air that is circulated

throughout the building supplies cooling. A minimum amount of fresh air is continuously introduced into the re-circulated air as the total air flow is reduced.

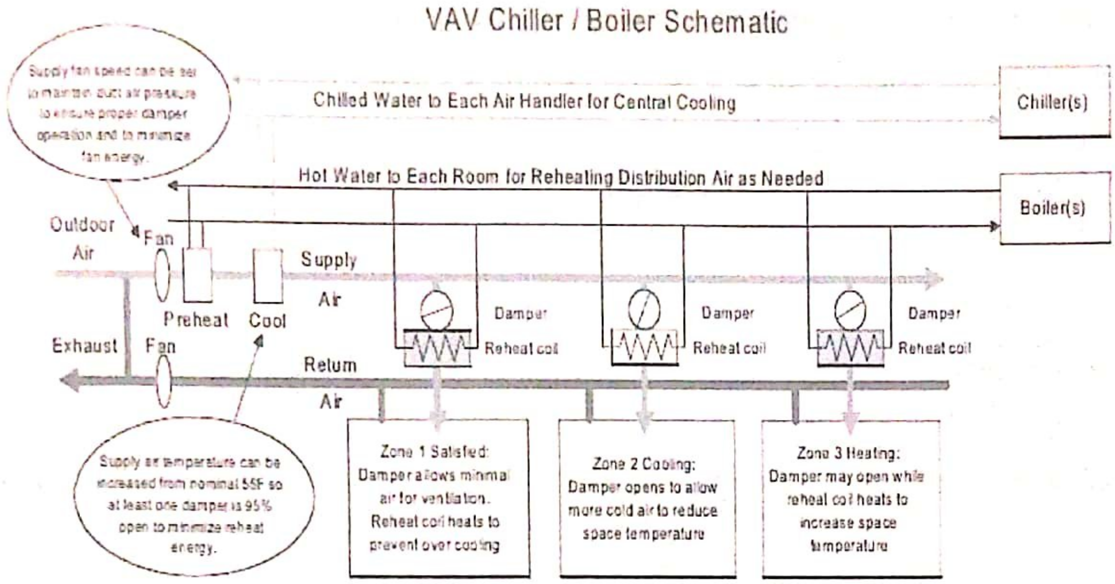

Figure 4.7: VAV Chiller/Boiler Schematic

The Geothermal Heat Pump system is less complicated than the VAV system. Heat pumps located in each room or zone simply heat or cool the space as needed by conditioning the air circulated between the heat pump and the space. A fluid loop connected to the ground heat exchanger circulates throughout the building, providing the heat pumps with a source or sink for heat. Stopping flow through heat pumps that are turned off, and reducing the speed of the pump, minimizes pumping energy on the ground loop.

Fresh air is often introduced through a dedicated outdoor air system. This system preconditions the outdoor air by recovering energy from the exhaust air stream through a heat exchanger. A heat pump tempers the ventilation air to a neutral condition before it is distributed to the heat pumps serving each room. Providing ventilation air via a separate system ensures that the proper amount of fresh air is delivered to each space. There is no mixing of fresh air with re-circulated air until it reaches the room heat pump.

This Geothermal Heat Pump air distribution system is smaller than the air system in a conventional system because it contains no re-circulated air. Only the required outdoor air is delivered to each space, as opposed to a central VAV system that often over-ventilates many zones. The fan energy is minimized because the air can be delivered at lower pressure (see Figure 4.8), and there is no damper or coil to pass through in each room.

For the most part, the space conditioning of each room is independent of other rooms. The only common reliance is on the ground loop. Any problem with a heat pump only affects the room it serves and cannot impact upon the performance or energy use of the entire system.

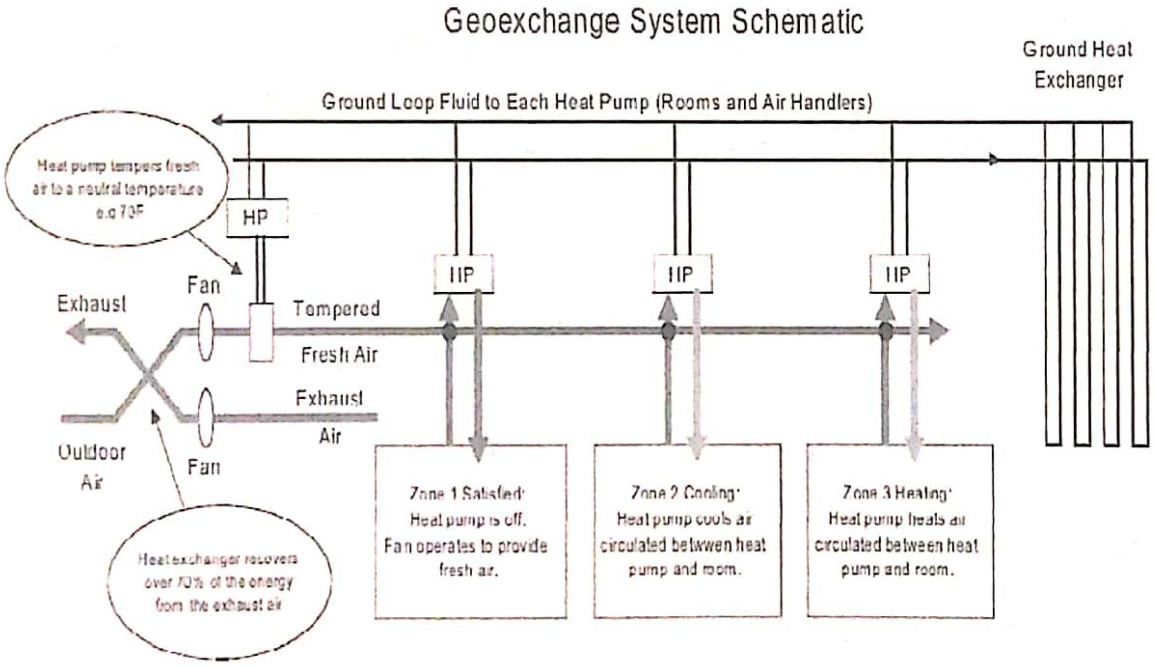

Figure 4.8: GHP System Schematic

CHAPTER FIVE

Design and Calculation of a Geothermal Heat Pump

Chapter Five

Design and Calculation of a Geothermal Heat Pump

5.1 Introduction

The designer must perform their normal tasks, such as zone-by-zone load analysis. In addition, the designer must also specify the geothermal type, total bore length, minimum separation distance, pipe diameter, U-bend type, operating parameters and antifreeze properties. This chapter will provide the designer with some detail on how to solve these issues.

5.2 Cooling Load

5.2.1 Data of project:

Correction of latitude is 32°

All data and calculation in august

T_i= 24 °C

T_{out}= 33.5 °C

T_{om} =33.5 - 4.25 =29.25 °C

Where T_{in} is the Room design temperature, T_{out} is the outdoor design temperature, T_{om} is the outdoor mean temperature. [10]

5.2.2 Heat gain through Sunlit Walls

Construction of the wall:

(Stone) + (concrete) + (insulation) + (plastering)

From Table (A-14) we can give Overall heat transfer coefficients (U):

$U=1.2\ w/m^2.k$

And we can calculate the heating load (q) transfer by wall:

$Q^{\cdot} = U\times A\times \Delta T$ (1)

where A is the area of the wall and ΔT is the total equivalent temperature deference, which takes into consideration the increase of wall temperature due to absorption of solar radiation. The values of ΔT are called cooling load temperature differences CLTD. The value of CLTD extracted from Table (A-2) needs to be corrected so that the actual value is found for different cases, and hence it will be called corrected CLTD and can be calculated from the following equation:

$(CLTD)_{corr.} = (CLTD + LM)\ k + (25.5 - T_i) + (T_{o,m} - 29.4)f$ (2)

where LM is latitude correction factor, which can be obtained from Table (A-3) for horizontal and vertical surfaces, the factor k is color adjustment factor such that k=1.0 for dark colored roof, k=0.5 for permanently light colored roofs, k=0.65 for permanent light colour walls, and the factor f is attic or roof fan factor such that f=1.0, if there is no attic or roof fan; f=0.75, if there is an attic or roof fan. [10]

The heat transfer rate through sunlit walls or sunlit roof is calculated from the following equation:

$Q^{\cdot} = U\times A\times\ (CLTD)_{corr}$ (3)

And we can show these calculations for ground and first floor in table (5.1) and table (5.2), respectively.

The component at Ground floor and First floor in all tables are shown in Figure (A-38) and Figure (A-39), respectively.

Table 5.1 Ground floor (Wall)

component	Direction	Lm	CLTD	$(CLTD)_{corr.}$	A(m^2)	$\dot{Q}$(W)
Office	SW	0.0	5	4.6	6.6	36.43
Office	NW	-0.5	1	1.675	11.35	22.8
Office	NE	-0.5	12	8.825	9.73	103.04
Guest	N	-1.1	0	0.635	12.6	9.6
Guest	E	0.0	12	9.15	20.4	224
Family	E	0.0	12	9.15	11.8	129.56
Family	S	0.5	9	7.525	4.5	40.64
Kitchen	E	0.0	12	9.15	16.4	180.1
Kitchen	S	0.5	9	7.525	9	81.27
Kitchen	E	0.0	12	9.15	3	32.94
Kitchen	S	0.5	9	7.525	8.8	79.5
BDR	S	0.5	9	7.525	12	108.36
BDR	W	0.0	1	2	10.5	25.2
BDR	N	-1.1	0	0.635	3.9	3
Path	W	0.0	1	2	3.94	9.46
Path	NW	-0.5	1	1.675	5.82	11.7
Path	W	0.0	1	2	3.94	9.46
Path	SW	0.0	5	4.6	5.82	32.13
BDR	W	0.0	1	2	7.5	18
BDR	S	0.5	9	7.525	3.9	35.22
lobby	N	-1.1	0	0.635	5.3	4.04

Table 5.2 First floor (Wall)

omponent	Direction	Lm	CLTD	$(CLTD)_{corr.}$	A(m^2)	$\dot{Q}$ (W)
MBDR	S	0.5	9	7.525	3.84	34.68
MBDR	W	0.0	1	2	7.8	18.72
MBDR	NW	-0.5	1	1.675	9.85	19.8
MBDR	NE	-0.5	12	8.825	4.89	51.79
MBDR	N	-1.1	0	0.635	8.1	6.2
BDR	N	-1.1	0	0.635	13.5	10.3
BDR	E	0.0	12	9.15	15.3	168
ath	E	0.0	12	9.15	5.4	59.3
iving	E	0.0	12	9.15	13.6	149.33
iving	S	0.5	9	7.525	4.5	40.64
iving	E	0.0	12	9.15	3.1	34.04
BDR	E	0.0	12	9.15	16	175.68
BDR	S	0.5	9	7.525	13.2	119.2
ath	S	0.5	9	7.525	5.4	48.8
BDR	S	0.5	9	7.525	12	108.36
BDR	W	0.0	1	2	13.5	32.4
itchen	W	0.0	1	2	4.14	9.94
itchen	NW	-0.5	1	1.675	5.82	11.7
ath	W	0.0	1	2	4.14	9.94
ath	SW	0.0	5	4.6	5.82	32.13

5.2.3 Heat Transmitted through Glass

5.2.3.1 Construction of the glass

- Single glass
- Distance=6mm
- U=5.6 W/m^2.k this value give from Table (A-4)

The total cooling load due to exposed glass area is the sum of transmission load due to inside-outside glass surface temperature difference (heat conduction) and heat gain due to solar energy (heat convection).

1- The Transmitted cooling load can be calculated from equation:

$$\dot{Q}_{tr.} = A(SHG)(SC)(CLF) \qquad (4)$$

where A is the area of the Glass, (SHG) is the Solar heat gain factor and can be extracted from Table (A-5), (SC) is the Shading coefficient and can be extracted from Table (A-6), and (CLF) is the Cooling load factor and can be extracted from Table (A-7). [10]

2- The Convicted cooling load can be calculated from equation:

$$\dot{Q}_{conv} = UA\,(CLTD)_{corr.} \qquad (5)$$

where CLTD is the value of the cooling load temperature difference for the glass and can be extracted Table (A-8).

And we can show these calculations for ground and first floor in table (5.3) and table (5.4), respectively.

Table 5.3 Ground floor (glass)

Dire.	A(m^2)	(CLTD)$_{corr.}$	SC	SHG	CLF	$Q^{\cdot}_{tr}$	$Q^{\cdot}_{conv}$	$Q^{\cdot}_{tot}$
NW	2	7.85	0.64	445	0.3	170.9	87.92	258.82
NE	1.43	7.85	0.64	445	0.24	97.7	62.89	160.6
N	1.2	7.25	0.55	117	0.86	66.41	48.72	115.13
N	1.2	7.25	0.55	117	0.86	66.41	48.72	115.13
E	1.5	8.35	0.55	691	0.22	125.42	70.14	195.56
E	1.5	8.35	0.55	691	0.22	125.42	70.14	195.56
E	1.5	8.35	0.55	691	0.22	125.42	70.14	195.56
E	2	8.35	0.39	691	0.22	118.58	93.52	212.1
E	1.7	8.35	0.39	691	0.22	100.8	79.5	180.3
S	1.7	8.85	0.39	350	0.68	157.8	84.25	242.05
S	1.5	8.85	0.39	350	0.68	139.23	70.14	209.37
W	1.5	8.35	0.39	691	0.53	214.24	70.14	284.38
W	0.4	8.35	0.55	691	0.53	80.57	18.7	99.27
W	0.4	8.35	0.55	691	0.53	80.57	18.7	99.27
W	1.5	8.35	0.39	691	0.53	214.24	70.14	284.38

Table 5.4 First floor (glass)

omp.	Dire.	A(m^2)	(CLTD)$_{corr.}$	SC	SHG	CLF	$Q^{\cdot}_{tr}$	$Q^{\cdot}_{conv}$	$Q^{\cdot}_{tot}$
IBDR	W	1.5	8.35	0.39	691	0.53	214.24	70.14	284.38
IBDR	NW	1.5	7.85	0.39	445	0.3	78.1	65.94	144.04
IBDR	N	1.5	7.25	0.39	117	0.86	58.86	60.9	119.76
DR	N	1.5	7.25	0.39	117	0.86	58.86	60.9	119.76
DR	E	1.5	8.35	0.39	691	0.22	88.93	70.14	159.07
ath	E	0.4	8.35	0.55	691	0.22	33.44	18.7	52.14
iving	E	2	8.35	0.64	691	0.22	194.6	93.52	288.12
DR	E	2	8.35	0.39	691	0.22	118.6	93.52	212.12
ath	S	0.4	8.85	0.55	350	0.68	52.36	18.7	71.06

DR	S	1.5	8.85	0.39	350	0.68	139.23	70.14	209.37
DR	W	1.5	8.35	0.39	691	0.53	214.24	70.14	284.38
itchen	W	0.4	8.35	0.39	691	0.53	57.13	18.7	75.83
th	W	0.4	8.35	0.55	691	0.53	80.57	18.7	99.27

5.2.4 Heat gain through Ceiling ($Q^{\cdot}_{ce}$) and Floor ($Q^{\cdot}_{f}$)

$Q^{\cdot}_{f} = UA\Delta T$ (6)

$\Delta T = (T_{in} - T_{out})$

$\Delta T_{floor} = (27.5-24) = 3.5°C$

$Q^{\cdot}_{ce} = U*A*CLTD_{corr}$ (7)

U = 1.261 W/m².°C this value give from Table (A-16)

U = 1.08 W/m².°C this value give from Table (A-17)

Tables (5.5) and (5.6) shown these calculations for ground and first floor.

Table 5.5 Ground Floor (Floor)

Component	A(m^2)	U(W/m^2.°C)	ΔT(°C)	$Q^{\cdot}_{f}$(W)
Office	17.5	1.261	3.5	77.24
Guest	41.5	1.261	3.5	183.16
Family	36.8	1.261	3.5	162.42
Kitchen	48.6	1.261	3.5	214.5
BDR	18	1.261	3.5	79.44
Path	6.3	1.261	3.5	27.81
Path	6.3	1.261	3.5	27.81
BDR	13.1	1.261	3.5	57.82
Lobby	10	1.261	3.5	44.14

Table 5.6 First Floor (ceiling)

Component	A(m^2)	U($W/m^2.°C$)	$(CLTD)_{corr.}$	$\dot{Q}_{ce}$(W)
MBDR	37	1.08	16	639.36
BDR	28	1.08	16	483.84
Path	5	1.08	16	86.4
Living	63.2	1.08	16	1092.1
BDR	26.4	1.08	16	456.2
Path	5	1.08	16	86.4
BDR	22.5	1.08	16	388.8
Kitchen	8	1.08	16	138.24
Path	8	1.08	16	138.24

5.2.5 Heat gain through Ventilation, Light and Door

5.2.5.1 for Ventilation ($\dot{Q}_v$)

The amount of the outside air needed for ventilation depends on the type of application, see Table (A-9).

5.2.5.2 for Light ($\dot{Q}_l$)

$$\dot{Q}_{Lt} = P_{Lt}(F_u F_b)(CLF)_{Lt} \tag{8}$$

where P_{Lt} is the lamp rated power in watts, F_u is the fraction of lamps that are in use, F_b is the ballast factor that equals to 1.2 for fluorescent lamps and 1.0 for ordinary lamps, and $(CLF)_{li}$ is the light cooling load factor. Table (A-10) gives the light cooling load factor for two types of fixture arguments. [10]

5.2.5.3 for Door ($\dot{Q}_d$)

$$\dot{Q} = UA\Delta T \qquad (9)$$

$\Delta T = (33.5-24) = 9.5°C$

Tables (5.7) and (5.8) shown all these calculations for ground and first floor.

Table 5.7 Ground Floor (Door)

Comp.	$\dot{Q}_v$	$\dot{Q}_l$	$\dot{Q}_d$
BDR	---	299	---
office	---	175	110.2
Guest	---	866	---
family	---	576	---
kitchen	635	925	133
BDR	---	382	---
Path	2990	107	---
Path	2990	107	---
lobby	---	212	87.8

Table 5.8 First Floor (Door)

Comp.	$\dot{Q}v$	$\dot{Q}L$	$\dot{Q}D$
MBDR	---	725	133
BDR	---	595	---
Path	2957	106	---
Living	---	1000	133

BDR	---	561	---
Path	2957	106	---
BDR	---	478	---
Kitchen	788	107	---
Path	2990	107	---

5.2.6 Heat Gain Through Occupants And Equipment

5.2.6.1 For Occupants ($\dot{Q}_{oc}$)

The Heat gain through Occupants can be calculated from equation:

$$\dot{Q}oc=(\dot{Q}s*n*CLF)+(\dot{Q}l*n)\Delta F \qquad (10)$$

where $\dot{Q}s$ is the sensible heat and can be extracted from Table (A-15), n is the number of person, (CLF) is the cooling load factor and can be extracted from Table (A-11), $\dot{Q}l$ is the latent heat and ΔF is the diversity factor and can be extracted from Table (A-12). [10]

5.2.6.2 for Equipment ($\dot{Q}_{equ}$)

Sensible and latent heat arising from various equipment and appliances that are installed in a conditioned space are given in Table (A-13).

Tables (5.9) and (5.10) shown all these calculations for ground and first floor.

Table 5.9 Ground Floor Equipments

Comp.	$\dot{Q}_{oc}$	$\dot{Q}_{equ}$
BDR	179	795

office	235.55	290
guest	233.2	---
family	664.95	---
kitchen	288.88	3780
BDR	179	---
path	75.79	1465
path	75.79	---
lobby	263.12	---

Table 5.10 First Floor Equipments

Comp.	$\dot{Q}$oc.	$\dot{Q}$app
MBDR	179	1445
BDR	179	---
path	75.79	---
living	1061.06	1425
BDR	179	---
path	75.79	---
BDR	179	---
kitchen	287.88	3040
path	75.79	---

5.2.7 Heat gain through Infiltration

The ~~heat~~ load $\dot{Q}_{inf}$, ~~due~~ to infiltration is given by the following equation:

$$\dot{Q}_{inf} = \rho_o * C_p * \dot{V}_f * (T_i - T_{out}) \qquad (11)$$

where, $\dot{V}_f$ is the volumetric flow rate of infiltrated air, Cp is its specific heat at constant pressure, and ρ_o is the density of infiltrated air.

The heat load due to infiltration $\dot{Q}_{\text{inf}}$, when computed by using Eq. (11), requires the estimation of ρ_o. This can be done by using the psychrometric chart if the outside design conditions are specified. If these conditions are not specified, the density of the infiltrated air is taken as 1.25 Kg/m³, and its specific heat at constant pressure as 1000 J/Kg.K. If these values are substituted into Eq. (11), then

$$Q_{\text{inf}} = \left(\frac{1250}{3600}\right) V_f \left(T_i - T_o\right) \qquad (12)$$

$\dot{V}_f = V$ * Air changes per hour

where, V is the Volume of the Room, and Air changes per hour we give from Table (A-18).

Tables (5.11) and (5.12) shown all these calculations for ground and first floor.

Table 5.11 Ground floor (Infiltration)

Component	V(m³)	Air changes per hour	ΔT(°C)	$\dot{Q}$(W)
Office	52.6	2	9.5	347
Guest	124.5	3	9.5	1232.03
Family	110.3	1	9.5	363.84
Kitchen	145.7	2	9.5	961.22
BDR	54	1.5	9.5	267.2
Path	18.9	2	9.5	124.69
Path	18.9	2	9.5	124.69
BDR	39.3	1	9.5	129.64
Lobby	30	2	9.5	197.92

Table 5.12 First floor (Infiltration)

Component	V(m³)	Air changes per hour	ΔT(°C)	$\dot{Q}$(W)
MBDR	111	2	9.5	732.3
BDR	84	1.5	9.5	415.63
Path	15	2	9.5	98.96
Living	189.5	3	9.5	1875.26
BDR	79.2	1	9.5	261.25
Path	15	2	9.5	98.96
BDR	67.5	1.5	9.5	334
Kitchen	24	2	9.5	158.33
Path	24	2	9.5	158.33

5.2.8 Total Cooling Load

5.2.8.1 Total Cooling Load of Ground Floor

$$\dot{Q}\text{tot} = \dot{Q}_{\text{wall}} + \dot{Q}_{\text{Glass}} + \dot{Q}_{\text{inf}} + \dot{Q}_{\text{floor}} + \dot{Q}_{\text{Door}} + \dot{Q}_{\text{v}} + \dot{Q}_{\text{l}} + \dot{Q}_{\text{oc}} + \dot{Q}_{\text{equ}} \qquad (13)$$

Table (5.13) shown all these calculations for ground floor.

Table 5.13 Ground floor total

Comp.	$\dot{Q}$s(W)	$\dot{Q}$L(W)	$\dot{Q}_{\text{tot}}$(W)
office	1656.28	160.4	1816.68
guest	3472.9	92.2	3565.1
family	1935.25	214.26	2149.51
kitchen	6669.35	884.31	7553.66
BDR	1475.95	62	1537.95

path	4548.9	361.82	4910.72
path	3439.33	26.82	3466.15
BDR	1616.06	182	1798.06
lobby	711.82	97.2	809.02
Sum	25525.84	2081.01	27606.85

5.2.8.2 Total Cooling Load of First Floor

$$\dot{Q}_{tot} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{inf} + \dot{Q}_{Ceiling} + \dot{Q}_{Door} + \dot{Q}_{v} + \dot{Q}_{l} + \dot{Q}_{oc} + \dot{Q}_{equ} \quad (14)$$

Table (5.14) shown all these calculations first floor.

Table 5.14 First floor total

Comp.	$\dot{Q}_s$(W)	$\dot{Q}_L$(W)	$\dot{Q}_{tot}$(W)
MBDR	4251.03	282	4533.03
BDR	2068.6	62	2130.6
path	3408.77	26.82	3435.59
living	6392.31	706.24	7098.55
BDR	1902.45	62	1964.45
path	3417.19	26.82	3444.01
BDR	1952.31	62	2014.31
kitchen	3669.66	947.26	4616.92
path	3583.88	26.82	3610.7
Sum	30646.2	2201.96	32848.16

$Q^{\cdot}_{tot}$ Cooling of Building = $Q^{\cdot}_{tot1} + Q^{\cdot}_{tot2} + Q^{\cdot}_{face}$

$Q^{\cdot}_{face} = Q^{\cdot}_{gla} + Q^{\cdot}_{wall}$

$= 4598.1 + 25.54$

$= 4623.64$ W

$Q^{\cdot}_{tot}$ Cooling of Building = 27606.85 + 32848.16 + 4623.64

= 65078.65 W

$Q^{\cdot}_{design\ of\ cooling} = 65078.65 + (0.1*65078.65)$

= 71586.515 W

5.3 Heating load

5.3.1 Heat loss through Walls

We can calculate the heat loss through Walls by:

$Q^{\cdot}_{wall} = UA\Delta T$ (15)

Where U is overall heat transfer coefficients, A is the area of the wall and ΔT is the total equivalent temperature deference.

$\Delta T = (T_i - T_{out})$

Where T_{in} is the Room design temperature (24°C) and T_{out} is the outdoor design temperature (4°C).

$\Delta T = (24 - (4))$

$= 20$ °C

Tables (5.15) and (5.16) shown all these calculations for ground and first floor.

Table 5.15 Ground floor (Wall)

Component	Direction	A(m²)	U(W/m².°C)	ΔT(°C)	Q˙(W)
Office	SW	6.6	1.2	20	158.4
Office	NW	11.35	1.2	20	272.4
Office	NE	9.73	1.2	20	233.5
Guest	N	12.6	1.2	20	302.4
Guest	E	20.4	1.2	20	489.6
Family	E	11.8	1.2	20	283.2
Family	S	4.5	1.2	20	108
Kitchen	E	16.4	1.2	20	393.6
Kitchen	S	9	1.2	20	216
Kitchen	E	3	1.2	20	72
Kitchen	S	8.8	1.2	20	211.2
BDR	S	12	1.2	20	288
BDR	W	10.5	1.2	20	252
BDR	N	3.9	1.2	20	93.6
Path	W	3.94	1.2	20	94.6
Path	NW	5.82	1.2	20	139.7
Path	W	3.94	1.2	20	94.6
Path	SW	5.82	1.2	20	139.7
BDR	W	7.5	1.2	20	180
BDR	S	3.9	1.2	20	93.6
lobby	N	5.3	1.2	20	127.2

Table 5.16 First floor (Wall)

Component	Direction	A(m²)	U(W/m².°C)	ΔT(°C)	Q˙(W)
MBDR	S	3.84	1.2	20	92.2
MBDR	W	7.8	1.2	20	187.2
MBDR	NW	9.85	1.2	20	236.4

MBDR	NE	4.89	1.2	20	117.4
MBDR	N	8.1	1.2	20	194.4
BDR	N	13.5	1.2	20	324
BDR	E	15.3	1.2	20	367.2
Path	E	5.4	1.2	20	129.6
Living	E	13.6	1.2	20	326.4
Living	S	4.5	1.2	20	108
Living	E	3.1	1.2	20	74.4
BDR	E	16	1.2	20	384
BDR	S	13.2	1.2	20	316.8
Path	S	5.4	1.2	20	129.6
BDR	S	12	1.2	20	288
BDR	W	13.5	1.2	20	324
Kitchen	W	4.14	1.2	20	99.4
Kitchen	NW	5.82	1.2	20	139.7
Path	W	4.14	1.2	20	99.4
Path	SW	5.82	1.2	20	139.7

5.3.2 Heat loss through Glass

The total Heating load due to exposed glass area is:

$Q'_{Glass}=UA\Delta T$ (16)

Where U is overall heat transfer coefficients, A is the area of the Glass and ΔT is the total equivalent temperature deference.[9]

$\Delta T = (T_i - T_{out})$

Where T_{in} is the Room design temperature (24°C) and T_{out} is the outdoor design temperature (4°C).

$\Delta T = (24 - (4))$

$= 20\ °C$

Tables (5.17) and (5.18) shown all these calculations for ground and first floor.

Table 5.17 Ground floor (glass)

Component	Direction	A(m²)	U(W/m².°C)	ΔT(°C)	$Q^{\cdot}$(W)
Office	NW	2	5.6	20	224
Office	NE	1.43	5.6	20	160.2
Guest	N	2.4	5.6	20	268.8
Guest	E	4.5	5.6	20	504
Family	E	2	5.6	20	224
Kitchen	E	1.7	5.6	20	190.4
Kitchen	S	1.7	5.6	20	190.4
BDR	S	1.5	5.6	20	168
BDR	W	1.5	5.6	20	168
Path	W	0.4	5.6	20	44.8
Path	W	0.4	5.6	20	44.8
BDR	W	1.5	5.6	20	168

Table 5.18 First floor (glass)

Component	Direction	A(m²)	U(W/m².°C)	ΔT(°C)	$Q^{\cdot}$(W)
MBDR	W	1.5	5.6	20	168
MBDR	NW	1.5	5.6	20	168
MBDR	N	1.5	5.6	20	168
BDR	N	1.5	5.6	20	168
BDR	E	1.5	5.6	20	168
Path	E	0.4	5.6	20	44.8

Living	E	2	5.6	20	224
BDR	E	2	5.6	20	224
Path	S	0.4	5.6	20	44.8
BDR	S	1.5	5.6	20	168
BDR	W	1.5	5.6	20	168
Kitchen	W	0.4	5.6	20	44.8
Path	W	0.4	5.6	20	44.8

5.3.3 Heat Loss through Infiltration

The heat load Q'_{inf}, due to infiltration is given by the following equation:

$$Q'_{inf} = \rho_o * C_p * V'_f * (T_i - T_{out}) \qquad (17)$$

where, V'_f is the volumetric flow rate of infiltrated air, Cp is its specific heat at constant pressure, and ρ_o is the density of infiltrated air.[9]

The heat load due to infiltration Q'_{inf} , when computed by using Eq. (17), requires the estimation of ρ_o. This can be done by using the psychrometric chart if the outside design conditions are specified. If these conditions are not specified, the density of the infiltrated air is taken as 1.25 Kg/m³, and its specific heat at constant pressure as 1000 J/Kg.K. If these values are substituted into Eq. (17), then

$$Q_{inf} = \left(\frac{1250}{3600}\right) V_f (T_i - T_o) \qquad (18)$$

V'_f = V * Air changes per hour

where, V is the Volume of the Room, and Air changes per hour we give from Table (A-18).[9]

Tables (5.19) and (5.20) shown all these calculations for ground and first floor.

Table 5.19 Ground floor (Infiltration)

Component	V(m³)	Air changes per hour	ΔT(°C)	$Q^{\cdot}$(W)
Office	52.6	2	20	730.6
Guest	124.5	3	20	2593.8
Family	110.3	1	20	766
Kitchen	145.7	2	20	2023.6
BDR	54	1.5	20	562.5
Path	18.9	2	20	262.5
Path	18.9	2	20	262.5
BDR	39.3	1	20	273
Lobby	30	2	20	416.7

Table 5.20 First floor (Infiltration)

Component	V(m³)	Air changes per hour	ΔT(°C)	$Q^{\cdot}$(W)
MBDR	111	2	20	1541.7
BDR	84	1.5	20	875
Path	15	2	20	208.3
Living	189.5	3	20	3947.9
BDR	79.2	1	20	550
Path	15	2	20	208.3
BDR	67.5	1.5	20	703.2
Kitchen	24	2	20	333.3
Path	24	2	20	333.3

5.3.4 Heat loss through Floor

$$\dot{Q}_{floor} = UA\Delta T \qquad (19)$$

$\Delta T = (T_i - T_{out})$

$= (24 - 10)$

$= 14$ °C

$U = 1.261$ W/m².°C this value give from Table (A-16).

Tables (5.21) shown all these calculations for ground floor.

Table 5.21 Ground Floor (Floor)

Component	A(m²)	U(W/m².°C)	ΔT(°C)	$\dot{Q}$ (W)
Office	17.5	1.261	14	309
Guest	41.5	1.261	14	732.6
Family	36.8	1.261	14	649.7
Kitchen	48.6	1.261	14	858
BDR	18	1.261	14	317.8
Path	6.3	1.261	14	111.2
Path	6.3	1.261	14	111.2
BDR	13.1	1.261	14	231.3
Lobby	10	1.261	14	176.5

5.3.5 Heat Loss through Ceiling

$$\dot{Q}_{Ceiling} = UA\Delta T \qquad (20)$$

$\Delta T = (T_i - T_{out})$

$= (24 - 4)$

$= 20$ °C

$U = 1.08$ W/m².°C this value ~~give from~~ Table (A-17).

Tables (5.22) shown all these calculations for first floor.

Table 5.22 First Floor (ceiling)

Component	A(m²)	U(W/m².°C)	ΔT(°C)	$\dot{Q}$(W)
MBDR	37	1.08	20	799.2
BDR	28	1.08	20	604.8
Path	5	1.08	20	108
Living	63.2	1.08	20	1365.1
BDR	26.4	1.08	20	570.2
Path	5	1.08	20	108
BDR	22.5	1.08	20	486
Kitchen	8	1.08	20	172.8
Path	8	1.08	20	172.8

5.3.6 Heat Loss through Door

$$\dot{Q}_{Door} = UA\Delta T \qquad (21)$$

$\Delta T = 20$ °C

we give U from Table (A-17), value of U depended on Door type.

Tables (5.23) and (5.24) shown all these calculations for ground and first floor.

Table 5.23 Ground floor (Door)

Component	A(m²)	U(W/m².°C)	ΔT(°C)	$\dot{Q}$(W)
Office	2	5.8	20	232
Kitchen	2	7	20	280
Lobby	2.8	3.3	20	184.8

Table 5.24 First Floor (Door)

Component	A(m^2)	U($W/m^2.°C$)	ΔT(°C)	$\dot{Q}$(W)
MBDR	2	7	20	280
Living	2	7	20	280

5.3.7 Total Heating Load

5.3.7.1 Total Heating Load of Ground Floor

$$\dot{Q}_{tot} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{inf} + \dot{Q}_{floor} + \dot{Q}_{Door} \quad (22)$$

Tables (5.25) shown all these calculations for ground floor.

Table 5.25 Ground floor ($\dot{Q}$tot)

Comp.	$\dot{Q}$tot(W)
office	2320.1
guest	4891.2
family	2030.9
kitchen	4435.2
BDR	1850
path	652.8
path	652.8
BDR	946
lobby	905.2
Sum	18683.2

5.3.7.2 Total Heating Load of First Floor

$$Q'_{tot} = Q'_{wall} + Q'_{Glass} + Q'_{inf} + Q'_{Ceiling} + Q'_{Door} \qquad (23)$$

Tables (5.26) shown all these calculations for first floor.

Table 5.26 First Floor (Q'tot)

Comp.	Q'tot(W)
MBDR	3952.5
BDR	2507
path	490.7
living	6325.8
BDR	2045
path	490.7
BDR	2137.2
kitchen	790
path	790
Sum	19528.9

Q'_{tot} heat of Building $= Q'_{tot1} + Q'_{tot2} + Q'_{face}$

$Q'_{face} = Q'_{gla} + Q'_{wall}$

$= 966 + 255.36$

$= 1221.36$ W

Q'_{tot} heat of Building $= 18683.2 + 19528.9 + 1221.36$

$= 39433.46$ W

$Q'_{design\ of\ heating} = 39433.46 + (0.1*39433.46)$

$= 43376.81$ W

5.4 Duct Design

5.4.1 Warm and Cool Air Quantities

The calculated heat load and cool load for a given space must be met by introduction sufficient amount of warm and cool air into that space, according to the following relation.[9]

$$Q_s = \rho C_p \dot{V}(T_s - T_i) \tag{24}$$

$$\Rightarrow \dot{V} = \frac{Q_s}{\rho C_p (T_s - T_i)}$$

where Q_s is the room sensible heat or cool load, ρ and C_p are the density and specific heat of the air, respectively, $\dot{V}$ is the volumetric flow rate of the air, T_s and T_i are the temperature of the supply air and the temperature of the inside air, respectively.[9]

$$\rho = 1.23 Kg/m^3$$
$$C_p = 1.012 KJ/Kg.K$$
$$T_i = 24^\circ C$$
$$T_{s\,cooling} = 14^\circ C$$
$$T_{s\,heating} = 57^\circ C$$

$$Q_{s\,cooling} = 60.79568\,KW$$

$$Q_{s\,heating} = 43.37681\,KW$$

$$\Rightarrow V_{cooling} = 4.88 m^3/s$$

$$\Rightarrow V_{heating} = 1.056 m^3/s$$

The highest air flow rate is used for sizing duct system.

5.4.2 Duct sizing

The relation between round duct diameter d, rate of air flow $\dot{V}$, pressure drop per unit length ($\Delta P/EL$), and velocity v, are presented in figure (A-37).

These figures are usually used to find duct diameters required for any flow of air quantities. The duct diameter can also be calculated from the relation:

$$\dot{V} = \frac{\pi}{4} d^2 * v \qquad (25)$$

Four different methods are used to size ducts:

1- The Velocity method.
2- The Equal Pressure Drop Method.
3- Balanced pressure Drop Method.
4- Static Pressure Regain Method.

The calculation of total pressure drop ΔP, from fan to any air outlet diffuser is easier when the Equal Pressure Drop Method of duct sizing is used as compared with the velocity method. For this reason, the equal pressure drop method is the most common method used for duct sizing.[9]

By using table (A-20):

$V_{main\ duct} = 5$ m/s

By using equation (25):

$d_{main\ duct} = 1.115$m

From figure (A-37):

$\Delta P/EL = 0.21$ Pa/m

In tables (5.27) and (5.28) show all calculations of the Duct sizing for ground and first floor.

The Line and components for Ground floor in all tables are shown in Figure (A-40) and Figure (A-38), respectively.

Table 5.27 Ground floor (Duct sizing)

Line & Component	$\dot{Q}s$ KW	$\dot{V}$ m^3/s	ΔP/EL Pa/m	v m/s	d cm
A→B	6.025	0.484	0.21	2.87	46.3
B→C	1.476	0.119	0.21	1.97	27.74
A→D	21.813	1.752	0.21	3.9	75.6
D→E	15.143	1.216	0.21	3.67	65
E→F	10.896	0.875	0.21	3.3	58.12
F→G	7.4231	0.6	0.21	3.04	50.14
G→H	6.712	0.54	0.21	2.865	49
H→I	3.272	0.263	0.21	2.5	36.6
I→J	1.656	0.133	0.21	2	29.1
Office	1.65628	0.133	0.21	2	29.1
Guest	3.4729	0.28	0.21	2.6	37.5
Family	4.25	0.3411	0.21	2.58	41
Kitchen	6.66935	0.5356	0.21	2.9	48.5
BDR	1.47595	0.1185	0.21	1.97	27.74
Path	4.5489	0.365	0.21	2.636	42
Path	3.43933	0.276	0.21	2.435	38
BDR	1.61606	0.13	0.21	1.97	29
Lobby	0.71182	0.0572	0.21	1.6	21.34

The Line and components for First floor in all tables are shown in Figure (A-41) and Figure (A-39), respectively.

Table 5.28 First floor (Duct sizing)

Line & Component	$\dot{Q}$s KW	$\dot{V}$ m^3/s	ΔP/EL Pa/m	v m/s	d cm
A→A'	32.958	2.65	0.21	4.4	87.6
A'→B'	5.622	0.452	0.21	2.77	46.3
B'→C'	1.952	0.175	0.21	2.1	27.74
A'→D'	27.336	2.2	0.21	4.1	75.6
D'→E'	23.92	1.92	0.21	4.04	65
E'→F'	22.016	1.77	0.21	3.95	58.12
F'→G'	13.312	1.07	0.21	3.49	50.14
G'→H'	9.903	0.795	0.21	3.25	49
H'→I'	7.835	0.63	0.21	3.1	36.6
I'→J'	3.584	0.288	0.21	2.6	29.1
MBDR	4.251	0.34	0.21	2.58	41
BDR	2.07	0.1662	0.21	2.133	31.5
Path	3.408	0.274	0.21	2.435	38
Living	8.704	0.7	0.21	3.15	53.2
		0.2752	0.21	2.436	38.1
BDR	1.902	0.153	0.21	2.09	30.5
Path	3.417	0.2745	0.21	2.435	38
BDR	1.952	0.157	0.21	2.1	30.86
Kitchen	3.67	0.3	0.21	2.52	39
Path	3.583	0.288	0.21	2.6	37.5

5.4.3 Non-Circular Ducts

Most of the used ducts in the air systems are rectangular or non-circular. This is due to the shape of residences and living spaces. If the diameter of circular ducts is calculated from Eq(25) or obtained from table (A-22), then the table (A-21) gives the equivalents of rectangular ducts for equal pressure drop and equal flow rate, tables (5.29) and (5.30) show the equivalent of rectangular ducts.[9]

Table 5.29 Ground floor (Non-Circular Ducts)

Line& Component	d mm	H mm	W mm
Main duct	1115	800	1400
A→B	463	400	500
B→C	277.4	225	300
A→D	756	400	1400
D→E	650	400	1000
E→F	581.2	400	800
F→G	490	400	500
G→H	366	400	500
H→I	291	250	500
I→J	501.4	250	300
Office	291	250	300
Guest	375	300	400
Family	410	400	400
Kitchen	485	400	500
BDR	2774	225	300
Path	420	400	400
Path	380	250	500
BDR	290	250	300

Lobby	213.4	200	200

Table 5.30 First floor (Non-Circular Ducts)

Line& Component	d mm	H mm	W mm
A→A'	876	500	1400
A'→B'	456	300	600
B'→C'	308.6	275	300
A'→D'	826.77	450	1400
D'→E'	790	450	1200
E'→F'	755.5	450	1200
F'→G'	625	400	900
G'→H'	558.2	400	700
H'→I'	508.8	400	600
I'→J'	375	300	400
MBDR	410	400	400
BDR	315	300	300
Path	380	250	500
Living	532	400	600
	381	250	500
BDR	305	200	400
Path	380	250	500
BDR	308.6	275	300
Kitchen	390	225	600
Path	375	300	400

5.4.4 Supply Air Ceiling Diffuser

From tables (A-23) and (A-24) we are give the information of Supply Air Ceiling Diffuser, tables (5.31) and (5.32) show the information of Supply Air Ceiling Diffuser (see figures (A-42) & (A-43)).

Table 5.31 Ground floor (Diffuser)

Component	$\dot{V}$ m³/s	ΔP in w.g	Size in*in	Type of Diff.	CFM
Office	0.133	0.067	9*12	4RCD	300
Guest	0.28	0.067	12*18	4RCD	600
Family	0.3411	0.019	24*24	4SCD	800
Kitchen	0.5356	0.039	24*24	4SCD	1200
BDR	0.1185	0.1	9*9	4SCD	280
Path	0.365	0.019	24*24	4SCD	800
Path	0.276	0.019	21*21	4SCD	612
BDR	0.13	0.067	9*12	4RCD	300
Lobby	0.0572	0.1	6*6	4SCD	125

Table 5.32 First floor (Diffuser)

Component	$\dot{V}$ m³/s	ΔP in w.g	Size in*in	Type of Diff.	CFM
MBDR	0.34	0.019	24*24	4SCD	800
BDR	0.1662	0.067	12*12	4SCD	400
Path	0.274	0.019	21*21	4SCD	612
Living	0.4248	0.067	18*18	4SCD	900
Living	0.2752	0.019	21*21	4SCD	612
BDR	0.153	0.1	9*15	4RCD	375
Path	0.2745	0.019	21*21	4SCD	612

BDR	0.157	0.1	9*12	4RCD	375
Kitchen	0.3	0.039	15*21	4RCD	657
Path	0.288	0.067	12*18	4RCD	612

5.4.5 Design of Return Ducts

The design of return ducts are based on using the above described methods. Usually, equal pressure drop method is used. For the return duct system, air flows through the branches into the main duct and back to the fan. Tables (5.33) and (5.34) show all calculations of the Return Duct for ground and first floor.[9]

The Line and components for Ground floor in all tables are shown in Figure (A-44) and Figure (A-38), respectively.

Table 5.33 Ground floor (Return Duct)

Line & Component	$\dot{Q}s$ KW	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v m/s	d cm
1→2	1.656	0.133	0.21	2	29.1
2→3	3.272	0.263	0.21	2.5	36.6
3→10	6.711	0.54	0.21	2.865	49
4→5	4.549	0.364	0.21	2.635	42
5→6	6.025	0.484	0.21	2.87	46.3
6→7	12.694	1.02	0.21	3.36	62.2
7→8	16.94	1.36	0.21	3.75	68
8→9	20.413	1.64	0.21	3.82	74
9→10	21.125	1.697	0.21	3.843	75
10→main	60.7957	4.88	0.21	5	111.5

Office	1.65628	0.133	0.21	2	29.1
Guest	3.4729	0.28	0.21	2.6	37.5
Family	4.25	0.3411	0.21	2.58	41
Kitchen	6.66935	0.5356	0.21	2.9	48.5
BDR	1.47595	0.1185	0.21	1.97	27.74
Path	4.5489	0.365	0.21	2.636	42
Path	3.43933	0.276	0.21	2.435	38
BDR	1.61606	0.13	0.21	1.97	29
Lobby	0.71182	0.0572	0.21	1.6	21.34

The Line and components for First floor in all tables are shown in Figure (A-45) and Figure (A-39), respectively.

Table 5.34 First floor (Return Duct)

Line & Component	$\dot{Q}s$ KW	$\dot{V}$ m³/s	ΔP/EL Pa/m	v m/s	d cm
1'→2'	4.251	0.341	0.21	2.58	41
2'→10'	7.835	0.63	0.21	3.1	50.88
3'→4'	3.67	0.295	0.21	2.52	38.8
4'→5'	5.62231	0.452	0.21	2.77	45.6
5'→6'	9.04	0.726	0.21	3.172	54
6'→7'	10.942	0.879	0.21	3.3	58.12
7'→8'	19.646	1.578	0.21	3.77	73
8'→9'	23.055	1.852	0.21	4	76.8
9'→10'	25.124	2.05	0.21	4.02	80
10'→10	32.958	2.65	0.21	4.4	87.6
MBDR	4.251	0.34	0.21	2.58	41
BDR	2.07	0.1662	0.21	2.133	31.5
Path	3.408	0.274	0.21	2.435	38

Living	8.704	0.2752	0.21	2.436	38.1
		0.7	0.21	3.15	53.2
BDR	1.902	0.153	0.21	2.09	30.5
Path	3.417	0.2745	0.21	2.435	38
BDR	1.952	0.157	0.21	2.1	30.86
Kitchen	3.67	0.3	0.21	2.52	39
Path	3.583	0.288	0.21	2.6	37.5

5.4.6 Non-Circular Return Ducts

Tables (5.35) and (5.36) show the equivalents rectangular ducts of the return ducts.

Table 5.35 Ground floor (Non-Circular Return Ducts)

Line& Component	d mm	H mm	W mm
1→2	291	250	300
2→3	366	250	500
3→10	490	400	500
4→5	420	400	400
5→6	463	400	500
6→7	622	400	900
7→8	680	450	900
8→9	740	450	1200
9→10	750	450	1200
10→main	1115	800	1400
Office	291	250	300
Guest	375	300	400

Family	410	400	400
Kitchen	485	400	500
BDR	2774	225	300
Path	420	400	400
Path	380	250	500
BDR	290	250	300
Lobby	213.4	200	200

Table 5.36 First floor (Non-Circular Return Ducts)

Line& Component	d mm	H mm	W mm
1'→2'	410	400	400
2'→10'	508.8	400	600
3'→4'	388	350	400
4'→5'	456	350	500
5'→6'	540	400	700
6'→7'	581.2	400	800
7'→8'	730	400	1200
8'→9'	768	450	1200
9'→10'	800	450	1400
10'→10	876	500	1400
MBDR	410	400	400
BDR	315	300	300
Path	380	250	500
Living	532	400	600
	381	250	500
BDR	305	200	400
Path	380	250	500
BDR	308.6	275	300

Kitchen	390	225	600
Path	375	300	400

5.4.7 Return Air Grille

from table (A-25) we are give the information of Return Air Grille. table (5.37) and (5.38) show the information of Return Air Grille.

Table 5.37 Ground floor (Grille)

Component	$\dot{V}$ m^3/s	ΔP in w.g	Size in*in	CFM
Office	0.133	0.029	10*12	283
Guest	0.28	0.056	12*16	638
Family	0.3411	0.041	16*16	732
Kitchen	0.5356	0.041	20*20	1500
BDR	0.1185	0.029	10*12	283
Path	0.365	0.056	16*16	854
Path	0.276	0.056	10*20	665
BDR	0.13	0.029	10*12	283
Lobby	0.0572	0.029	8*8	150

Table 5.38 First floor (Grille)

Component	$\dot{V}$ m^3/s	ΔP in w.g	Size in*in	CFM
MBDR	0.34	0.041	16*16	732
BDR	0.1662	0.041	12*12	408
Path	0.274	0.056	10*20	665

Living	0.4248	0.056	14*20	935
Living	0.2752	0.056	10*20	665
BDR	0.153	0.041	8*16	362
Path	0.2745	0.056	10*20	665
BDR	0.157	0.041	10*12	339
Kitchen	0.3	0.018	24*8	364
Path	0.288	0.056	12*16	638

5.5 Fan Selection

The fan is an essential and important component of any summer air conditioning and winter warm air heating systems. It is used to circulate the air through ducts and branches.[9]

From table (A-26) selected model CM96 with air CFM = 11000

The fan pressure rise ΔP_{fan}, is expressed as

$\Delta P_{fan} = \Delta P_{duct} + \Delta P_{fitt} + \Delta P_{diffuser} + \Delta P_{coil} + \Delta P_{filter} + \Delta P_{fan,\ inlet} + \Delta P_{fan,\ exit} + \Delta P_{dyn}$.

$\Delta P_{duct} = \Delta P_{supply\ air,\ duct} + \Delta P_{return\ air,\ duct}$

$\Delta P_{supply\ air,\ duct} = \Delta P_{Basement \rightarrow J'} + \Delta P_{fitt}$

$\Delta P_{Basement \rightarrow A} = 0.21*3 = 0.63$ Pa

$\Delta P_{A \rightarrow A'} = 0.21*(3+1.5+6) = 2.205$ Pa

$\Delta P_{A' \rightarrow D'} = 0.21*(0.96+1.5+6) = 1.777$ Pa

$\Delta P_{D' \rightarrow E'} = 0.21*(1.82+1.5+6) = 1.96$ Pa

$\Delta P_{E' \rightarrow F'} = 0.21*(1.9+1.6+1.5+6) = 2.31$ Pa

$\Delta P_{F' \rightarrow G'} = 0.21*(4.7+1.5+6) = 2.562$ Pa

$\Delta P_{G' \rightarrow H'} = 0.21*(4.12+1.5+6) = 2.44$ Pa

$\Delta P_{H' \rightarrow I'} = 0.21*(1.18+7.14+6+1.5+6+1.9) = 5$ Pa

$\Delta P_{I' \rightarrow J'} = 0.21*(2.91+1.5+6) = 2.2$ Pa

$\Sigma\, \Delta P_{\text{supply air, duct}} = 21.1$ Pa

$\Delta P_{\text{return air, duct}} = \Delta P_{\text{Basement} \rightarrow 3'} + \Delta P_{\text{fitt}}$

$\Delta P_{\text{Basement} \rightarrow 10} = 0.21*3 = 0.63$ Pa

$\Delta P_{10 \rightarrow 10'} = 0.21*(3+1.5+6) = 2.205$ Pa

$\Delta P_{10' \rightarrow 9'} = 0.21*(2.48+1.5+6) = 2.1$ Pa

$\Delta P_{9' \rightarrow 8'} = 0.21*(0.6+1.5+6) = 1.701$ Pa

$\Delta P_{8' \rightarrow 7'} = 0.21*(3.15+3+1.5+6) = 2.87$ Pa

$\Delta P_{7' \rightarrow 6'} = 0.21*(7.02+1.5+6) = 3.05$ Pa

$\Delta P_{6' \rightarrow 5'} = 0.21*(2.4+2.73+3+1.5+6) = 3.28$ Pa

$\Delta P_{5' \rightarrow 4'} = 0.21*(2.14+1.5+3+1.5+6) = 2.97$ Pa

$\Delta P_{4' \rightarrow 3'} = 0.21*(3.91+1.5+6) = 2.4$ Pa

$\Sigma\, \Delta P_{\text{return air, duct}} = 21.206$ Pa

$\Delta P_{\text{dyn.}} = (v/1.29)^2$

$= (5/1.29)^2$

$= 15$ Pa

$\Delta P_{\text{diffuser}} = 17$ Pa

$\Delta P_{\text{grill}} = 4.5$ Pa

ΔP_{coil}, ΔP_{filter}, $\Delta P_{\text{fan, inlet}}$ and, $\Delta P_{\text{fan, exit}}$ given from figure (A-27) and table (A-28).

$\Delta P_{\text{coil}} = 54.55$ Pa

$\Delta P_{\text{filter}} = 35.9$ Pa

$\Delta P_{\text{fan, inlet}} = 80$ Pa

$\Delta P_{\text{fan, exit}} = 60$ Pa

$\Delta P_{\text{fan}} = 21.1+21.206+15+17+4.5+54.55+35.9+80+60$

$= 309.256$ Pa

$$Power = \frac{V\Delta P}{\eta} \tag{26}$$

$$Power = \frac{4.88 * 309.256}{0.9 * 1000}$$
$$= 1.7\ KW$$

5.6 Summer Air Conditioning and Winter Warm Air Heating Systems

5.6.1 Summer Air Conditioning and Winter Warm Air Heating System Selection

we select VWV System from Petra company since:

1. Less Power consumption of the system due to the thermal storage tank and capacity control modulating water valves.
2. Flexibility in installation with no limitation on the distance between the indoor and outdoor units.
3. Very efficient in high-rise buildings.
4. Safe system, since water is used inside the building as the cooling fluid. The refrigerant is only used in the outdoor units.
5. Spare parts are available in any A/C workshop.
6. Constant speed compressors are used. Frequency invertors is not used in this system.
7. No ~~service on compressors are~~ required.
8. No oil return problems.
9. Works up to 55°C ambient temperature.
10. The initial cost of this system is less than the Chiller and Boiler system.

5.6.2 Selection Model

Total cooling load = 71.6 KW

So we select RWC Model 310 from Petra company table(A-29).

Cost of this model = 62400 NIS

5.6.2.1 General Data

Cooling capacity [KW] = 84.3

Heating capacity [KW] = 79.8

Compressor: Hermetically sealed Scroll

Number of Compressors: 2

Refrigerant: R-22

Water connection size = 2.5 in

Number of Fans = 2

Air flow rate [L/s] = 12384

5.6.2.2 Electrical Data

Power supply : 380/420 Volt
3Ph
50 HZ

Total [KW] = 25.6

5.6.3 Annual Power Consumption

Annual Power Consumption = (load [KW]/COP) * No. of month per year * No. of day per month * No. of hour per day * Price of electricity (27)

Annual Power Consumption for Cooling = (71.586515/3.293)*5*30*16*0.6
= 31305.6 NIS

$COP_{cooling} = 84.3/25.6$
$= 3.293$

Annual Power Consumption for Heating = (43.37681/3.12)*5*30*16*0.6
= 20020.1 NIS

$COP_{heating} = 79.8/25.6$
$= 3.12$

5.7 Ground Temperature

Undisturbed ground temperature is best obtained from local water well logs and geological surveys. The undisturbed ground temperature will remain constant throughout the year below 20 ft. Above 20 ft., the ground temperature will change with the season. Table (A-1) Ground Temperatures has the ground temperatures for many locations around the world. [6]

5.8 Materials

A completed Geo Source earth loop system will consist of the heat pump equipment, a series of buried pipes outside the building, antifreeze and water solution and a circulator pump to transfer the fluid to and from the earth loop. The heat pump used with an earth loop must be capable of operating efficiently and provide a comfortable output temperature with inlet earth loop temperatures down to 25°F. The underground pipe buried outside must be either a high density polybutylene or high density polyethylene manufactured for earth loop applications and tested by the American Society for Testing and Materials (ASTM) standards for such usage. This type of pipe has been in service by both the gas and electric utilities for many years and has an estimated life span of over 200 years and normally carries 50 year warranties [8].

5.9 Loop Fabrication Practices

5.9.1 Heat Fusion

Heat fusion is the process in which plastic pipe materials are aligned, cleaned or trimmed, heated to their melting point, brought together, and allowed to cool to form. For reliability, all underground piping joints must be thermally fused rather than mechanically coupled.

1. Heat fusion joining results in a joint which is stronger than the pipe itself.
2. The connection or joint is all plastic, eliminating corrosion problems.
3. Industry standards (ASTM, Plastics Pipe Institute (PPI)) recommend thermal fusion for proper joining.

5.9.2 Methods of Heat Fusion

5.9.2.1 Socket Fusion Joining

In the socket fusion method, the two pipe ends are joined by fusing each pipe end to a socket fitting. This requires two heat fusion procedures for each joint.

5.9.2.2 Butt Fusion

The butt fusion procedure is where the two pipe ends are simultaneously heated to a plastic state by a heater plate and brought together to form the heat-fused joint. A single heat fusion process is required to form the joint between the two plastic pipe ends. The butt fusion process is performed by using specially designed machines which provide for securely holding the two pieces to be fused, aligning them, trimming and squaring their ends, heating the surfaces to be joined with a heater plate, and butting them together while they remain in a plastic state which produces a double rollback head. [6]

5.10 Antifreeze Solutions

5.10.1 Water

Water is the least expensive and most readily available circulating fluid. Water has a relatively low viscosity and high thermal conductivity which can yield low frictional pressure drops and high heat transfers coefficients.

The purity and softness of the water are important. The presence of impurities, as ions or dissolved solids, can play a significant role in scale build-up, heat exchanger fouling, and pump maintenance and life in open systems. This would not be a major concern in a closed earth loop system.

Water would normally be the chosen earth loop circulating fluid if it were not for its following two disadvantages:

1. Water has a relatively high freezing point of 32°F.
2. Water expands upon freezing.

These two disadvantages eliminate water from being the chosen earth loop circulating fluid in northern climates. A fluid with a lower freezing point must be chosen.

Table 5.39 states pure water density, viscosity, and thermal conductivity at various temperatures. Water's specific heat can be taken to be 1.000 Btu/(lbm.°F). [6]

Table 5.39 Pure Water Physical Properties

Temp	Density	Viscosity	Thermal/Conductivity
(°F)	(lb/gal)	(centipoises)	(Btu/hr.ft.°F)
32	8.344	1.789	0.327
40	8.344	1.550	0.332
50	8.339	1.310	0.338
60	8.334	1.200	0.344
70	8.338	0.979	0.349
80	8.311	0.860	0.355
90	8.303	0.764	0.360
100	8.287	0.682	0.364

110	8.267	0.616	0.368
Note: Specific heat = 1.000 Btu/lbm . °F			

5.10.2 Methyl Alcohol (Methanol)

Methyl alcohol, sometimes referred to as a methanol has been widely used as an antifreeze. Methanol in water offers low cost, low corrosively, low viscosity, and good thermal conductivity. Methanol water offers relatively low frictional pressure drops and relatively high heat transfer coefficients. Methanol, however, presents the disadvantages of high volatility, high flammability, and high toxicity. Pure methanol has a flash point of 54°F to 60°F. Table 5.40 gives pertinent data for methanol waters at 25°F, 30°F, 35°F, and 40°F. [6]

Table 5.40 Methanol Solution Physical Properties

Mean Temperature (°F)	25	30	35	40
Freezing Point (°F)	15	20	25	30
Weight % Methanol	13.6	10.0	6.3	2.0
Methanol Mass (1) (lbm)	131.6	92.7	56.1	17.0
Methanol Volume (2) (gal)	19.41	13.63	8.29	2.53
Specific Gravity (SG t/59)	0.813	0.815	0.811	0.807
Density	8.180	7.546	8.254	8.257

(lb/gal)				
Specific Heat (Btu/lbm .°F)	1.01	1.02	1.025	1.02
Viscosity (Centipoise)	3.30	2.70	2.15	1.60
Thermal Conductivity (Btu/hr.ft .°F)	0.286	0.296	0.310	0.324

NOTE: (1) Pounds mass of pure methanol needed per 100 gallons of pure water.

(2) Gallons of pure methanol needed per 100 gallons of pure water.

5.10.3 Propylene Glycol

Propylene glycol, which is nontoxic, can offer low corrosively and low volatility, and presents a low flammability hazard. However, propylene glycol yields more viscous solutions.

A reasonable lower limit threshold would be a maximum 25% mixture by volume and operating above 25°F. Lower operating temperatures and/or higher concentrations of propylene glycol are not economical when the energy required pumping the fluid and maintaining turbulent flow under those conditions is considered. In order to obtain good heat transfer within the buried pipe system the calculated Reynolds number should not fall below 2500. Table 5.41 gives pertinent propylene glycol properties at 25°F, 30°F, 35°F, and 40°F. [6]

Table 5.41 Propylene Glycol Solution Physical Properties

Mean Temperature (°F)	25	30	35	40
Freezing Point (°F)	15	20	25	30
Weight % Glycol	23.5	18.3	12.9	5.9
Glycol Mass (1) (lbm)	256	187	124	52
Glycol Volume (2) (gal)	29.9	22.0	14.7	6.2
Specific Gravity (SG t/59)	1.025	1.018	1.013	1.006
Density (lb/gal)	8.55	8.49	8.45	8.39
Specific Heat (Btu/lbm .°F)	0.96	0.97	0.98	0.99
Viscosity (Centipoise)	5.3	4.4	4.0	3.7
Thermal Conductivity (Btu/hr.ft .°F)	0.225	0.236	0.25	0.275

NOTE: (1) Pounds mass of pure Glycol needed per 100 gallons of pure water.

(2) Gallons of pure Glycol needed per 100 gallons of pure water.

5.11 Earth Connection - Closed-Loop Ground Heat Exchangers (GHX)

This section introduces the procedure to estimate the size and the performance of closed-loop ground heat exchangers (GHXs). Since this estimation also requires the calculation of elements that specifically belong to the heat pump system.[7]

5.11.1 Vertical Loop Design

5.11.1.1 Ground Testing

Ground testing provides the designer with accurate information on the thermal conductivity. With this information, the loop design can be optimized (in most cases) and the length of piping reduced. If the bidding contractors will test bore data and drilling conditions on the site, this will remove some of the uncertainty and they may provide a price with less of a hedge in it.[13]

The tests are generally conducted by drilling a bore hole and adding a loop. Hot water from a portable electric heater is circulated as shown in (Figure 5.1). A data ~~log~~ is ~~run~~ ~~over~~ ~~48 hours~~ and ~~the~~ energy absorbed by the ground is measured. From this, the conductivity and diffusivity can be calculated.[14]

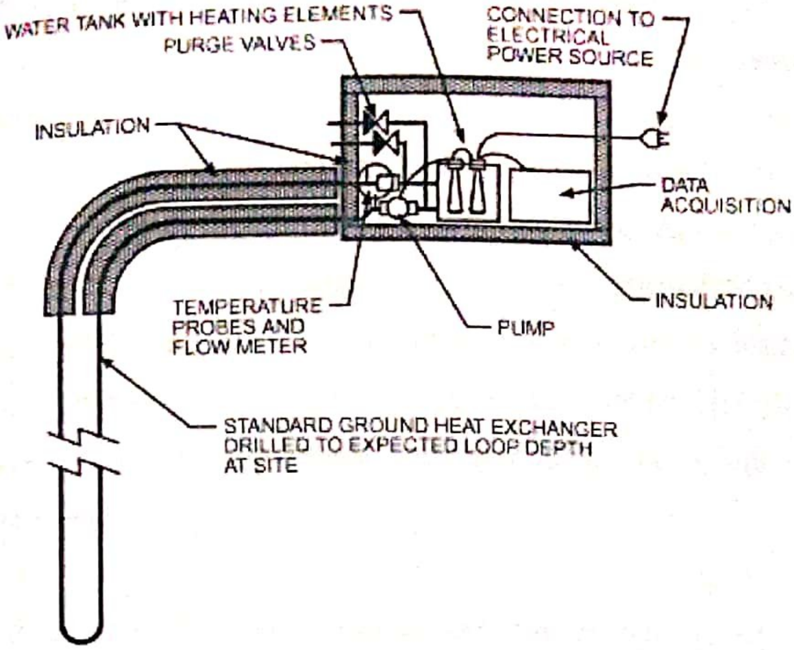

Figure 5.1: Field Testing Apparatus

5.11.1.2 Vertical Heat Exchanger Length

To find the required vertical heat exchanger length of bore length takes the following equation for heating:

$$L_h = \frac{q_a R_{ga} + (C_{fh} \times q_{lh})(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_p + \frac{t_{wi} + t_{wo}}{2} - t_g} \tag{28}$$

And takes the following equation for cooling:

$$L_c = \frac{q_a R_{ga} + (C_{fc} \times q_{lc})(R_b + PLF_m R_{gm} + R_{gd} F_{sc})}{t_p + \frac{t_{wi} + t_{wo}}{2} - t_g} \tag{29}$$

where L_c is the length of bore required for cooling, L_h is the bore required for heating, q_a net annual average heat transfer to the ground, C_{fh} heat pump correction factor for heating, C_{fc} heat pump correction factor for cooling, q_{lh} building design heating load, q_{lc} building design cooling load, R_b thermal resistivity of bore, R_{ga} effective thermal resistivity of the ground, annual pulse, R_{gm} effective thermal resistivity of the ground, monthly pulse, R_{gd} effective thermal resistivity of the ground, daily pulse, PLF_m part load factor during design month, F_{sc} short-circuit heat loss factor, t_g undisturbed ground temperature, t_p temperature penalty for interference of adjacent bores, t_{wi} liquid temperature at heat pump inlet, and t_{wo} liquid temperature at heat pump outlet.[15]

To use these equations, the net annual heat transfer to the ground, q_a, needs to be calculated. The net annual heat transfer to the ground is given by the following equation:

$$q_a = \frac{C_{fc} q_{lc} EFLhours_c + C_{fh} q_{lh} EFLhours_h}{8760} \qquad (30)$$

where 8760 is the number of hours per year, $EFLhours_c$ is the equivalent full-load hours for cooling, and $EFLhours_h$ is the equivalent full-load hours for heating.

The heat pump correction factors, C_{fc} and C_{fh}, are taken from table (A-30) and everything is plugged into the above equation for net annual heat transfer.

$C_{fc} = 1.2$

$C_{fh} = 0.8$

$q_{lc} = 71.586515$ KW = 244426.85466 Btu/h

$q_{lh} = 43.37681$ KW = 148106.90568 Btu/h

$EFLhours_c = 2400$ h

$EFLhours_h = 2400$ h

$$q_a = \frac{(1.2 * 244426.85466 * 2400) + (0.8 * 148106.90568 * 2400)}{8760}$$

q_a = 112821.3 Btu/h

The program currently uses a length calculation that involves a single value for the ground resistivity. This neglects long-term heat changes in the soil that may arise over the life-of the system. By using several values, which are based on three different pulses, a more accurate calculation for the length of bore can be found that takes into account the long-term temperature changes of the soil. These resistivity values are labeled R_{ga} (annual), R_{gm} (monthly), and R_{gd} (daily). To solve for these, calculate τ,or the length of each pulse, for the three different time intervals:

τ_1= 3650 (10 yrs.); τ_2= 3680 (1 month); τ_f= 3680.25 (6 hours).

Then the following equations are used to solve for the Fourier number for each of the pulses:

$$F_{01} = \frac{4\alpha(\tau_f - \tau_1)}{d^2} \quad (31)$$

$$F_{02} = \frac{4\alpha(\tau_f - \tau_2)}{d^2} \quad (32)$$

$$F_{0f} = \frac{4\alpha\tau_f}{d^2} \quad (33)$$

where α is thermal diffusivity, and d is diameter of pipe.[16]

Using the values of F_o find the G value associated with each of these Fourier values if found from a logarithmic fit of figure (A-35):

$$G = 0.0769\,Ln(F_0) + 0.0901 \quad (34)$$

Finally, to solve for the thermal resistivity (R_{ga}, R_{gm}, and R_{gd}), use the equations:

$$R_{ga} = \frac{G_f - G_1}{k_g} \tag{35}$$

$$R_{gm} = \frac{G_1 - G_2}{k_g} \tag{36}$$

$$R_{gd} = \frac{G_2}{k_g} \tag{37}$$

where K_g thermal conductivity of earth.[16]

$\alpha = 0.8$ ft²/day

$k_g = 1.19$ Btu/h ft °F

$d = 0.105$ ft

$$\Rightarrow G_f = 1.1575$$

$$G_1 = 0.7884$$
$$G_2 = 0.4196$$

$R_{ga} = 0.31$ h ft °F/Btu

$R_{gm} = 0.3099$ h ft °F/Btu

$R_{gd} = 0.3526$ h ft °F/Btu

Next, a specific type of pipe needs to be assumed for use in the heat exchanger. A commonly used pipe for this purpose is 32 mm diameter polyethylene tube (SDR-11).

Kavanaugh cites the work of Remund and Paul (1997), and their use of a method of solving for thermal resistivity of bore, R_b. The equation:

$$R_b = R_{bf} + R_p \tag{38}$$

where R_{bf} is the backfill resistivity, and R_p thermal resistivity of pipe.

$R_{bf} = 0.7$ h °F ft /Btu

$R_p = 0.075$ h °F ft /Btu

$R_b = 0.7 + 0.075 = 0.775$ h °F ft /Btu

Next the short-circuit heat loss factor, F_{sc}, which is the heat lost between adjacent pipes in the same borehole.

$F_{sc} = 1.03$

Now the part load factor can be taken from the equation:

$$PLF_m = \left(\frac{Load \times Hours}{Peakload \times 24h}\right) \times \left(\frac{DaysOccupiedPerMonth}{DaysPerMonth}\right) \quad (39)$$

$$PLF_m = \left(\frac{65.079 \times 16}{71.586515 \times 24}\right) \times \left(\frac{27}{31}\right)$$

$$PLF_m = 0.528$$

For vertical installation, it is assumed that the ground temperature, t_g, is equal to the mean of the winter and summer average temperatures.

$t_g = 17.33$ °C

$= 63.2$ °F

Water inlet temperature is suggested to be 20 to 30 degrees higher than t_g in cooling, and 10 to 20 degrees lower than t_g in heating (both temperatures in Fahrenheit).[15]

$t_{wi\,c} = 29$ °C

$= 84.2$ °F

$t_{wi\,h} = 11$ °C

$= 52$ °F

$t_{wo\,c} = 32.22$ °C

$= 90$ °F

$t_{wo\,h} = 8.811$ °C

$= 47.86$ °F

Finally, the temperature penalty due to bores affecting one another, tp, see table (A-31) can be used to estimate this value. Interpolation can be done with values not exactly matching the chart.

$t_p = 2.6\ ^{\circ}\mathrm{C}$

$= 36.68\ ^{\circ}\mathrm{F}$

With all of these values determined, equations 1 and 2 can be used to solve for the bore length required for heating and cooling.

$$L_h = \frac{(112821.3 \times 0.31) + (0.8 \times 148106.90568)(0.775 + (0.528 \times 0.3099) + (0.3526 \times 1.03))}{36.68 + \dfrac{52 + 47.86}{2} - 63.2}$$

$L_h = 8082.8567\ ft$

$L_h = 2463.65 m$

$$L_c = \frac{(112821.3 \times 0.31) + (1.2 \times 244426.85466)(0.775 + (0.528 \times 0.3099) + (0.3526 \times 1.03))}{36.68 + \dfrac{84.2 + 90}{2} - 63.2}$$

$L_c = 6880.32\ ft$

$L_c = 2097.122 m$

We depend in design bore length on Lh because Lh is larger than Lc.

Number of Bores = (Bore length) / (deep of each Bore)

= 2463.65 / 100

= 24.6365 ≈ 25 Bores

Length of heat exchanger (polyethylene Pipe) = 2*Lh

= 2*2463.65

= 4927.3 m

5.11.1.3 Pump Selection

To select the pump must be know the friction loss in pipe and coil of heat pump, so we use the table (A-32) to calculate the friction in pipe, and use the table (A-33) to know the value of friction in coil, and must be know Pump flow:

Total Equivalent Length of pipe = 4927.3 * 1.5

= 7390.95 m

Friction loss in Pipe = 446.431 KPa

Friction loss in heat pump coil = 30.8 KPa

Total friction loss = 446.431 + 30.8

= 477.231 KPa

Pump flow = 8.5 L/s

From Grundfoss company we are determine the type of Pump:

Pump type is: Grundfoss TPE Serles 1000 (see figure (A-36)).

5.11.1.4 Selection Geothermal Heat Pump

we select EKW Chiller type from WFI Global company, because satisfied the following specification of Project; weather, load, system,....ect.

5.11.1.4.1 Selection Model

Total cooling load = 71.6 KW

Total heating load = 43.4 KW

So we select Heating and Cooling Part Load Model EKW130 from WFI Global company see tables (A-33) and (A-34).

5.11.1.4.2 General Data

Cooling capacity [KW] = 74.1
Heating capacity [KW] = 80.8
Number of compressor: 2
Refrigerant: R-410a
Water Floe rate = 8.5 L/s

5.11.1.4.3 Electrical Data

Power supply : 380 Volt
3Ph
50 HZ
Total for cooling [KW] = 12.9
Total for heating [KW] = 17.4

5.11.2 Cost of Geothermal Heat Pump Equipment

cost of heat Pump = 33500 $
= 130650 NIS
cost of Pipe = 2463.65 * 2 * 3.7
= 18231.01 NIS
cost of Ground test = 1500 $
= 5850 NIS

cost of drilling = 25 * 1500 *3.9

= 146250 NIS

cost of Pump = 27000 NIS

So the Initial cost for Geothermal heat Pump = 130650 + 18231.01 + 5850 + 146250 + 27000

= 327981 NIS

5.11.3 Annual Power consumption

Annual Power Consumption for Cooling = (71.586515/5.8)*5*30*16*0.6

= 17773.2 NIS

$COP_{cooling}$ = 5.8 (see table (A-33))

Annual Power Consumption for Heating = (43.37681/4.6)*5*30*16*0.6

= 13578.83 NIS

$COP_{heating}$ = 4.6 (see table (A-34))

5.12 System Comparison

Initial cost difference between two system = (initial cost of GHP) – (initial cost of Traditional system)

= 327981 – 62400

= 265581 NIS

(Annual Power Consumption(APC) = (APC of Traditional system) – (APC of GHP)

difference between two system)

= 51325.7 – 31352

= 19973.7 NIS

So the number of years necessary to offset the cost difference between the two types:

No. of year = (265581/19973.7)

= 13.3 Years

Conclusion

The initial cost of Geothermal heat pump system is very high but it can return the initial cost after several years, depend that on load of building, type of ground properties, and other reasons.

Recommendation

1. we recommend applied this project in residential and commercial building in Palestine, despite his high cost, because the Palestinian suffering from a lack in electrical energy, and this reduces the power consumption.
2. we recommend this technology to teach at Palestine Polytechnic university, Given the importance of this technology.
3. we recommend that the government is educating the owners of companies and enterprises use GHP in the process of conditioning and refrigeration, this is because it reduces the power consumption.

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Appendix A

Figure A-45 Ground Floor Return Line

Figure A-46 First Floor Return Line

Figure A-47 Sections

Figure A-48 Basement Floor Plan & line GHP

Table A-1 Ground Temperatures

State	City	GWT (F)	State/Country	City	GWT (F)	State/Country	City	GWT (F)
Alabama	Birmingham	65	South Carolina	Charleston	66	Germany	Frankfurt	52
Alabama	Mobile	70	South Carolina	Columbia	64	Germany	Hamburg	51
Alabama	Montgomery	67	South Carolina	Greenville	62	Germany	Munich	49
Alaska	Anchorage	40	South Dakota	Sioux Falls	51	Germany	Stuttgart	51
Alaska	Fairbanks	0	Tennessee	Knoxville	61	Greece	Athens	67
Arizona	Phoenix	73	Tennessee	Memphis	63	Hungary	Budapest	53
Arkansas	Little Rock	64	Tennessee	Nashville	60	Indonesia	Jakarta	83
California	Fresno	68	Texas	Austin	71	Ireland	Dublin	52
California	Los Angeles	64	Texas	Dallas	68	Israel	Jerusalem	63
California	Sacramento	67	Texas	Houston	71	Italy	Genova	60
California	San Diego	64	Texas	San Antonio	72	Italy	Milan	57
California	San Francisco	60	Utah	Salt Lake City	53	Italy	Naples	63
Colorado	Denver	52	Vermont	Burlington	46	Italy	Palermo	66
Connecticut	Hartford	51	Virginia	Norfolk	61	Italy	Rome	61
Delaware	Dover	57	Virginia	Richmond	60	Italy	Torino	58
Florida	Daytona Beach	70	Virginia	Roanoke	59	Italy	Trieste	58
Florida	Jacksonville	71	DC	Washington	57	Italy	Venice	58
Florida	Miami	78	Washington	Seattle	53	Japan	Nagoya	62
Florida	Tallahassee	69	Washington	Spokane	49	Japan	Osaka	63
Florida	Tampa	75	West Virginia	Charleston	58	Japan	Sapporo	51
Georgia	Atlanta	62	Wisconsin	La Crosse	48	Japan	Tokyo	64
Georgia	Savannah	67	Wisconsin	Milwaukee	47	Korea	Inch'on	56
Hawaii	Honolulu	79	Wyoming	Cheyenne	48	Korea	Pusan	59
Idaho	Boise	47	Alberta	Calgary	42	Korea	Seoul	57
Illinois	Chicago	51	Alberta	Edmonton	40	Kuwait	Kuwait City	80
Illinois	Springfield	56	British Columbia	Vancouver	53	Libyan Arab Jamahiriya	Tripoli	71
Indiana	Fort Wayne	53	Manitoba	Winnipeg	40	Malaysia	George Town	84
Indiana	Indianapolis	55	New Brunswick	Moncton	42	Malaysia	Kuala lumpur	83
Iowa	Des Moines	53	Newfoundland	Saint John's	43	Mexico	Acapulco	78
Kansas	Wichita	59	Nova Scotia	Halifax	45	Mexico	Mexico City	65
Ohio	Cincinatti	57	Ontario	Ottawa	45	Mexico	Veracruz	75
Kentucky	Lexington	60	Ontario	Toronto	48	Morocco	Casablanca	66
Kentucky	Louisville	60	Prince Edward Island	Charlottetown	42	Netherlands	Amsterdam	52
Louisiana	New Orleans	70	Quebec	Montreal	46	New Zealand	Auckland	56
Louisiana	Shreveport	66	Saskatchewan	Regina	39	New Zealand	Christchurch	54
Maine	Caribou	46	Argentina	Buenos Aires	64	New Zealand	Wellington	57
Maine	Portland	48	Australia	Adelaide	64	Norway	Oslo	46
Maryland	Baltimore	57	Australia	Brisbane	72	Paraguay	Asuncion	64
Massachusetts	Boston	50	Australia	Canberra	67	Peru	Lima	70
Massachusetts	Worchester	50	Australia	Melbourne	59	Philippines	Manila	67
Michigan	Detroit	50	Australia	Perth	67	Poland	Krakow	48
Michigan	Flint	49	Australia	Sydney	67	Poland	Warsaw	49
Michigan	Grand Rapids	46	Austria	Salzburg	51	Portugal	Porto	64
Minnesota	Duluth	41	Austria	Vienna	50	Puerto Rico	San Juan	84
Minnesota	Minneapolis	47	Bahrain	Manama	80	Qatar	Doha	83
Mississippi	Jackson	67	Belgium	Brussels	52	Romania	Bucharest	54
Missouri	Kansas City	58	Bolivia	La Paz	50	Saudi Arabia	Riyadh	82
Missouri	St. Louis	58	Brazil	Belem	82	Singapore	Singapore	82
Montana	Billings	49	Brazil	Brasilia	80	Spain	Barcelona	62
Montana	Helena	47	Brazil	Recife	78	Spain	Madrid	60
Nebraska	Omaha	53	Brazil	Sao Paulo	78	Spain	Sevilla	67
Nevada	Las Vegas	69	Bulgaria	Sofia	55	Spain	Valencia	65
Nevada	Reno	50	Chile	Santiago	61	Sweden	Stockholm	47
New Hampshire	Concord	50	China	Beijing	58	Switzerland	Geneva	53
New Jersey	Trenton	55	China	Guangzhou	77	Syria	Damascus	71
New Mexico	Albuquerque	59	China	Harbin	53	Taiwan	Taipei	75
New York	Albany	50	China	Hong Kong	77	Thailand	Bangkok	85
New York	Buffalo	50	China	Shanghai	62	Tunisia	Tunis	69
New York	New York City	52	China	Shenyang	55	Turkey	Ankara	52
North Carolina	Asheville	59	Colombia	Bogota	58	Turkey	Istanbul	60
North Carolina	Charlotte	62	Cuba	Havana	77	Turkey	Izmir	64
North Carolina	Greensboro	60	Czech Republic	Prague	50	United Arab Emirates	Abu Dhabi	80
North Carolina	Raleigh	62	Denmark	Copenhagen	47	United Arab Emirates	Dubai	80
North Dakota	Bismarck	44	Ecuador	Quito	60	United Kingdom	Aberdeen	49
North Dakota	Fargo	42	Egypt	Aswan	78	United Kingdom	Belfast	51
Ohio	Cleveland	51	Egypt	Cairo	73	United Kingdom	Birmingham	52
Ohio	Columbus	55	Finland	Helsinki	47	United Kingdom	Edinburgh	50
Ohio	Dayton	50	France	Bordeaux	61	United Kingdom	Liverpool	54
Oklahoma	Oklahoma City	62	France	Lyon	57	United Kingdom	London	54
Oregon	Portland	54	France	Marseille	59	Uruguay	Montevideo	64
Pennsylvania	Harrisburg	52	France	Nantes	56	Venezuela	Caracas	78
Pennsylvania	Philadelphia	55	France	Paris	54	Vietnam	Hanoi	84
Pennsylvania	Pittsburgh	52	Germany	Berlin	52	Yugoslavia	Belgrade	55

Table A-2 Cooling load temperature differences for calculating cooling loade from sunlit roofs

Roof No.	Description of Construction	U, W/m²·°C	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
			Solar Time, h																							
Without Suspended Ceiling																										
1	Steel sheet with 25.4 mm (or 50.8 mm) insulation	1.209 (0.704)	0	−1	−2	−2	−3	−2	3	11	19	27	34	40	43	44	43	39	33	25	17	10	7	5	3	1
2	25 mm wood with 25.4 mm insulation	0.963	3	2	0	−1	−2	−2	−1	2	8	15	22	29	35	39	41	41	39	35	29	21	15	11	8	5
3	101.6 mm L.W concrete	1.209	5	3	1	0	−1	−2	−2	1	5	11	18	25	31	36	39	40	40	37	32	25	19	14	10	7
4	50.8 mm H.W. concrete 25.4 mm (or 50.8 mm) insulation	1.170 (0.693)	7	5	3	2	0	−1	0	2	6	11	17	23	28	33	36	37	37	34	30	25	20	16	12	10
5	25.4 mm wood with 50.8 insulation	0.619	2	0	−2	−3	−4	−4	−4	−2	3	9	15	22	27	32	35	36	35	32	27	20	14	10	6	3
6	152.4 mm L.W concrete	0.897	12	10	7	5	3	2	1	0	2	4	8	13	18	24	29	33	35	36	35	32	28	24	19	16
7	63.5 mm wood with 25.4 mm insulation	0.738	16	13	11	9	7	6	4	3	4	5	8	11	15	19	23	27	29	31	31	30	27	25	22	19
8	203.4 mm L.W. concrete	0.715	20	17	14	12	10	8	6	5	4	4	5	7	11	14	18	22	25	28	30	30	29	27	25	22
9	101.6 mm H.W. concrete with 25.4 mm (or 50.8 mm) insulation	1.136 (0.681)	14	12	10	8	7	5	4	4	6	8	11	15	18	22	25	28	29	30	29	27	24	21	19	16
10	63.5 mm wood with insulation	0.528	18	15	13	11	9	8	6	5	5	5	7	10	13	17	21	24	27	28	29	29	27	25	23	20
11	Roof terrace system	0.602	19	17	15	14	12	11	9	8	7	8	8	10	12	15	18	20	22	24	25	26	25	24	22	21
12	152.4 mm H.W concrete with 25.4 mm (or 50.8 mm) insulation	0.664	18	16	14	12	11	10	9	8	8	9	10	12	15	17	20	22	24	25	25	25	24	22	20	19
13	101.6 mm wood with 25.4 mm (or 50.8 mm) insulation	0.602 (0.443)	21	20	18	17	15	14	13	11	10	9	9	9	10	12	14	16	18	20	22	23	24	24	23	22
With Suspended Ceiling																										
1	Steel sheet with 25.4 mm (or 50.8 mm) insulation	0.761 (0.522)	1	0	−1	−2	−3	−3	0	5	13	20	28	35	40	43	43	41	37	31	32	15	10	7	5	3
2	25-mm wood with 25.4 mm insulation	0.653	11	8	6	5	3	2	1	2	4	7	12	17	22	27	31	33	35	34	32	28	24	20	17	14
3	101.6 mm L.W concrete	0.761	10	8	6	4	2	1	0	0	2	6	10	16	21	27	31	34	36	36	34	30	26	21	17	13
4	50.8 mm H.W concrete 25.4 mm insulation	0.744	16	14	13	11	10	8	7	7	8	9	11	14	17	19	22	24	25	26	26	25	23	21	20	18
5	25.4 mm wood with 50.8 insulation	0.471	14	11	9	7	5	4	3	3	4	6	10	14	18	23	27	30	31	32	31	29	26	22	19	16
6	152.4 mm L.W. concrete	0.619	18	15	13	11	9	7	6	4	4	4	6	9	12	16	20	24	27	29	30	30	28	26	23	20
7	63.5 mm wood with 25.4 mm insulation	0.545	19	18	16	14	13	12	10	9	8	8	9	10	12	14	17	19	21	23	24	25	24	23	22	21
8	203.4 mm L.W concrete	0.528	22	20	18	16	15	13	11	10	9	8	8	8	9	11	14	16	19	21	23	25	25	25	24	23
9	101.6 mm H.W concrete with 25.4 mm (or 50.8 mm) insulation	0.727 (0.511)	17	16	15	14	13	13	12	11	11	11	12	13	15	16	18	19	20	21	21	21	21	20	19	18
10	63.5 mm wood with 50.8 mm insulation	0.409	19	18	17	16	14	13	12	11	10	10	10	11	12	14	16	18	19	21	22	23	23	22	22	21

Table A-3 CLTD correction for latitude and month applied to walls and roofs, north latitudes

Lat	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	Horiz
16	Dec	-2.2	-3.3	-4.4	-4.4	-2.2	-0.5	2.2	5.0	7.2	-5.0
	Jan/Nov	-2.2	-3.3	-3.8	-3.6	-2.2	-0.5	2.2	4.4	6.6	-3.8
	Feb/Oct	-1.6	-2.7	-2.7	-2.2	-1.1	0.0	1.1	2.7	5.8	-2.2
	Mar/Sept	-1.6	-1.6	-1.1	-1.1	-0.5	-0.5	0.0	0.0	1.6	-0.5
	Apr/Aug	0.5	0.0	-0.5	-0.5	-0.5	-1.6	-1.6	-2.7	-3.3	0.0
	May/Jul	2.2	1.6	1.6	0.0	-0.5	-2.2	-2.7	-3.8	-3.8	0.0
	Jun	3.3	2.2	2.2	0.5	-0.5	-2.2	-3.3	-4.4	-4.4	0.0
24	Dec	-2.7	-3.6	-5.5	-6.1	-4.4	-2.7	1.1	5.0	6.6	-9.4
	Jan/Nov	-2.2	-3.3	-4.4	-5.0	-3.3	-1.6	1.6	5.0	7.7	-6.1
	Feb/Oct	-2.2	-2.7	-3.3	-3.3	-1.6	-0.5	1.6	3.8	5.5	-3.8
	Mar/Sept	-1.6	-2.2	-1.6	-1.6	-0.5	-0.5	0.5	1.1	2.2	-1.6
	Apr/Aug	-1.1	-0.5	0.0	-0.5	-0.5	-1.1	-0.5	-1.1	-1.6	0.0
	May/Jul	0.5	1.1	1.1	0.0	0.0	-1.6	-1.6	-2.7	-3.3	0.5
	Jun	1.6	1.6	1.6	0.5	0.0	-1.6	-2.2	-3.3	-3.3	0.5
32	Dec	-2.7	-3.8	-5.5	-6.1	-4.4	-2.7	1.1	5.0	6.6	-9.4
	Jan/Nov	-2.7	-3.8	-5.0	-6.1	-4.4	-2.2	1.1	5.0	6.6	-8.3
	Feb/Oct	-2.2	-3.3	-3.8	-4.4	-2.2	-1.1	2.2	4.4	6.1	-5.5
	Mar/Sept	-1.6	-2.2	-2.2	-2.2	-1.1	-0.5	1.6	2.7	3.8	-2.7
	Apr/Aug	-1.1	-1.1	-0.5	-1.1	0.0	-0.5	0.0	0.5	0.5	-0.5
	May/Jul	0.5	0.5	0.5	0.0	0.0	-0.5	-0.5	-1.6	-1.6	0.5
	Jun	0.5	1.1	1.1	0.5	0.0	-1.1	-1.1	-2.2	-2.2	1.1
40	Dec	-3.3	-4.4	-5.5	-7.2	-5.5	-3.8	0.0	3.8	5.5	-11.6
	Jan/Nov	-2.7	-3.8	-5.5	-6.6	-5.5	-3.3	0.5	4.4	6.1	-10.5
	Feb/Oct	-2.7	-3.8	-4.4	-5.0	-3.3	-1.6	1.6	4.4	6.6	-7.7
	Mar/Sept	-2.2	-2.7	-2.7	-3.3	-1.6	0.5	2.2	3.8	3.5	4.4
	Apr/Aug	-1.1	-1.6	-1.6	-1.1	0.0	0.0	1.1	1.6	2.2	1.6
	May/Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5
	Jun	0.5	0.5	0.5	0.5	0.0	0.5	0.0	0.0	-0.5	1.1

Table A-4 Overall heat transfer coefficient for windos. W/m².°C

Material Type and Frames	Wind Speed (m/s)					
	Single Glass			Double Glass		
	< 0.5	0.5 - 5.0	> 5.0	≤ 0.5	0.5 - 5.0	< 5.0
Wood	3.8	4.3	5.0	2.3	2.5	2.7
Aluminium	5.0	5.6	6.7	3.0	3.2	3.5
Steel	5.0	5.6	6.7	3.0	3.2	3.5
PVC	3.8	4.3	5.0	2.3	2.5	2.7

Table A-5 Solar heat gain factor (SHG). W/m², for a latitude angle of 32°

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
N	76	85	101	114	120	139	126	117	104	88	76	69
NNE/NNW	76	85	117	252	350	385	350	249	110	88	76	69
NE/NW	91	205	338	461	536	555	527	445	325	199	91	69
ENE/WNW	331	470	577	631	656	656	643	615	546	451	325	265
E/W	552	647	716	716	694	675	678	691	678	615	546	511
ESE/WSW	722	764	748	691	628	596	612	663	716	738	710	688
SE/SW	786	782	716	590	489	439	473	571	688	754	773	776
SSE/SSW	789	732	615	445	213	262	303	429	596	710	776	795
S	776	697	555	363	233	189	227	350	540	678	767	795
Horizontal	555	685	795	855	874	871	861	836	770	672	552	498

Table A-6 Shading coefficient (SC). for single, double and insulting glass without interior shading

Type of Glass	Nominal Thickness, mm	Solar Trans.	Shading Coefficient, W/m²·K	
			$h_o = 22.7$	$h_o = 17.0$
		Single Glass		
Clear	3	0.84	1.00	1.00
	6	0.78	0.94	0.95
	10	0.72	0.90	0.92
	12	0.67	0.87	0.88
Heat absorbing	3	0.64	0.83	0.85
	6	0.46	0.69	0.73
	10	0.33	0.60	0.64
	12	0.42	0.53	0.58
		Double Glass		
Regular	3	—	0.90	—
Plate	6	—	0.83	—
Reflective	6	—	0.20-0.40	—
		Insulating Glass		
Clear	3	0.71	0.88	0.88
	6	0.61	0.81	0.82
Heat absorbing'	6	0.36	0.55	0.58

Table A-7 Colling load factors for glass without interior shading, north latitudes

Glass Facing	Building Construction	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		Solar Time, h																
W	M	0.15	0.13	0.11	0.10	0.09	0.09	0.09	0.10	0.11	0.12	0.13	0.14	0.19	0.29	0.40	0.50	0.56
	H	0.14	0.13	0.12	0.11	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.21	0.30	0.40	0.49	0.54
WNW	L	0.12	0.10	0.08	0.06	0.05	0.06	0.07	0.09	0.10	0.12	0.13	0.15	0.17	0.26	0.40	0.53	0.63
	M	0.15	0.13	0.11	0.10	0.09	0.09	0.10	0.11	0.12	0.11	0.14	0.15	0.17	0.24	0.35	0.47	0.55
	H	0.14	0.13	0.12	0.11	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.25	0.36	0.46	0.53
NW	L	0.11	0.09	0.08	0.06	0.05	0.06	0.08	0.10	0.12	0.14	0.16	0.17	0.19	0.23	0.33	0.47	0.59
	M	0.14	0.12	0.11	0.09	0.08	0.09	0.10	0.11	0.13	0.14	0.16	0.17	0.18	0.21	0.30	0.42	0.51
	H	0.14	0.12	0.11	0.10	0.10	0.10	0.12	0.13	0.15	0.16	0.18	0.18	0.19	0.22	0.30	0.41	0.50
NNW	L	0.12	0.09	0.08	0.06	0.05	0.07	0.11	0.14	0.18	0.22	0.25	0.27	0.29	0.30	0.33	0.44	0.57
	M	0.15	0.13	0.11	0.10	0.09	0.10	0.12	0.15	0.18	0.21	0.23	0.26	0.27	0.28	0.31	0.39	0.51
	H	0.14	0.13	0.12	0.11	0.10	0.12	0.15	0.17	0.20	0.23	0.25	0.26	0.28	0.28	0.31	0.38	0.49
HORIZ.	L	0.11	0.09	0.07	0.06	0.05	0.07	0.14	0.24	0.36	0.48	0.58	0.66	0.72	0.74	0.73	0.67	0.59
	M	0.16	0.14	0.12	0.11	0.11	0.11	0.16	0.24	0.33	0.43	0.52	0.59	0.64	0.67	0.66	0.62	0.56
	H	0.17	0.16	0.15	0.14	0.13	0.15	0.20	0.28	0.36	0.45	0.52	0.59	0.62	0.64	0.62	0.58	0.51

Cooling Load factors (CLF) for glass windows with interior shading, North latitude.

Fenestration Facing	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	Solar Time, h																
N	0.08	0.07	0.06	0.06	0.07	0.73	0.66	0.65	0.73	0.80	0.86	0.89	0.89	0.86	0.82	0.75	0.78
NNE	0.03	0.03	0.02	0.02	0.03	0.64	0.77	0.62	0.42	0.37	0.37	0.37	0.36	0.35	0.32	0.28	0.23
NE	0.03	0.02	0.02	0.02	0.02	0.56	0.76	0.74	0.58	0.37	0.29	0.27	0.26	0.24	0.22	0.20	0.16
ENE	0.03	0.02	0.02	0.02	0.02	0.52	0.76	0.80	0.71	0.52	0.31	0.26	0.24	0.22	0.20	0.18	0.15
E	0.03	0.02	0.02	0.02	0.02	0.47	0.72	0.80	0.76	0.62	0.41	0.27	0.24	0.22	0.20	0.17	0.14
ESE	0.03	0.03	0.02	0.02	0.02	0.41	0.67	0.79	0.80	0.72	0.54	0.34	0.27	0.24	0.21	0.19	0.15
SE	0.03	0.03	0.02	0.02	0.02	0.30	0.57	0.74	0.81	0.79	0.68	0.49	0.33	0.28	0.25	0.22	0.18
SSE	0.04	0.03	0.03	0.03	0.02	0.12	0.31	0.54	0.72	0.81	0.81	0.71	0.54	0.38	0.32	0.27	0.22
S	0.04	0.04	0.03	0.03	0.03	0.09	0.16	0.23	0.38	0.58	0.75	0.83	0.80	0.68	0.50	0.35	0.27
SSW	0.05	0.04	0.04	0.03	0.03	0.09	0.14	0.18	0.22	0.27	0.43	0.63	0.78	0.84	0.80	0.66	0.46
SW	0.05	0.05	0.04	0.04	0.03	0.07	0.11	0.14	0.16	0.19	0.22	0.38	0.59	0.75	0.83	0.81	0.69
WSW	0.05	0.05	0.04	0.04	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.23	0.44	0.64	0.78	0.84	0.78
W	0.05	0.05	0.04	0.04	0.03	0.06	0.09	0.11	0.13	0.15	0.16	0.17	0.31	0.53	0.72	0.82	0.81
WNW	0.05	0.05	0.04	0.03	0.03	0.07	0.10	0.12	0.14	0.16	0.17	0.18	0.22	0.43	0.65	0.80	0.84
NW	0.05	0.04	0.04	0.03	0.03	0.07	0.11	0.14	0.17	0.19	0.20	0.21	0.22	0.30	0.52	0.73	0.82
NNW	0.05	0.05	0.04	0.03	0.03	0.11	0.17	0.22	0.26	0.30	0.32	0.33	0.34	0.34	0.39	0.61	0.82
HORIZ.	0.06	0.05	0.04	0.04	0.03	0.12	0.27	0.44	0.59	0.72	0.81	0.85	0.85	0.81	0.71	0.58	0.42

Table A-8 Colling load temperature differences for glass convection

Solar Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CLTD (°C)	1	0	-1	-1	-1	-1	-1	0	1	2	4	5	7	7	8	8	7	7	6	4	3	2	2	1

Table A-9 Outdoor air requirements for ventilation

Application	Maximum Occupancy Per 100 m^2	Outdoor Air Requirement	
		L/s/Person	L/s/m^2
Offices			
Office space	7	10.0	—
Reception area	60	8.0	—
Telecomm. Centers	60	10.0	—
Conference rooms	50	10.0	—
Public spaces			
Corridors	—	—	0.25
Public restrooms	—	25.0	—
Locker rooms	—	—	2.50
Smoking lounge	70	30.0	—
Elevators	—	—	5.00
Laundries			
Commercial laundry	10	13.0	—
Commercial dry cleaner	30	15.0	—
Coin-operated laundries	20	8.0	—
Coin operated dry cleaner	20	8.0	—
Food and beverage services			
Dining rooms	70	10.0	—
Cafeteria	100	10.0	—
Bars	100	15.0	—
Kitchens	20	8.0	—
Garages, service stations			
Enclosed parking garage	—	—	7.50
Auto repair rooms	—	—	7.50

Table A-10 Cooling load factors for lighting

No of hours after lights are turned on	Fixture X† hours of operation		Fixture Y† hours of operation	
	10	16	10	16
0	0.08	0.19	0.01	0.05
1	0.62	0.72	0.76	0.79
2	0.66	0.75	0.81	0.83
3	0.69	0.77	0.84	0.87
4	0.73	0.80	0.88	0.89
5	0.75	0.82	0.90	0.91
6	0.78	0.84	0.92	0.93
7	0.80	0.85	0.93	0.94
8	0.82	0.87	0.95	0.95
9	0.84	0.88	0.96	0.96
10	0.85	0.89	0.97	0.97
11	0.32	0.90	0.22	0.98
12	0.29	0.91	0.18	0.98
13	0.26	0.92	0.14	0.98
14	0.23	0.93	0.12	0.99
15	0.21	0.94	0.09	0.99
16	0.19	0.94	0.08	0.99
17	0.17	0.40	0.06	0.24
18	0.15	0.36	0.05	0.20

† Fixture description: X, recessed lights which are not vented. The supply and return air registers are below the ceiling or through the ceiling space and grille. Y, vented or free-hanging lights. The supply air registers are below or through the ceiling with the return air registers around the fixtures and through the ceiling space.

Table A-11 Sensible heat cooling load factors for people

Hours after each entry into space	Total hours in space							
	2	4	6	8	10	12	14	16
1	0.49	0.49	0.50	0.51	0.53	0.55	0.58	0.62
2	0.58	0.59	0.60	0.61	0.62	0.64	0.66	0.70
3	0.17	0.66	0.67	0.67	0.69	0.70	0.72	0.75
4	0.13	0.71	0.72	0.72	0.74	0.75	0.77	0.79
5	0.10	0.27	0.76	0.76	0.77	0.79	0.80	0.82
6	0.08	0.21	0.79	0.80	0.80	0.81	0.83	0.84
7	0.07	0.16	0.34	0.82	0.83	0.84	0.85	0.87
8	0.06	0.14	0.26	0.84	0.85	0.86	0.87	0.88
9	0.05	0.11	0.21	0.38	0.87	0.88	0.89	0.90
10	0.04	0.10	0.18	0.30	0.89	0.89	0.9	0.91
11	0.04	0.08	0.15	0.25	0.42	0.91	0.91	0.92
12	0.03	0.07	0.13	0.21	0.34	0.92	0.92	0.93
13	0.03	0.06	0.11	0.18	0.28	0.45	0.93	0.94
14	0.02	0.06	0.10	0.15	0.23	0.36	0.94	0.95
15	0.02	0.05	0.08	0.13	0.20	0.30	0.47	0.95
16	0.02	0.04	0.07	0.12	0.17	0.25	0.38	0.96
17	0.02	0.04	0.06	0.10	0.15	0.21	0.31	0.49
18	0.01	0.03	0.06	0.09	0.13	0.19	0.26	0.39

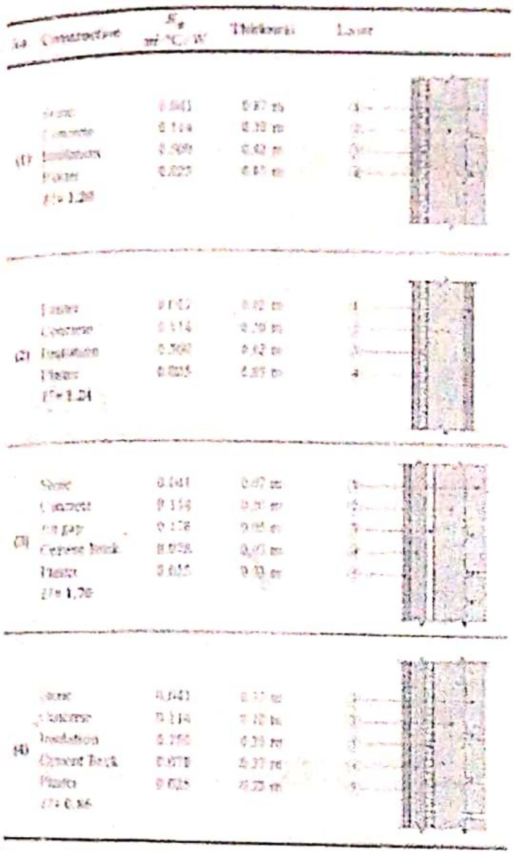
Table A-12 Cooling load factors for lighting

Application	Diversity Factor	
	Lights	People
Peripheral areas of offices with glazing area of 20%-50%	0.70-0.85	0.7-0.8
Core areas of offices and peripheral areas with less than 20% glazing	0.90-1.00	0.7-0.8
Apartments and hotel bedrooms	0.30-0.50	0.4-0.6
Public rooms in hotels	0.90-1.00	0.4-0.6
Department stores and supermarkets	0.90-1.00	0.8-1.0

Table A-13 Cooling load factors for lighting

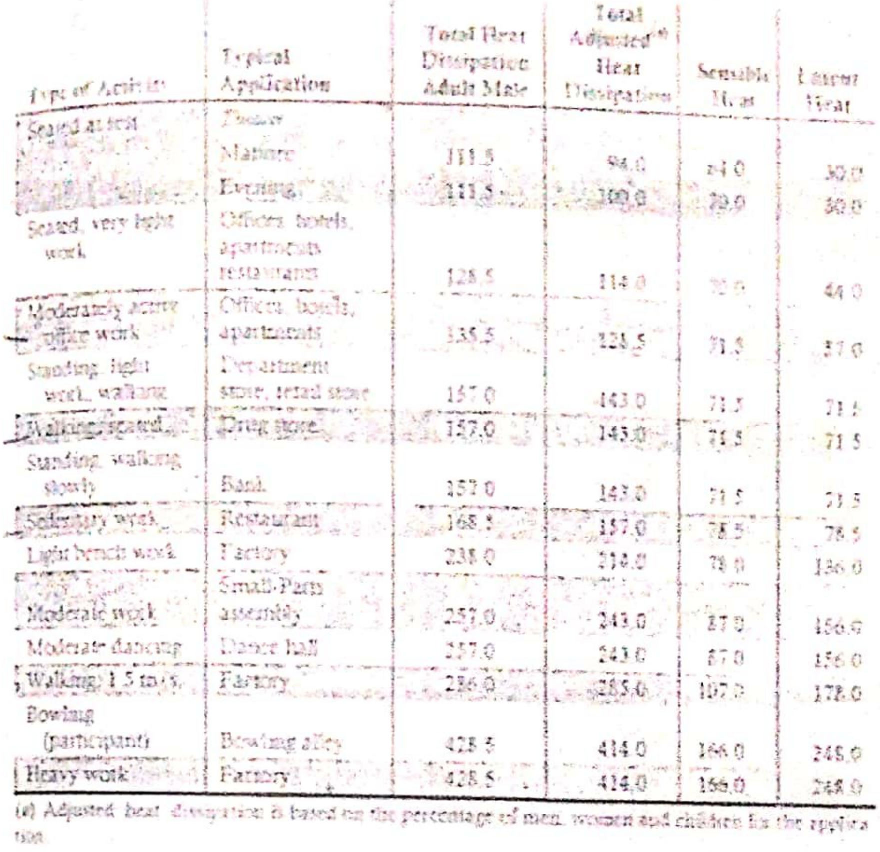
Appliance	Without Hood		
	Sensible	Latent	Total
Hair dryers (Blower type)	675	120	795
Hair dryers (Helmet type)	550	100	650
Coffee brewer (electrical)	225	65	290
Coffee brewer (gas)	490	210	700
Water heater	1,130	335	1,465
Coffee urn (electrical)	1,075	350	1,425
Coffee urn (gas)	1,460	625	2,085
Deep fat fryer (electrical)	820	1,930	2,750
Deep fat fryer (gas)	2,080	2,080	4,160
Toaster	1,055	705	1,760
Domestic gas oven	2,430	1200	3,630
Roasting oven	500	320	820
Food warmer (gas)	1,550	400	1,950
Egg boiler	335	220	555
Frying griddle	13,600	7,200	20,800
Hotplate	1,550	1,060	2,610
Neon sign, per meter length	56	—	56
Sterilizer	190	350	640
Laboratory burner	470	120	690
Small copy machine	1,760	—	1,760
Large copy machine	3,515	—	3,515
Motors			
400-2,000 W	1,100	—	1,100
2,000-15,000 W	2,430	—	880

Table A-14 Overall heat transfer coefficients for typical wall constructions, W/m².°C for Rc = 0.03 m².°C/W



No.	Construction	R_e m².°C/W	Thickness	Layer
(1)	Stone	0.041	0.07 m	1
	Concrete	0.114	0.20 m	2
	Insulation	0.500	0.02 m	3
	Plaster	0.025	0.02 m	4
	U = 1.20			
(2)	Plaster	[illegible]	0.02 m	1
	Concrete	0.114	0.20 m	2
	Insulation	0.500	0.02 m	3
	Plaster	0.025	0.02 m	4
	U = 1.24			
(3)	Stone	0.041	0.07 m	1
	Concrete	0.114	0.20 m	2
	Air gap	0.178	0.05 m	3
	Cement brick	0.078	0.10 m	4
	Plaster	0.025	0.02 m	5
	U = 1.70			
(4)	Stone	0.041	0.07 m	1
	Concrete	0.114	[illegible]	2
	Insulation	0.750	0.03 m	3
	Cement Brick	0.078	[illegible]	4
	Plaster	0.025	0.02 m	5
	U = 0.86			

Table A-15 Heat gain from occupants in watt person

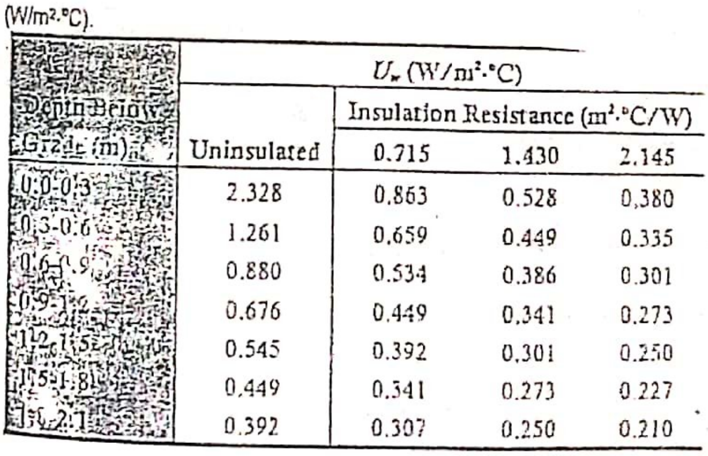


Type of Activity	Typical Application	Total Heat Dissipation Adult Male	Total Adjusted[a] Heat Dissipation	Sensible Heat	Latent Heat
Seated at rest	Theater Matinee	111.5	94.0	64.0	30.0
	Evening	111.5	100.0	70.0	30.0
Seated, very light work	Offices, hotels, apartments restaurants	128.5	114.0	70.0	44.0
Moderately active office work	Offices, hotels, apartments	135.5	128.5	71.5	57.0
Standing, light work, walking	Department store, retail store	157.0	143.0	71.5	71.5
Walking, seated	Drug store	157.0	143.0	71.5	71.5
Standing, walking slowly	Bank	157.0	143.0	71.5	71.5
Sedentary work	Restaurant	168.5	157.0	78.5	78.5
Light bench work	Factory	238.0	214.0	78.0	136.0
Moderate work	Small-Parts assembly	257.0	243.0	87.0	156.0
Moderate dancing	Dance hall	257.0	243.0	87.0	156.0
Walking, 1.5 m/s	Factory	286.0	285.0	107.0	178.0
Bowling (participant)	Bowling alley	428.5	414.0	166.0	248.0
Heavy work	Factory	428.5	414.0	166.0	248.0

(a) Adjusted heat dissipation is based on the percentage of men, women and children for the application.

Table A-16 Overallheat transfer coefficients Uw. for basement walls below grade (W/m².°C).

(W/m².°C).



	U_w (W/m².°C)			
		Insulation Resistance (m².°C/W)		
Depth Below Grade (m)	Uninsulated	0.715	1.430	2.145
0.0-0.3	2.328	0.863	0.528	0.380
0.3-0.6	1.261	0.659	0.449	0.335
0.6-0.9	0.880	0.534	0.386	0.301
0.9-1.2	0.676	0.449	0.341	0.273
1.2-1.5	0.545	0.392	0.301	0.250
1.5-1.8	0.449	0.341	0.273	0.227
1.8-2.1	0.392	0.307	0.250	0.210

Table A-17 Overallheat transfer coefficients for typical ceilling constructions. W/m².°C. for R_0 = 0.03 m².°C/W

·°C/W.

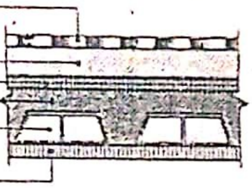
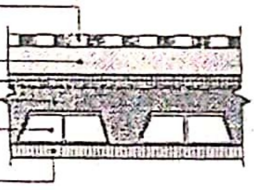
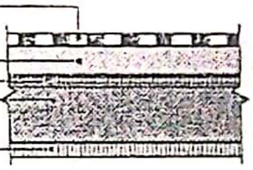
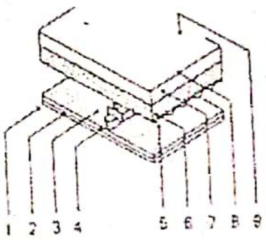
Construction	R_{th} m²·°C/W	Thickness	Layer	
Asphalt Mix	0.028	0.02 m	①	
Concrete	0.029	0.05 m	②	
Insulation	0.750	0.03 m	③	
Reinforced Concrete	0.034	0.03 m	④	
Cement Block	0.147	0.14 m	⑤	
Plaster	0.017	0.02 m	⑥	
U = 0.88				
Asphalt Mix	0.028	0.02 m	①	
Concrete	0.029	0.05 m	②	
Insulation	0.500	0.02 m	③	
Reinforced Concrete	0.034	0.06 m	④	
Cement Block	0.189	0.18 m	⑤	
Plaster	0.017	0.02 m	⑥	
U = 1.08				
Asphalt Mix	0.028	0.02 m	①	
Concrete	0.029	0.05 m	②	
(3) Insulation	0.750	0.03 m	③	
Reinforced Concrete	0.057	0.10 m	④	
Plaster	0.017	0.02 m	⑤	
U = 1.00				
Inside Surface	0.110	—	①	
Metal Lath	0.083	0.02 m	②	
4) Air Gap	0.164	0.10 m	③	
Metal Ceiling Suspension	—	—	④	
Corrugated Metal Deck	—	—	⑤	
Concrete Slab	0.029	0.05 m	⑥	
Insulation	0.500	0.02 m	⑦	
built-up roofing	0.058	0.01 m	⑧	
Outside Surface	0.030	—	⑨	
U = 1.03				

Table A-18 Air change per hours in residences and commerical application

able 4-6 Air change per hour

Kind of Room or Building	Air Changes pe Hour
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side only	1.0
Rooms tithe windows or exterior doors on two sides	1.5
Rooms with windows or exteriors doors on three sides	2.0
Entrance halls	2.0
Factories, machine shops	1.0-1.5
Recreation rooms, assembly rooms, gymnasium	1.5
Homes, apartments, offices	1.0-2.0
Classrooms, dining rooms, lounges, toilets, hospital rooms, kitchens, laundries, ballrooms, bathrooms	2.0
Stores, public buildings	2.0-3.0
Toilets, auditorium	3.0

Table A-19 Overallheat transfer coefficients for wood and steel doors. W/m².°C.

Door Type	Without Storm Door	With Wood Storm Door	With Metal Storm Door
25 mm-wood	3.6	1.7	2.2
35 mm-wood	3.1	1.6	1.9
40 mm-wood	2.8	1.5	1.8
45 mm-wood	2.7	1.5	1.8
50 mm-wood	2.4	1.4	1.7
Aluminum	7.0	—	—
Steel	5.8	—	—
Steel with:			
Fiber core	3.3	—	—
Polystyrene core	2.7	—	—
Polyurethane core	2.3	—	—

Table A-20 Recommended and maximum air velocities for warm and cool air systems.

	Recommended Velocity (m/s)			Maximum Velocity (m/s)		
Description	Residence Buildings	Public Buildings	Industrial Buildings	Residence Buildings	Public Buildings	Industrial Buildings
Outside air intake	2.5	2.5	2.5	4.0	4.5	6.0
Heating coils	2.3	2.5	2.8	2.5	2.8	3.8
Cooling coils	2.3	2.5	3.0	2.5	3.6	[illegible]
Fan suction	3.5	4.0	5.0	[illegible]	[illegible]	[illegible]
Fan outlets	5.0-8.0	6.5-10.0	8.0-12.0	[illegible]	[illegible]	[illegible]
Main ducts	3.5-4.5	5.0-6.5	6.0-9.0	4.0-5.0	5.5-8.0	[illegible]
Branch ducts	3.0	3.0-4.5	4.0-5.0	3.5-5.0	4.0-6.5	5.0-9.0
Branch riser	2.5	3.0-3.5	4.0	3.5-4.0	4.0-6.0	5.0-8.0

Table A-21 Circular equivalents of rectangular ducts for equal friction and capacity.

Lgth Adj.	Length of One Side of Rectangular Duct , mm																			
	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800	900
100	109																			
150	133	150	164																	
200	152	172	189	204	219															
250	169	190	210	228	244	259	273													
300	183	207	229	248	266	283	299	314	328											
400	207	235	260	283	305	325	343	361	378	409	437									
500	227	258	287	313	337	360	381	401	420	455	488	518	547							
600	245	279	310	339	365	390	414	436	457	496	533	567	598	628	656					
700	261	298	331	362	391	418	443	467	490	533	573	610	644	677	708	737	765			
800	275	314	350	383	414	442	470	496	520	567	609	645	687	722	755	787	818	847	875	
900	289	330	367	402	435	465	494	522	548	597	643	686	726	763	799	833	866	897	927	984
1000	301	344	384	420	454	486	517	546	574	626	674	719	762	802	840	876	911	944	976	1037
1200	324	370	413	457	490	525	558	590	620	677	731	780	827	872	914	954	993	1030	1066	1133
1400	344	394	439	482	522	559	595	629	662	724	781	835	886	934	980	1024	1066	1107	1146	1220
1600	362	415	463	508	551	591	629	665	700	766	827	885	939	991	1041	1088	1133	1177	1219	1298
1800	379	434	485	533	577	619	660	698	735	804	869	930	988	1043	1096	1146	1195	1241	1286	1371
2000	395	453	506	555	602	646	688	728	767	840	908	973	1034	1092	1147	1200	1252	1301	1348	1438
2200	410	470	525	577	625	671	715	757	797	874	945	1013	1076	1137	1193	1251	1305	1354	1406	1501
2400	424	486	543	597	647	695	740	784	826	903	980	1030	1116	1180	1241	1299	1355	1409	1461	1561
2600	437	501	560	616	668	717	764	810	853	935	1012	1085	1154	1220	1283	1344	1402	1459	1513	1617
2800	450	516	577	634	688	738	787	834	879	964	1043	1119	1190	1259	1324	1387	1447	1506	1562	1670

Lgth. Adj.[b]	Length of One Side of Rectangular Duct (a), mm																			
	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
1000	1093																			
1100	1146	1202																		
1200	1196	1256	1312																	
1300	1244	1306	1365	1421																
1400	1289	1354	1416	1475	1330															
1500	1332	1400	1464	1326	1584	1640														
1600	1373	1444	1511	1574	1635	1693	1749													
1700	1413	1486	1555	1621	1684	1745	1803	1858												
1800	1451	1527	1598	1667	1732	1794	1854	1912	1968											
1900	1488	1566	1640	1710	1778	1842	1904	1964	2021	2077										
2000	1523	1604	1680	1753	1822	1885	1952	2014	2073	2131	2186									
2100	1558	1640	1719	1793	1865	1933	1999	2063	2124	2183	2240	2296								
2200	1591	1676	1756	1833	1906	1977	2044	2110	2173	2233	2292	2350	2405							
2300	1623	1710	1793	1871	1947	2019	2088	2155	2220	2283	2343	2402	2459	2514						
2400	1655	1744	1828	1909	1986	2060	2131	2200	2266	2330	2393	2453	2511	2568	2624					
2500	1685	1776	1862	1945	2024	2100	2173	2243	2311	2377	2441	2503	2562	2621	2678	2733				
2600	1715	1808	1896	1980	2061	2139	2213	2285	2355	2422	2487	2551	2612	2672	2730	2757	2842			
2700	1744	1839	1929	2015	2097	2177	2253	2327	2398	2466	2533	2598	2661	2722	2782	2840	2896	2952		
2800	1772	1869	1961	2048	2133	2214	2292	2367	2439	2310	2578	2644	2708	2771	2832	2891	2949	3006	3061	
2900	1800	1898	1992	2081	2167	2250	2329	2406	2480	2552	2621	2689	2755	2819	2851	2941	3001	3058	3115	3170

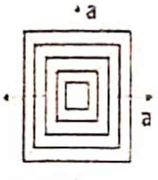
Table based on $D_e = 1.30(ab)^{0.625}/(a + b)^{0.25}$.

[b] Length of adjacent side of rectangular duct , mm.

Table A-22 Equivalent length Le. of various fittings.

Fitting	L_e (m)
45° Round elbow	1.5
90° Four pieces elbow	3.0
Gradual reduction	6.0
45° Round Tee	
Main run	1.5
Branch	11.0
90° Round Tee	
Main run	1.5
Branch	15.0
90° Rectangular elbow	5.0
Abrupt round contraction or expansion	11.0

Table A-23 Model 4SCD four-way throw square diffuser.



NECKSIZE AK	Neck VELOCIY FPM	200	300	400	500	600	700	800	900
	TOTAL PRESSURE	.019	.039	.067	.10	.14	.19	.24	.30
6"x6"	TOTAL CFM	50	75	100	125	150	175	200	225
	CFM each side – a	13	19	25	32	38	44	50	57
AK= 0.13	Throw each side – a	2-3	3-5	4-7	5-9	6-11	7-13	8-15	9-17
9"x9"	TOTAL CFM	112	168	224	280	336	392	448	504
	CFM each side – a	28	42	56	70	84	98	112	126
AK= 0.28	Throw each side – a	2-3	3-5	4-8	5-10	6-12	7-14	9-17	9-18
12"x12"	TOTAL CFM	200	300	400	500	600	700	800	900
	CFM each side – a	50	75	100	125	150	175	200	225
AK= 0.5	Throw each side – a	2-4	4-7	5-9	6-11	7-14	8-16	10-19	11-21
15"x15"	TOTAL CFM	312	468	624	780	936	1092	1248	1404
	CFM each side – a	78	117	156	159	235	273	312	351
AK= 0.79	Throw each side – a	3-5	4-8	5-10	7-13	8-16	10-19	11	12-24
18"x18"	TOTAL CFM	450	675	900	1125	1350	1575	1800	2025
	CFM each side – a	113	169	225	281	338	394	450	507
AK= 0.13	Throw each side – a	3-5	4-8	5-10	7-13	9-17	10-20	12-24	13-26
21"x21"	TOTAL CFM	612	918	1224	1530	1836	2142	2448	275
	CFM each side – a	153	229	306	382	459	535	612	689
AK= 1.54	Throw each side – a	3-5	4-8	6-11	7-13	9-18	11-21	13-25	14-28
24"x24"	TOTAL CFM	800	1200	1600	2000	2400	2800	3200	3600
	CFM each side – a	200	300	400	500	600	700	800	900
AK= 2	Throw each side – a	3-6	5-9	6-12	7-14	10-19	11-22	13-26	15-30

Table A-24 Model 4RCD way throw rectangular diffuser.

NECKSIZE AK	Neck VELOCITY FPM	200	300	400	500	600	700	800	900
	TOTAL PRESSURE	.019	.039	.067	.10	.14	.19	.24	.30
6"x9"	TOTAL CFM	75	113	150	190	225	260	300	338
	CFM each side – a	25	38	50	65	75	85	100	113
AK= 0.19	CFM each side – b	13	19	25	30	38	45	50	56
	Throw each side – a	2-4	3-6	4-8	5-10	6-11	7-13	8-15	9-17
	Throw each side – b	1-2	2-3	2-4	2-5	3-6	4-7	4-8	5-9
6"x12"	TOTAL CFM	100	150	200	250	300	350	400	450
	CFM each side – a	37	56	75	93	112	131	150	169
AK= 0.25	CFM each side – b	13	19	25	32	38	44	50	56
	Throw each side – a	2-4	4-7	5-9	6-11	7-13	8-15	9-17	10-19
	Throw each side – b	2-3	2-3	2-4	3-5	3-6	4-7	4-8	5-9
6"x15"	TOTAL CFM	125	188	250	312	375	438	500	563
	CFM each side – a	50	75	102	124	150	175	200	226
AK= 0.32	CFM each side – b	13	19	25	32	38	44	50	56
	Throw each side – a	3-5	4-7	5-9	6-11	7-13	8-15	9-18	10-20
	Throw each side – b	1-2	2-3	2-4	3-5	3-5	3-6	4-7	4-8
6"x18"	TOTAL CFM	150	225	300	375	450	525	600	675
	CFM each side – a	62	94	125	156	188	218	250	280
AK= 0.38	CFM each side – b	13	19	25	32	38	44	50	58
	Throw each side – a	3-5	4-7	5-9	6-12	7-14	8-16	9-18	11-21
	Throw each side – b	1-2	2-3	2-4	2-4	3-5	3-6	4-7	4-8
6"x21"	TOTAL CFM	175	263	350	438	525	612	700	788
	CFM each side – a	75	112	150	187	224	262	300	335
AK= 0.44	CFM each side – b	13	19	25	33	38	44	50	59
	Throw each side – a	3-5	4-7	5-10	6-12	7-14	9-17	10-19	11-21
	Throw each side – b	1-2	2-3	2-3	2-4	3-5	3-6	3-6	4-7
6"x24"	TOTAL CFM	200	300	400	500	600	700	800	900
	CFM each side – a	87	131	174	218	261	305	348	392
AK= 0.5	CFM each side – b	13	19	26	32	39	45	52	58
	Throw each side – a	3-5	4-8	5-10	6-12	8-15	9-17	10-19	11-22
	Throw each side – b	1-2	2-3	2-3	2-4	3-5	3-5	3-6	4-7
9"x12"	TOTAL CFM	150	225	300	375	450	525	600	675
	CFM each side – a	47	70	94	118	141	165	118	209
AK= 0.38	CFM each side – b	28	42	56	70	84	98	112	129
	Throw each side – a	2-4	3-6	5-9	6-11	7-13	8-15	9-17	9-18
	Throw each side – b	2-3	3-5	4-8	5-9	6-11	6-12	7-14	8-16
9"x15"	TOTAL CFM	188	282	375	470	563	657	750	844
	CFM each side – a	66	99	132	165	198	230	263	295
AK= 0.47	CFM each side – b	28	42	56	70	84	99	112	27
	Throw each side – a	3-5	4-7	5-10	6-12	7-14	8-16	10-19	11-21
	Throw each side – b	2-4	3-6	4-8	5-9	6-11	7-13	8-15	9-17
9"x18"	TOTAL CFM	225	338	450	562	675	788	900	1013
	CFM each side – a	85	127	169	211	234	296	338	380
AK= 0.57	CFM each side – b	28	42	56	70	84	98	112	127
	Throw each side – a	3-5	4-8	5-10	6-12	7-14	9-17	10-20	11-22
	Throw each side – b	2-4	3-6	4-7	5-9	6-11	7-13	7-14	8-16

MODEL 4RCD CONT.

NECKSIZE AK	Neck VELOCITY FPM	200	300	400	500	600	700	800	900
	TOTAL PRESSURE	.019	.039	.067	.10	.14	.19	.24	.30
9"x21"	TOTAL CFM	262	393	524	655	786	917	1050	1179
AK= 0.66	CFM each side – a	104	155	200	258	309	360	413	466
	CFM each side – b	27	42	56	70	84	98	112	124
	Throw each side – a	3-5	4-8	5-10	7-13	8-16	9-18	10-20	12-23
	Throw each side – b	2-4	3-5	4-7	5-9	4-11	7-13	7-14	8-16
9"x24"	TOTAL CFM	300	450	600	750	900	1050	1200	1350
AK= 0.76	CFM each side – a	125	187	249	311	374	436	498	560
	CFM each side – b	25	38	51	64	76	89	102	115
	Throw each side – a	3-5	4-8	6-11	7-13	8-16	10-19	11-21	12-24
	Throw each side – b	2-3	3-5	4-7	4-8	5-10	6-11	7-13	7-14
12"x15"	TOTAL CFM	250	375	500	625	750	875	1000	1125
AK= 0.63	CFM each side – a	75	113	150	188	225	263	300	338
	CFM each side – b	50	75	100	125	150	175	200	225
	Throw each side – a	3-5	4-8	5-10	7-13	8-15	9-17	10-20	11-22
	Throw each side – b	2-4	4-7	5-9	6-11	7-13	8-15	9-17	10-19
12"x18"	TOTAL CFM	300	450	600	750	900	1050	1200	1350
AK= 0.76	CFM each side – a	100	150	200	250	300	350	400	452
	CFM each side – b	50	75	100	125	150	175	200	223
	Throw each side – a	3-6	4-8	6-11	7-14	5-16	10-19	11-22	13-25
	Throw each side – b	3-5	4-7	5-9	6-11	7-13	8-15	9-18	10-20
12"x21"	TOTAL CFM	350	525	700	875	1050	1225	1400	1575
AK= 0.88	CFM each side – a	124	188	250	313	375	438	500	559
	CFM each side – b	51	75	100	125	150	175	200	229
	Throw each side – a	3-6	5-9	6-12	8-15	9-18	11-21	12-24	13-26
	Throw each side – b	3-5	4-7	5-9	6-11	7-13	8-16	9-18	10-20
12"x24"	TOTAL CFM	400	600	800	1000	1200	1400	1600	1800
AK= 1.0	CFM each side – a	150	225	300	375	450	525	600	675
	CFM each side – b	50	75	100	125	150	175	200	225
	Throw each side – a	4-7	5-10	7-13	8-16	10-19	11-22	13-25	14-28
	Throw each side – b	3-5	4-7	5-9	6-11	7-13	8-16	9-18	10-20
15"x18"	TOTAL CFM	375	563	750	938	1125	1313	1500	1688
AK= 0.95	CFM each side – a	111	165	219	274	329	384	438	498
	CFM each side – b	77	117	156	195	234	273	312	346
	Throw each side – a	3-6	4-8	6-11	7-14	8-16	10-19	11-22	13-25
	Throw each side – b	3-5	4-7	5-10	7-13	8-15	9-17	10-20	11-22
15"x21"	TOTAL CFM	438	657	876	1095	1313	1533	1750	1969
AK= 1.1	CFM each side – a	140	211	282	353	422	494	563	630
	CFM each side – b	79	118	156	195	235	273	312	355
	Throw each side – a	3-6	5-9	6-12	8-15	9-18	11-21	12-24	14-27
	Throw each side – b	3-5	4-8	5-10	7-13	8-15	9-18	10-20	12-23
15"x24"	TOTAL CFM	500	750	1000	1250	1500	1750	2000	2250
AK= 1.26	CFM each side – a	173	259	345	431	518	604	690	776
	CFM each side – b	77	116	155	194	232	271	310	349
	Throw each side – a	4-7	5-10	7-13	8-16	10-19	11-22	13-26	15-29
	Throw each side – b	3-5	4-8	5-10	7-13	8-15	9-18	10-20	12-23
18"x21"	TOTAL CFM	525	786	1048	1310	1572	1834	2096	2363
AK= 1.32	CFM each side – a	150	224	299	374	448	523	598	674
	CFM each side – b	113	169	225	281	338	394	450	508
	Throw each side – a	3-6	4-8	6-11	7-13	8-16	10-19	11-21	12-24
	Throw each side – b	3-5	4-7	5-10	6-12	7-14	9-17	10-19	11-21
18"x24"	TOTAL CFM	600	900	1200	1500	1800	2100	2400	2700
AK= 1.5	CFM each side – a	183	275	366	458	549	641	732	824
	CFM each side – b	117	175	234	292	351	409	468	526
	Throw each side – a	3-6	5-9	6-12	8-15	9-17	10-20	12-23	13-26
	Throw each side – b	3-5	4-8	5-10	7-13	8-16	9-18	10-20	12-23

Table A-25 Return Air Grille.

Face velocity*		300	400	500	600	700
6 x 4	CFM	33	44	55	66	77
Ak 0.111	Ps	0.010	0.018	0.029	0.041	0.056
6 x 6	CFM	50	67	83	100	117
Ak 0.167	Ps	0.010	0.018	0.029	0.041	0.056
8 x 4	CFM	44	59	74	89	104
Ak 0.148	Ps	0.010	0.018	0.029	0.041	0.056
8 x 6	CFM	67	89	112	134	156
Ak 0.223	Ps	0.010	0.018	0.029	0.041	0.056
8 x 8	CFM	90	120	150	179	209
Ak 0.299	Ps	0.010	0.018	0.029	0.041	0.056
10 x 4	CFM	56	74	93	111	130
Ak 0.186	Ps	0.010	0.018	0.029	0.041	0.056
10 x 6	CFM	84	112	140	168	196
Ak 0.28	Ps	0.010	0.018	0.029	0.041	0.056
10 x 8	CFM	112	150	187	225	262
Ak 0.375	Ps	0.010	0.018	0.029	0.041	0.056
10 x 10	CFM	141	188	235	282	329
Ak 0.47	Ps	0.010	0.018	0.029	0.041	0.056
12 x 6	CFM	101	135	168	202	236
Ak 0.337	Ps	0.010	0.018	0.029	0.041	0.056
12 x 8	CFM	135	180	226	271	316
Ak 0.451	Ps	0.010	0.018	0.029	0.041	0.056
12 x 10	CFM	170	226	283	339	396
Ak 0.566	Ps	0.010	0.018	0.029	0.041	0.056
12 x 12	CFM	204	272	340	408	476
Ak 0.681	Ps	0.010	0.018	0.029	0.041	0.056
12 x 18	CFM	308	411	513	616	719
Ak 1.027	Ps	0.010	0.018	0.029	0.041	0.056
14 x 6	CFM	118	158	197	236	276
Ak 0.394	Ps	0.010	0.018	0.029	0.041	0.056
14 x 8	CFM	158	211	264	316	369
Ak 0.527	Ps	0.010	0.018	0.029	0.041	0.056
14 x 10	CFM	198	265	331	397	463
Ak 0.661	Ps	0.010	0.018	0.029	0.041	0.056
14 x 12	CFM	239	318	398	477	557
Ak 0.796	Ps	0.010	0.018	0.029	0.041	0.056
14 x 14	CFM	279	372	465	558	651
Ak 0.93	Ps	0.010	0.018	0.029	0.041	0.056
14 x 18	CFM	360	480	600	720	840
Ak 1.2	Ps	0.010	0.018	0.029	0.041	0.056

Face velocity *		300	400	500	600	700
16 x 6	CFM	135	180	226	271	316
Ak 0.451	Ps	0.010	0.018	0.029	0.041	0.056
16 x 8	CFM	181	242	302	362	423
Ak 0.604	Ps	0.010	0.018	0.029	0.041	0.056
16 x 10	CFM	227	303	379	454	530
Ak 0.757	Ps	0.010	0.018	0.029	0.041	0.056
16 x 12	CFM	273	364	455	547	638
Ak 0.911	Ps	0.010	0.018	0.029	0.041	0.056
16 x 14	CFM	320	426	533	639	746
Ak 1.065	Ps	0.010	0.018	0.029	0.041	0.056
16 x 16	CFM	366	488	610	732	854
Ak 1.219	Ps	0.010	0.018	0.029	0.041	0.056
16 x 24	CFM	552	736	920	1104	1288
Ak 1.84	Ps	0.010	0.018	0.029	0.041	0.057
18 x 6	CFM	153	203	254	305	356
Ak 0.508	Ps	0.010	0.018	0.029	0.041	0.056
18 x 18	CFM	465	619	774	929	1084
Ak 1.548	Ps	0.010	0.018	0.029	0.041	0.057
20 x 6	CFM	170	226	283	339	396
Ak 0.566	Ps	0.010	0.018	0.029	0.041	0.056
20 x 10	CFM	285	380	475	570	665
Ak 0.949	Ps	0.010	0.018	0.029	0.041	0.056
20 x 12	CFM	343	457	571	685	800
Ak 1.142	Ps	0.010	0.018	0.029	0.041	0.056
20 x 14	CFM	401	534	668	801	935
Ak 1.335	Ps	0.010	0.018	0.029	0.041	0.056
20 x 20	CFM	575	767	959	1150	1342
Ak 1.917	Ps	0.010	0.018	0.029	0.041	0.057
20 x 24	CFM	692	923	1153	1384	1615
Ak 2.307	Ps	0.010	0.019	0.029	0.042	0.057
20 x 25	CFM	721	962	1202	1442	1683
Ak 2.404	Ps	0.010	0.019	0.029	0.042	0.057

Face velocity *		300	400	500	600	700
24 x 4	CFM	135	180	226	271	316
Ak 0.451	Ps	0.010	0.018	0.029	0.041	0.056
24 x 6	CFM	204	272	340	408	476
Ak 0.681	Ps	0.010	0.018	0.029	0.041	0.056
24 x 8	CFM	273	364	455	547	638
Ak 0.911	Ps	0.010	0.018	0.029	0.041	0.056
24 x 10	CFM	343	457	571	685	800
Ak 1.142	Ps	0.010	0.018	0.029	0.041	0.056
24 x 12	CFM	412	550	687	825	962
Ak 1.374	Ps	0.010	0.018	0.029	0.041	0.056
24 x 14	CFM	482	643	803	964	1125
Ak 1.607	Ps	0.010	0.018	0.029	0.041	0.057
24 x 22	CFM	762	1016	1270	1524	1778
Ak 2.541	Ps	0.010	0.019	0.029	0.042	0.057
24 x 24	CFM	832	1110	1387	1665	1942
Ak 2.775	Ps	0.010	0.019	0.029	0.042	0.057
30 x 4	CFM	170	226	283	339	396
Ak 0.566	Ps	0.010	0.018	0.029	0.041	0.056
30 x 6	CFM	256	341	427	512	597
Ak 0.853	Ps	0.010	0.018	0.029	0.041	0.056
30 x 8	CFM	343	457	571	685	800
Ak 1.142	Ps	0.010	0.018	0.029	0.041	0.056
30 x 10	CFM	430	573	716	859	1003
Ak 1.432	Ps	0.010	0.018	0.029	0.041	0.056
30 x 12	CFM	517	689	862	1034	1206
Ak 1.723	Ps	0.010	0.018	0.029	0.041	0.057
30 x 14	CFM	604	806	1007	1209	1410
Ak 2.015	Ps	0.010	0.018	0.029	0.042	0.057
30 x 18	CFM	780	1040	1300	1560	1819
Ak 2.599	Ps	0.010	0.019	0.029	0.042	0.057
30 x 20	CFM	868	1157	1446	1735	2025
Ak 2.892	Ps	0.010	0.019	0.029	0.042	0.057
30 x 24	CFM	1044	1392	1740	2088	2436
Ak 3.479	Ps	0.010	0.019	0.029	0.042	0.057
30 x 30	CFM	1309	1745	2181	2618	3054
Ak 4.363	Ps	0.010	0.019	0.029	0.042	0.057
36 x 8	CFM	308	411	513	616	719
Ak 1.027	Ps	0.010	0.018	0.029	0.041	0.056
36 x 8	CFM	412	550	687	825	962
Ak 1.374	Ps	0.010	0.018	0.029	0.041	0.056

Table A-26 Air Handling Unit.

Inlet Water Temp. 45°F - Coils are of 10 Fins/Inch

Model	On Coil		AFR	3 Rows				4 Rows				6 Rows				8 Rows			
	DB	WB	CFM	Tot. CAP MBH	Sen. CAP MBH	WFR GPM	WPD FT	Tot. CAP MBH	Sen. CAP MBH	WFR GPM	WPD FT	Tot. CAP MBH	Sen. CAP MBH	WFR GPM	WPD FT	Tot. CAP MBH	Sen. CAP MBH	WFR GPM	WPD FT
[illegible]	76	63	5400	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	76	63	6000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	76	63	6600	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	76	63	6750	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	76	63	7500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	76	63	8250	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	76	63	9000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	76	63	10000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	76	63	11000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	78	65		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	80	67		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	85	70		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Note:

AFR: Air Flow Rate (CFM)

Tot. CAP: Total Capacity (MBH)

WPD: Water Pressure Drop (feet of water)

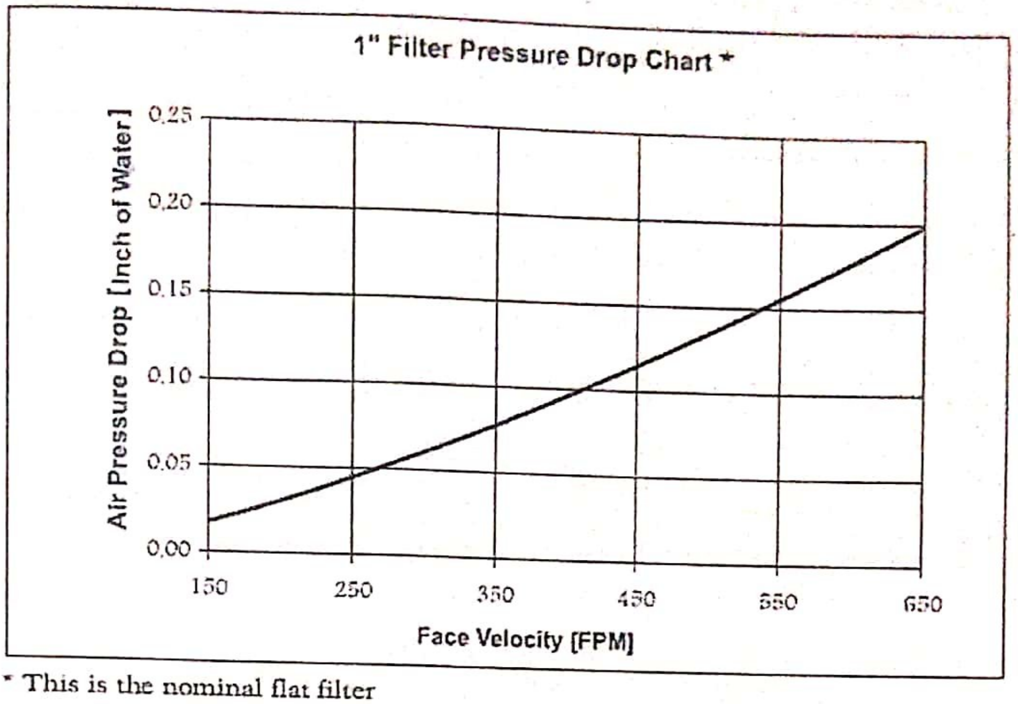
Sen. CAP: Sensible Cooling Capacity (MBH)

WFR: Water Flow Rate (U. S. Gallons per minute)

For other conditions, please refer to the nearest PETRA Sales Office.

Figure A-27 CM unit filters pressure drop chart.

The filter area is the same as the coil area



* This is the nominal flat filter

Table A-28 CM unit pressure drop table.

Face Velocity	Coil Status	No. of Rows	No. of Fins Per Inch				
			8	10	12	14	16
450	Dry	3	0.110	0.134	0.156	0.155	0.156
		4	0.147	0.169	0.210	0.209	0.216
		6	0.211	0.256	0.301	0.300	0.330
		8	0.282	0.340	0.389	0.400	0.403
	Wet	3	0.131	0.156	0.180	0.207	0.231
		4	0.176	0.209	0.242	0.276	0.310
		6	0.252	0.301	0.349	0.392	0.445
		8	0.336	0.400	0.465	0.529	0.593
500	Dry	3	0.130	0.160	0.187	0.186	0.186
		4	0.175	0.202	0.249	0.249	0.257
		6	0.254	0.307	0.362	0.362	0.397
		8	0.338	0.408	0.467	0.480	0.483
	Wet	3	0.156	0.186	0.216	0.247	0.276
		4	0.210	0.249	0.289	0.330	0.369
		6	0.303	0.362	0.419	0.472	0.536
		8	0.403	0.481	0.558	0.635	0.712
650	Dry	3	0.154	0.188	0.220	0.218	0.219
		4	0.206	0.237	0.293	0.293	0.302
		6	0.300	0.363	0.428	0.428	0.469
		8	0.399	0.482	0.551	0.566	0.570
	Wet	3	0.184	0.219	0.253	0.290	0.325
		4	0.246	0.292	0.339	0.387	0.431
		6	0.358	0.427	0.495	0.558	0.633
		8	0.475	0.567	0.658	0.749	0.840

Table A-29 Outdoor unit-RWC General data.

RWC Model		210	260	310	350	390	430	470	530	580	630
Cooling capacity [kW]*		55.6	63.2	84.3	92.8	99.8	113.7	123.2	129.4	142	166.8
Heating capacity [kW]*		50.4	64.2	70.8	77.6	83.4	102.7	112.5	121.5	119.8	151.9
Power supply**		3PH 50Hz									
Compressor		Hermetically sealed scroll									
No.of compressors		2			3		4	3	4		
Cooler		Shell and tube									
No of coolers		1									
Refrigerant		R-22									
Control		Expansion valve									
Refrigeration circuits		2			3		4	3	4		
Water connection size [inch]		2"	2 1/2"		3"						
Condenser		Copper tubes, Aluminum fins									
Fins per meter		472									
Rows		4									
Face area [m²]		2.2	2.4	2.9	3.8	3.8	3.8	3.9	5.4	5.4	5.6
Condenser fan		Propeller									
No of fans		4	2								
Air flow rate [L/S]		5105	11927	12384	13704	13704	13654	13704	14505	14505	20344
Dimensions (mm)											
Length(L)		2286	2286	2286	2286	2286	2286	2286	2921	2921	2921
Width(W)		1397	1397	1397	1397	1397	1524	1397	1473	1473	1727
Height(H)		1626	1727	1803	1727	1727	1524	1727	1499	1499	1524
Operation weight (Approximately)	**[kg]**	695	772	827	1015	1015	1091	1109	1389	1389	1547
Sound pressure level [dBA]***	**At 3 m**	49	47	47	48	48	47	47	47	48	48
	At 10 m	47	45	45	46	46	45	45	46	47	47

NOTES

* Cooling data are based on Water IN/OUT : 12.8 / 7.2 °C / °C and 35°C ambient
* Heating data are based on Water IN/OUT: 29.4 / 35 °C / °C and 7.2°C ambient
** For power supply voltage refer to electrical data table
*** Sound Pressure data for the units are measured according to BSI 3744

ELECTRICAL DATA TABLE

RWC	Power Supply	TOTAL kW	MCA	MOP
25	220/230V 1PH/50Hz	2.4	22	35
30		2.8	9	15
40	380/420 V 3PH 50Hz	3.7	10	15
47		4.4	13	20
55		4.7	13	20
76		6.6	19	30
105		8.4	23	40
128		9.4	27	45
160		13.1	34	60
210		17.1	40	60
260		18.7	51	90
310		25.6	65	90
350		25.3	68	90
390		27.6	71	90
430		33.7	79	90
470		39.2	90	110
530		37	91	110
580		45	105	125
630		55.6	120	150

Table A-30 Heat pump correction factors.

Cooling EER	C_{fc}	Heating	C_{fh}
		COP	
11	1.31	3.0	0.75
13	1.26	3.5	0.77
15	1.23	4.0	0.8
17	1.2	4.5	0.82

Table A-31 Long-Term Change in Ground Field Temperature

Equivalent Full Load Hours Heating/Cooling	Bore Separation, m	Temperature Penalty, K	Base Bore Length, m/kW (refrigeration)
1000/500	4.6	Negligible	16.6
1000/1000	4.6	2.6	19.5
	6.1	1.3	17.8
500/1000	4.6	4.2	22.5
	6.1	2.2	19.7
	4.6	7.1	29.9
500/1500	6.1	3.7	22.0
	7.6	1.9	19.4
	4.6	Not advisable	
0/2000	6.1	5.8	27.4
	7.6	3.1	21.8
Correction Factors for Other Grid Patterns			
1 × 10 grid $C_f = 0.36$	2 × 10 grid $C_f = 0.45$	5 × 5 grid $C_f = 0.75$	20 × 20 grid $C_f = 1.14$

Table A-32 Long-Term Change in Ground Field Temperature

Flow			Velocity		Pressure Drop			
(m^3/s)	(liter/s)	(US gpm)	(m/s)	(ft/s)	(Pa/100m)	(mmH$_2$O/100m)	(psi/100ft)	(ftH$_2$O/100ft)
1.3E-4	0.13	2.1	0.135	0.44	1041	106	0.045	0.106
1.4E-4	0.14	2.2	0.146	0.48	1178	120	0.052	0.12
1.5E-4	0.15	2.4	0.156	0.51	1317	134	0.058	0.134
1.6E-4	0.16	2.5	0.166	0.55	1459	149	0.064	0.149
1.7E-4	0.17	2.7	0.177	0.58	1647	168	0.073	0.168
1.8E-4	0.18	2.9	0.187	0.61	1797	183	0.079	0.183
1.9E-4	0.19	3.0	0.197	0.65	2002	204	0.088	0.2
2.0E-4	0.2	3.2	0.21	0.68	2157	220	0.095	0.22
3.0E-4	0.3	4.8	0.31	1.02	4437	452	0.196	0.45
4.0E-4	0.4	6.3	0.42	1.36	7395	754	0.33	0.75
5.0E-4	0.5	7.9	0.52	1.7	10785	1100	0.48	1.1
6.0E-4	0.6	9.5	0.62	2.0	14975	1527	0.66	1.53
7.0E-4	0.7	11.1	0.73	2.4	19628	2001	0.87	2.0
8.0E-4	0.8	12.7	0.83	2.7	24651	2514	1.09	2.5
9.0E-4	0.9	14.3	0.94	3.1	31199	3181	1.38	3.2
0.0010	1.0	15.9	1.04	3.4	36976	3770	1.63	3.8
0.0011	1.1	17.4	1.14	3.8	44741	4562	1.98	4.6
0.0012	1.2	19.0	1.25	4.1	51027	5203	2.3	5.2
0.0013	1.3	21	1.35	4.4	59886	6107	2.6	6.1
0.0014	1.4	22	1.46	4.8	69454	7082	3.1	7.1
0.0015	1.5	24	1.56	5.1	76263	7777	3.4	7.6

Table A-33 Performance data cooling part load EKW130

ELT	EST	Load Flow		Source 6.8 L/s							Source 8.5 L/s						
		Flow	PD	Cooling						PD	Cooling						PD
°C	°C	L/s	kPa	LLT	TC	kW	HR	COP	LST	kPa	LLT	TC	kW	HR	COP	LST	kPa
-1.1	10.0	6.8	23.5	-3.2	56.5	9.8	66.2	5.8	12.4	22.1	-3.2	56.9	9.6	66.4	6.0	11.9	32.7
		8.5	34.4	-2.8	57.8	9.8	67.7	5.9	12.4	22.1	-2.8	58.4	9.6	68.0	6.1	12.0	32.7
	21.1	6.8	23.5	-3.0	50.9	12.1	63.1	4.2	23.4	20.7	-3.0	51.3	11.8	63.2	4.3	22.9	30.8
		8.5	34.4	-2.6	52.2	12.2	64.4	4.3	23.4	20.7	-2.6	52.7	11.9	64.5	4.4	23.0	30.8
	32.2	6.8	23.5	-2.7	44.4	14.6	59.0	3.0	34.4	19.2	-2.7	44.7	14.3	59.0	3.1	33.9	29.2
		8.5	34.4	-2.4	45.4	14.7	60.1	3.1	34.4	19.2	-2.4	45.9	14.3	60.2	3.2	34.0	29.2
10.0	10.0	6.8	22.1	7.2	78.0	10.8	88.8	7.3	13.2	22.1	7.2	78.6	10.5	89.1	7.5	12.6	32.7
		8.5	32.7	7.7	79.9	10.8	90.7	7.4	13.3	22.1	7.7	80.7	10.5	91.2	7.7	12.6	32.7
	21.1	6.8	22.1	7.4	71.7	13.1	84.8	5.5	24.2	20.7	7.4	72.2	12.8	85.1	5.6	23.6	30.8
		8.5	32.7	7.9	73.5	13.2	86.7	5.6	24.2	20.7	7.9	74.1	12.9	87.0	5.8	23.6	30.8
	32.2	6.8	22.1	7.7	64.6	15.7	80.3	4.1	35.1	19.2	7.6	65.1	15.3	80.4	4.3	34.5	29.2
		8.5	32.7	8.1	66.2	15.7	81.9	4.2	35.2	19.2	8.1	66.8	15.3	82.1	4.4	34.6	29.2
21.1	10.0	6.8	20.7	17.6	98.0	11.7	109.7	8.4	14.0	22.1	17.5	98.7	11.4	110.1	8.6	13.2	32.7
		8.5	30.8	18.2	100.4	11.8	112.1	8.5	14.1	22.1	18.2	101.3	11.5	112.7	8.8	13.3	32.7
	21.1	6.8	20.7	17.8	91.8	14.1	106.0	6.5	24.9	20.7	17.8	92.5	13.8	106.3	6.7	24.2	30.8
		8.5	30.8	18.4	94.1	14.2	108.3	6.6	25.0	20.7	18.4	94.9	13.9	108.8	6.9	24.3	30.8
	32.2	6.8	20.7	18.1	83.9	16.5	100.4	5.1	35.9	19.2	18.1	84.5	16.1	100.7	5.2	35.1	29.2
		8.5	30.8	18.6	86.0	16.6	102.6	5.2	35.9	19.2	18.6	86.7	16.2	102.9	5.4	35.2	29.2
32.2	10.0	6.8	19.2	28.0	116.3	12.6	128.9	9.2	14.7	22.1	28.0	117.2	12.3	129.4	9.5	13.7	32.7
		8.5	29.2	28.8	119.1	12.7	131.8	9.4	14.8	22.1	28.7	120.2	12.3	132.6	9.7	13.8	32.7
	21.1	6.8	19.2	28.2	110.6	15.1	125.7	7.3	25.7	20.7	28.2	111.4	14.8	126.2	7.5	24.8	30.8
		8.5	29.2	28.9	113.3	15.2	128.5	7.4	25.8	20.7	28.9	114.3	14.8	129.2	7.7	24.9	30.8
	32.2	6.8	19.2	28.5	102.3	17.4	119.7	5.9	36.6	19.2	28.5	103.0	17.0	120.1	6.0	35.7	29.2
		8.5	29.2	29.2	104.8	17.5	122.3	6.0	36.6	19.2	29.2	105.7	17.1	122.8	6.2	35.8	29.2

Table A-34 Performance data heating part load EKW130

ELT	EST	Load Flow		Source 6.8 L/s							Source 8.5 L/s						
		Flow	PD	Heating						PD	Heating						PD
°C	°C	L/s	kPa	LLT	HC	kW	HE	COP	LST	kPa	LLT	HC	kW	HE	COP	LST	kPa
15.6	-1.1	6.8	21.4	17.9	65.7	10.9	54.8	6.0	-3.1	23.5	18.0	66.2	10.7	55.6	6.2	-2.7	34.4
		8.5	31.8	17.5	67.4	11.0	56.4	6.1	-3.2	23.5	17.5	68.0	10.7	57.2	6.3	-2.8	34.4
	4.4	6.8	21.4	18.3	74.5	11.4	63.1	6.5	2.2	22.8	18.3	75.1	11.1	64.0	6.8	2.6	33.5
		8.5	31.8	17.8	76.3	11.4	64.9	6.7	2.1	22.8	17.8	77.0	11.2	65.8	6.9	2.5	33.5
	10.0	6.8	21.4	18.5	82.6	11.9	70.8	7.0	7.4	22.1	18.6	83.2	11.6	71.7	7.2	7.9	32.8
		8.5	31.8	18.0	84.6	11.9	72.7	7.1	7.4	22.1	18.0	85.4	11.7	73.6	7.3	7.9	32.8
	15.6	6.8	21.4	18.8	90.0	12.3	77.7	7.3	12.7	21.4	18.8	90.7	12.0	78.6	7.5	13.3	31.5
		8.5	31.8	18.2	92.2	12.4	79.8	7.4	12.7	21.4	18.2	93.0	12.1	80.9	7.7	13.2	31.5
	21.1	6.8	21.4	19.1	96.7	12.8	83.9	7.6	18.1	20.7	19.1	97.4	12.5	84.9	7.8	18.7	30.5
		8.5	31.8	18.4	99.1	12.8	86.2	7.7	18.0	20.7	18.4	100.0	12.6	87.4	8.0	18.6	30.5
26.7	-1.1	6.8	20.0	29.0	63.8	13.5	50.3	4.7	-2.9	23.5	29.0	64.2	13.2	51.1	4.9	-2.6	34.4
		8.5	30.1	28.6	65.3	13.5	51.8	4.8	-3.0	23.5	28.6	65.9	13.2	52.7	5.0	-2.6	34.4
	4.4	6.8	20.0	29.3	72.8	13.9	58.9	5.2	2.3	22.8	29.3	73.3	13.6	59.7	5.4	2.7	33.5
		8.5	30.1	28.8	74.6	14.0	60.6	5.3	2.3	22.8	28.8	75.3	13.7	61.6	5.5	2.7	33.5
	10.0	6.8	20.0	29.6	81.0	14.4	66.6	5.6	7.6	22.1	29.6	81.6	14.1	67.6	5.8	8.0	32.8
		8.5	30.1	29.1	83.0	14.5	68.5	5.7	7.5	22.1	29.1	83.8	14.2	69.6	5.9	8.0	32.8
	15.6	6.8	20.0	29.9	88.4	14.9	73.5	5.9	12.9	21.4	29.9	89.1	14.5	74.6	6.1	13.4	31.5
		8.5	30.1	29.3	90.6	14.9	75.6	6.1	12.5	21.4	29.3	91.4	14.6	76.8	6.3	13.3	31.5
	21.1	6.8	20.0	30.1	95.0	15.3	79.6	6.2	18.2	20.7	30.1	95.7	15.0	80.7	6.4	18.8	30.5
		8.5	30.1	29.5	97.3	15.4	81.9	6.3	18.1	20.7	29.5	98.2	15.1	83.1	6.5	18.7	30.5
37.8	-1.1	6.8	18.6	40.0	61.7	17.0	44.7	3.6	-2.7	23.5	40.0	62.2	16.6	45.6	3.7	-2.4	34.4
		8.5	28.3	39.6	63.2	17.1	46.1	3.7	-2.5	23.5	39.6	63.8	16.7	47.1	3.8	-2.5	34.4
	4.4	6.8	18.6	40.3	70.3	17.4	52.9	4.0	2.5	22.8	40.3	70.8	17.0	53.9	4.2	2.9	33.5
		8.5	28.3	39.9	72.0	17.5	54.6	4.1	2.5	22.8	39.9	72.7	17.1	55.8	4.3	2.8	33.5
	10.0	6.8	18.6	40.6	78.2	17.7	60.4	4.4	7.8	22.1	40.6	78.7	17.3	61.4	4.6	8.2	32.8
		8.5	28.3	40.1	80.1	17.8	62.2	4.5	7.7	22.1	40.1	80.8	17.4	63.4	4.6	8.2	32.8
	15.6	6.8	18.6	40.9	85.3	18.1	67.2	4.7	13.1	21.4	40.9	85.9	17.7	68.2	4.9	13.6	31.5
		8.5	28.3	40.3	87.4	18.2	69.2	4.8	13.1	21.4	40.3	88.2	17.8	70.4	5.0	13.5	31.5
	21.1	6.8	18.6	41.1	91.7	18.5	73.2	5.0	18.5	20.7	41.1	92.3	18.0	74.3	5.1	19.0	30.5
		8.5	28.3	40.5	93.9	18.6	75.3	5.1	18.4	20.7	40.5	94.7	18.1	76.6	5.2	18.9	30.5
48.9	-1.1	6.8	17.3	51.0	59.1	21.3	37.8	2.8	-2.5	23.5	51.0	59.5	20.8	38.7	2.9	-2.2	34.4
		8.5	26.5	50.6	60.5	21.4	39.1	2.8	-2.5	23.5	50.7	61.1	21.0	40.1	2.9	-2.3	34.4
	4.4	6.8	17.3	51.3	66.4	21.5	44.9	3.1	2.8	22.8	51.3	66.9	21.0	45.9	3.2	3.1	33.5
		8.5	26.5	50.9	68.0	21.7	46.4	3.1	2.8	22.8	50.9	68.7	21.2	47.5	3.2	3.1	33.5
	10.0	6.8	17.3	51.5	73.4	21.8	51.6	3.4	8.1	22.1	51.6	73.9	21.3	52.7	3.5	8.5	32.8
		8.5	26.5	51.1	75.2	21.9	53.3	3.4	8.1	22.1	51.1	75.9	21.4	54.5	3.5	8.4	32.8
	15.6	6.8	17.3	51.8	80.0	22.0	58.0	3.6	13.5	21.4	51.8	80.6	21.5	59.2	3.8	13.8	31.5
		8.5	26.5	51.3	82.0	22.1	59.9	3.7	13.4	21.4	51.3	82.7	21.6	61.1	3.8	13.6	31.5
	21.1	6.8	17.3	52.0	86.3	22.2	64.1	3.9	18.6	20.7	52.0	87.0	21.7	65.3	4.0	19.2	30.5
		8.5	26.5	51.4	88.4	22.4	66.1	4.0	18.7	20.7	51.5	89.3	21.9	67.4	4.1	19.2	30.5

Figure A-35 F0 vs. G for a cylindrical heat source

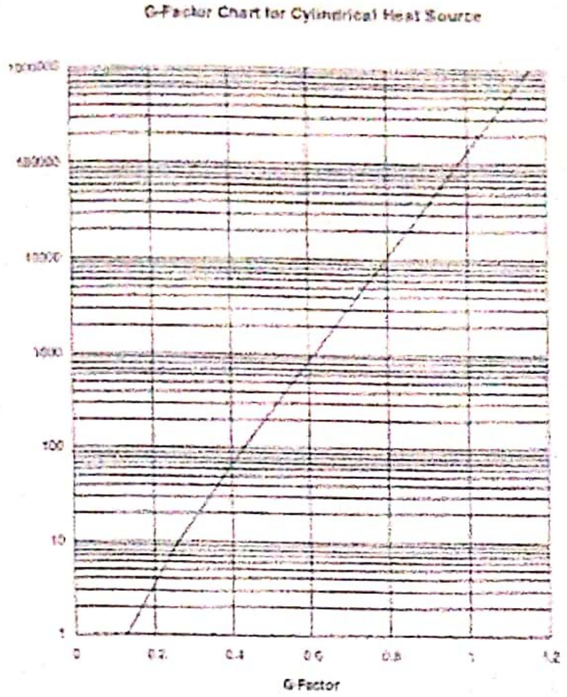
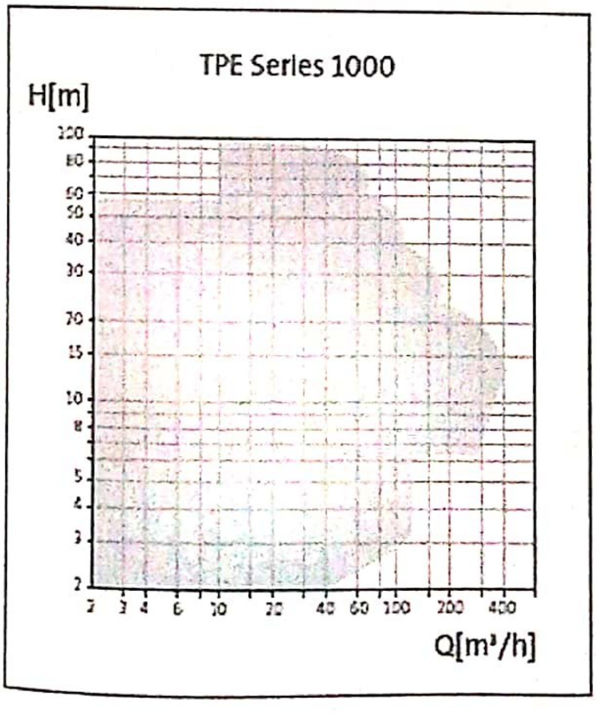


Figure A-36 Performance curves for Grundfoss pump



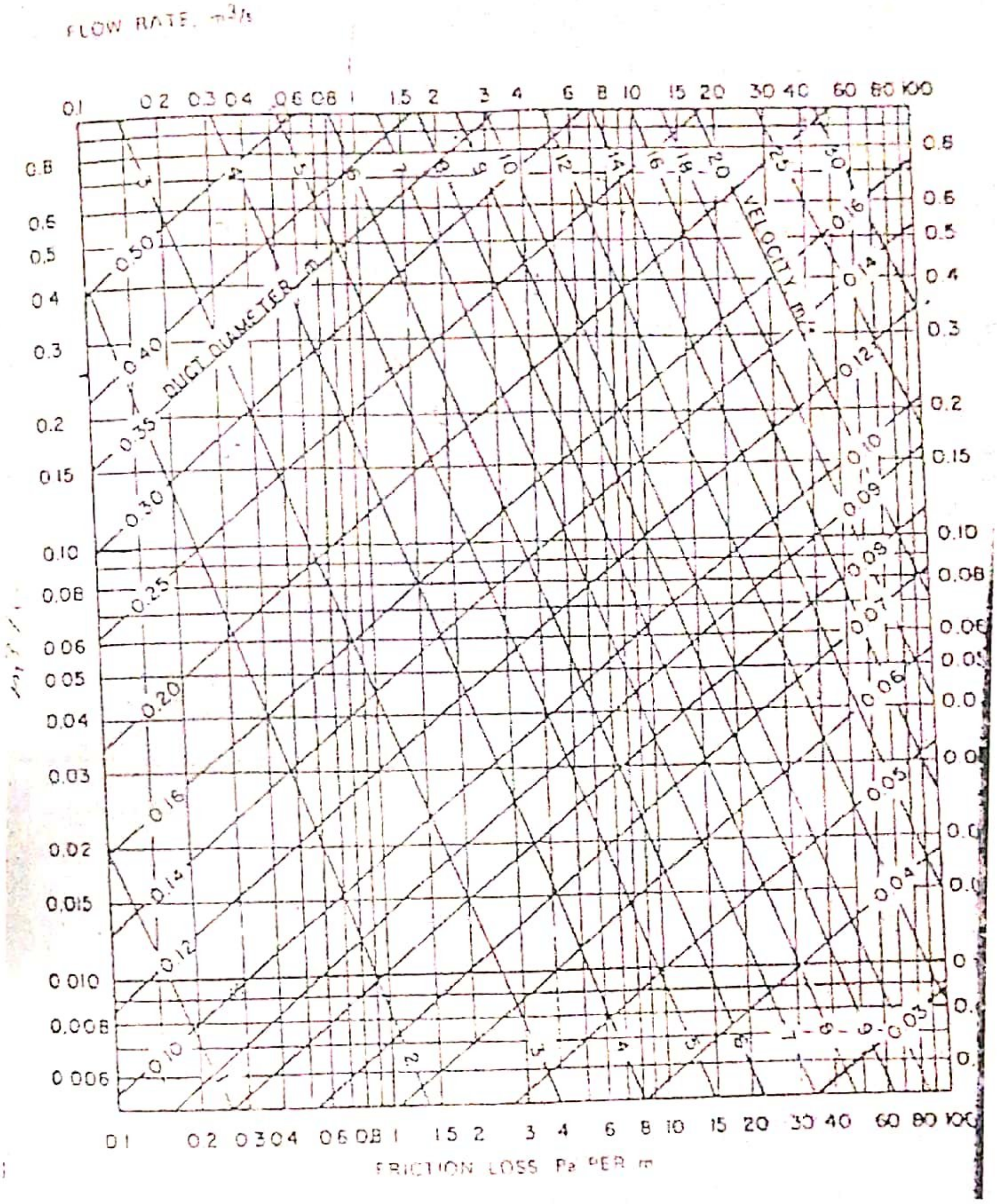


Figure A-37 Pressure drop (ΔP/EL), for air in galvanized steel ducts, based on round duct diameter

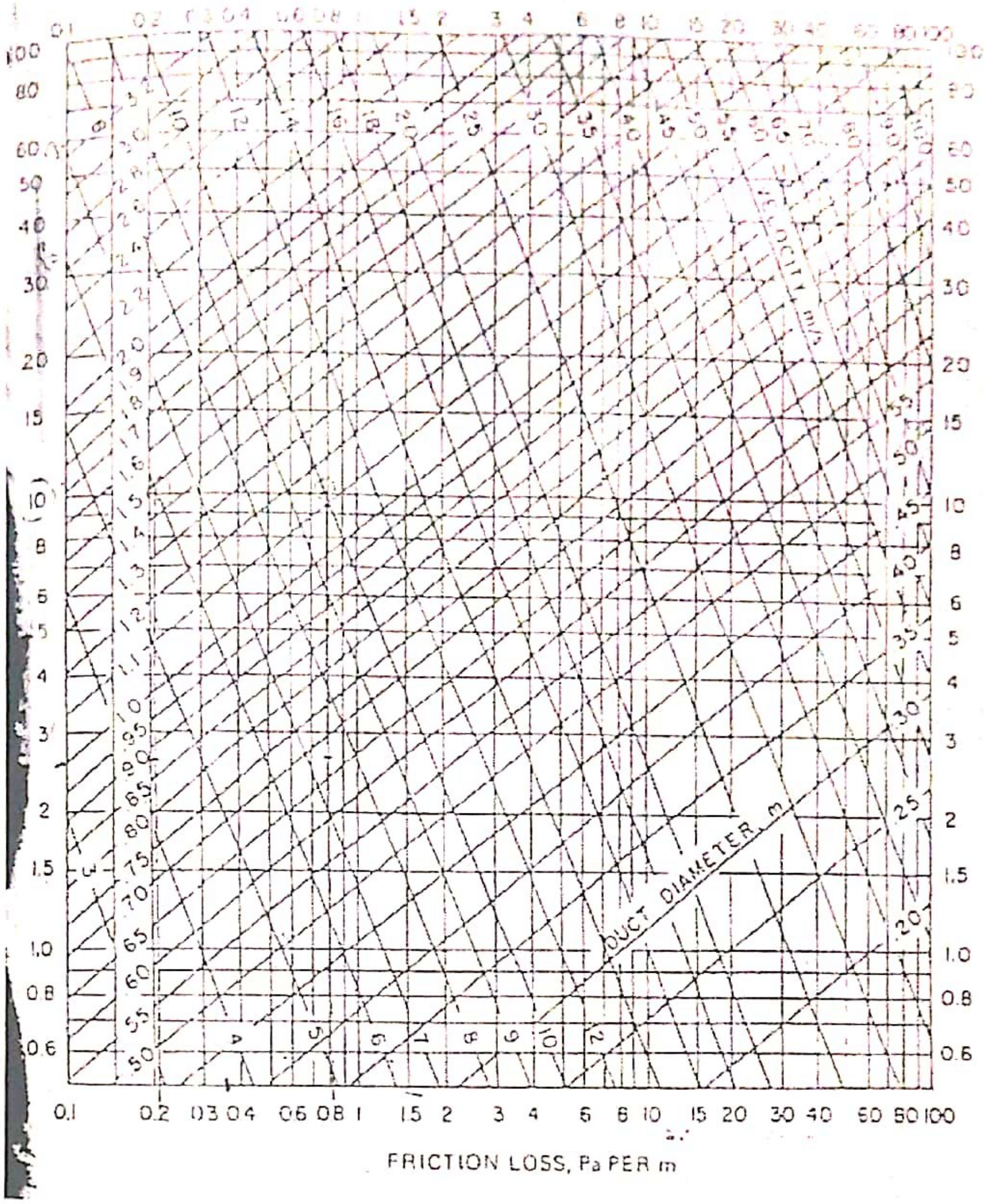
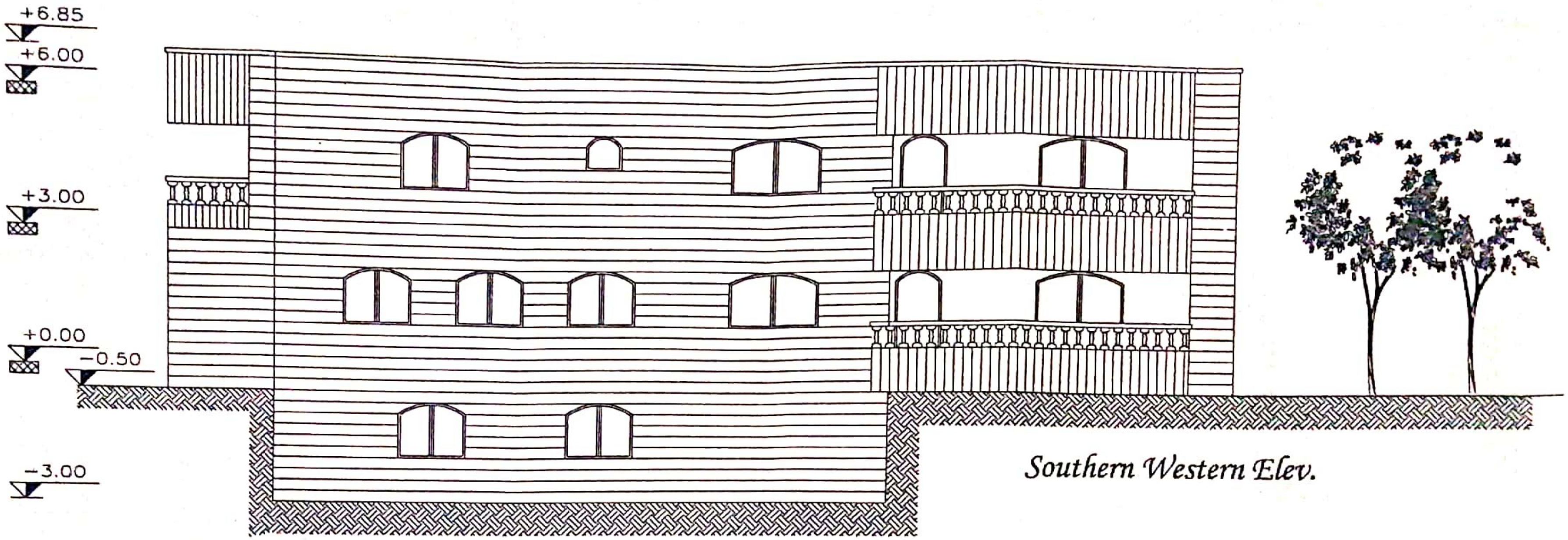
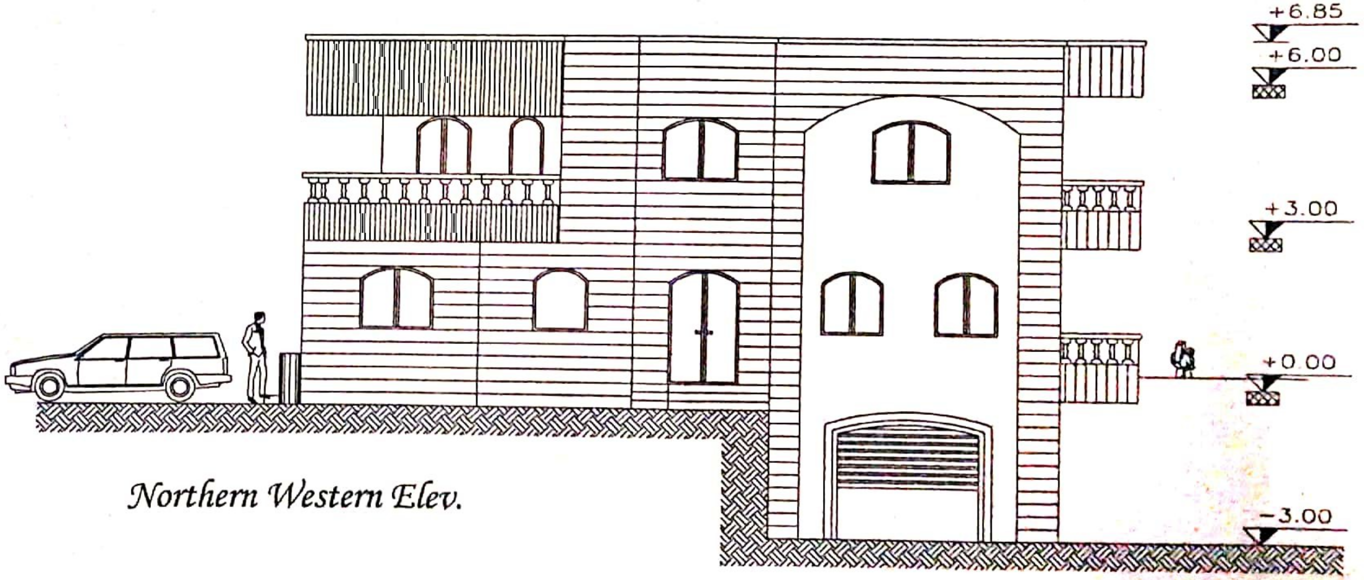

0.1
0.2
0.3
0.4
0.6
0.8
1
1.5
2
3
4
6
8
10
15
20
30
40
60
80
100
0.6
0.8
1.0
1.5
2
3
4
5
6
8
10
15
20
30
40
50
60
80
100
VELOCITY m/s
DUCT DIAMETER, m
FRICTION LOSS, Pa PER m

Figure A-38



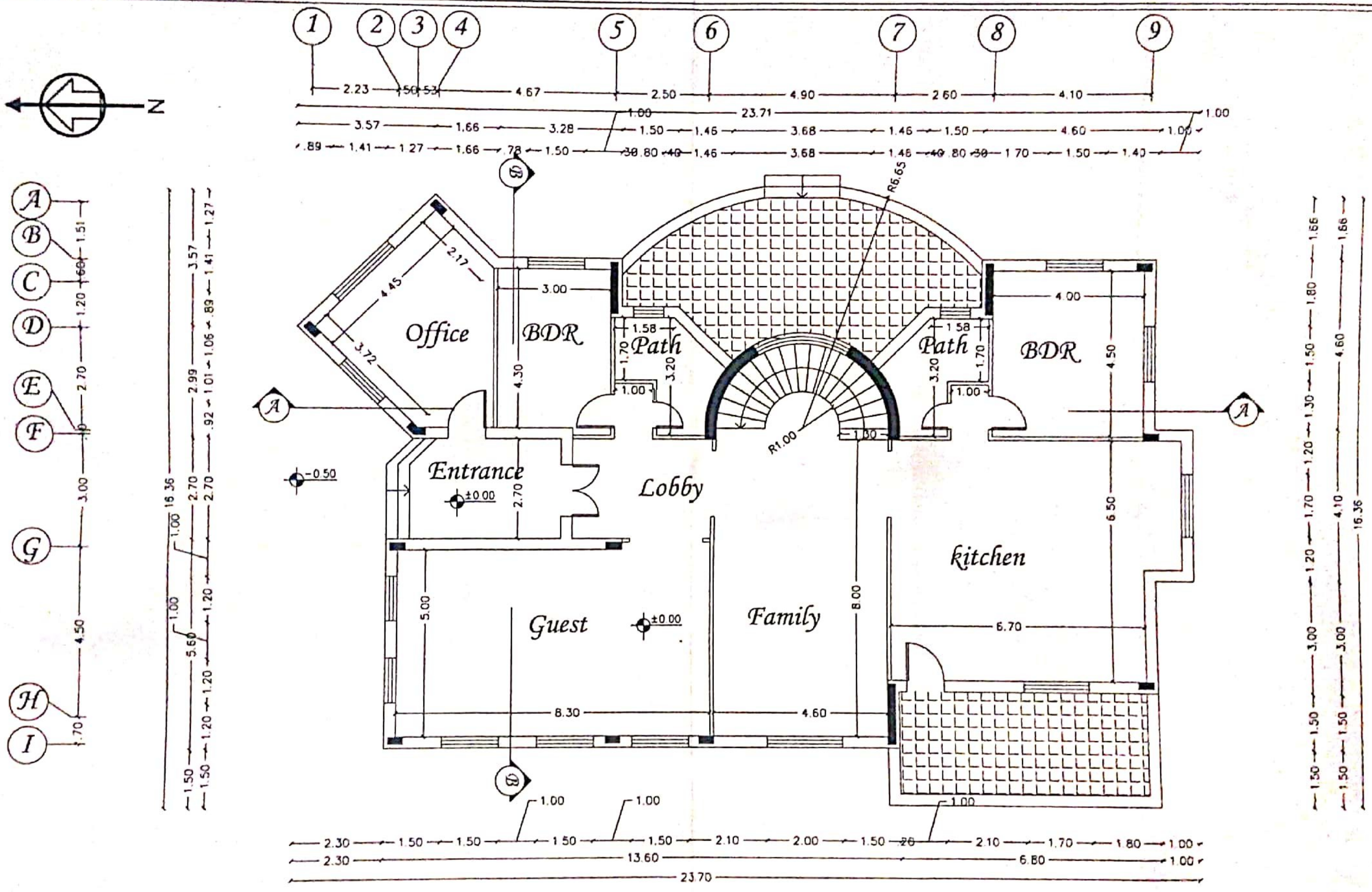
Southern Western Elev.



Northern Western Elev.

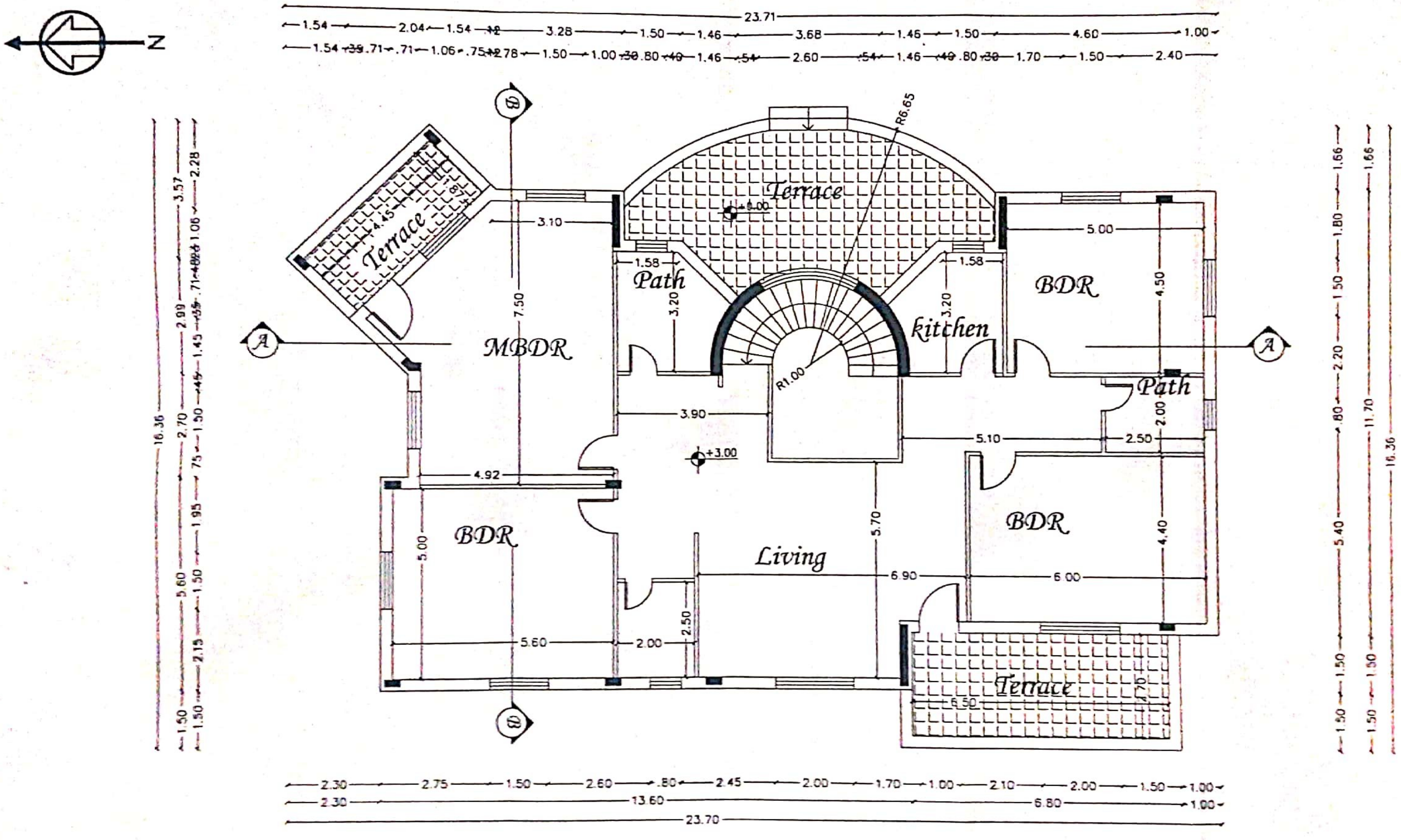
Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Elevations*	D1
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-39



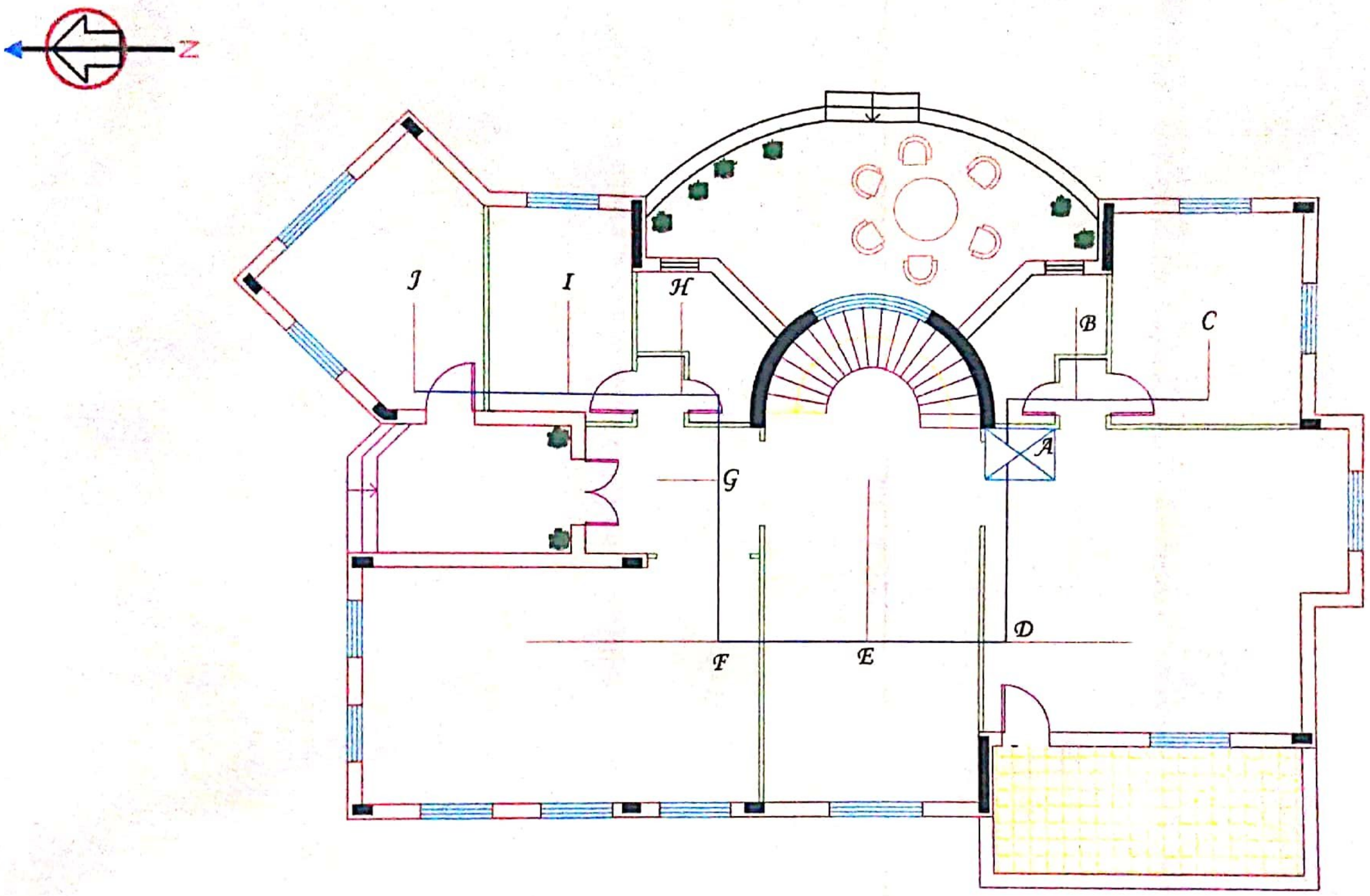
Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Ground Floor Plan*	D 2
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-40



Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*First Floor Plan*	D 3
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-41



Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Ground Floor Duct line*	D 4
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-42

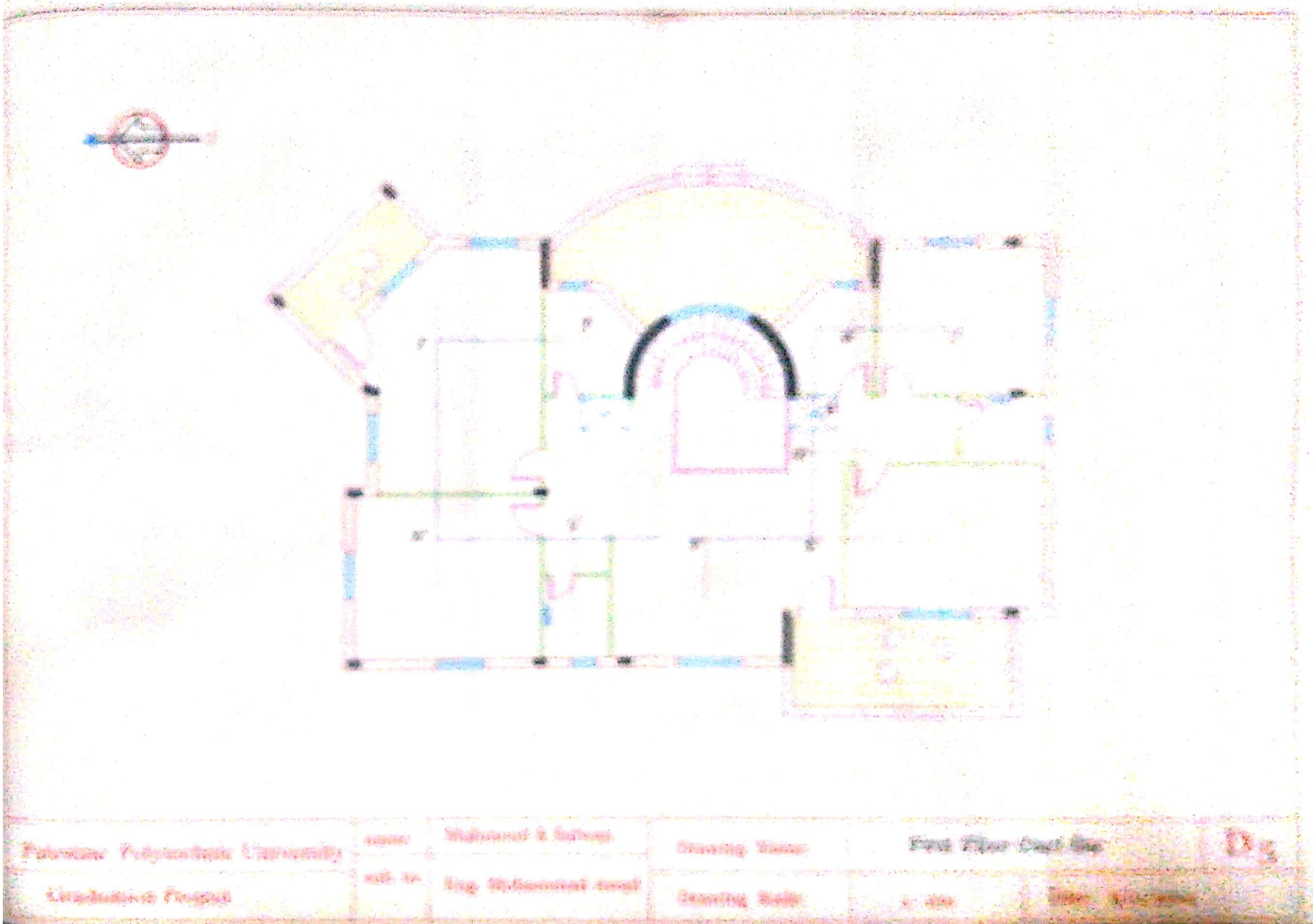
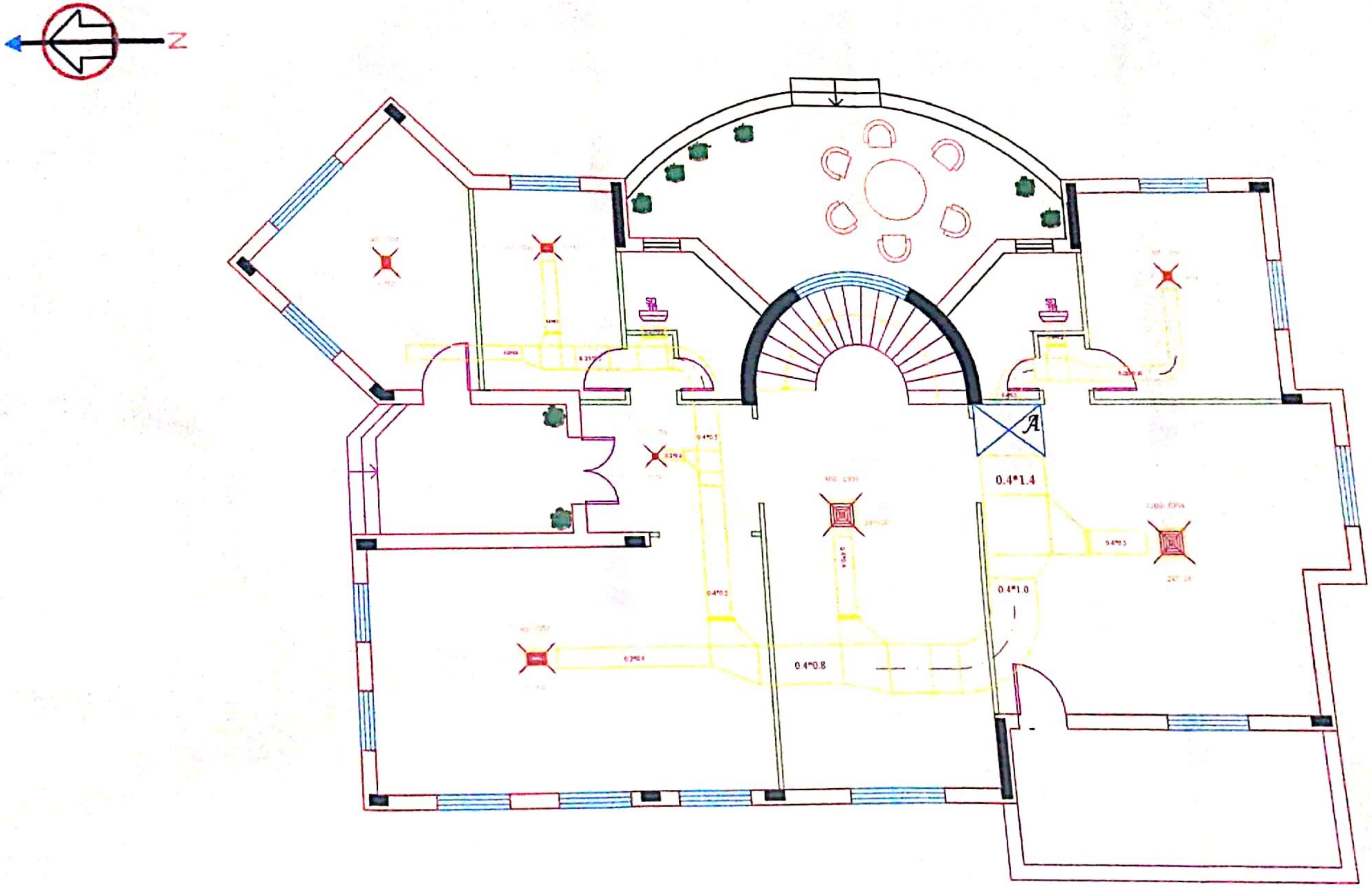
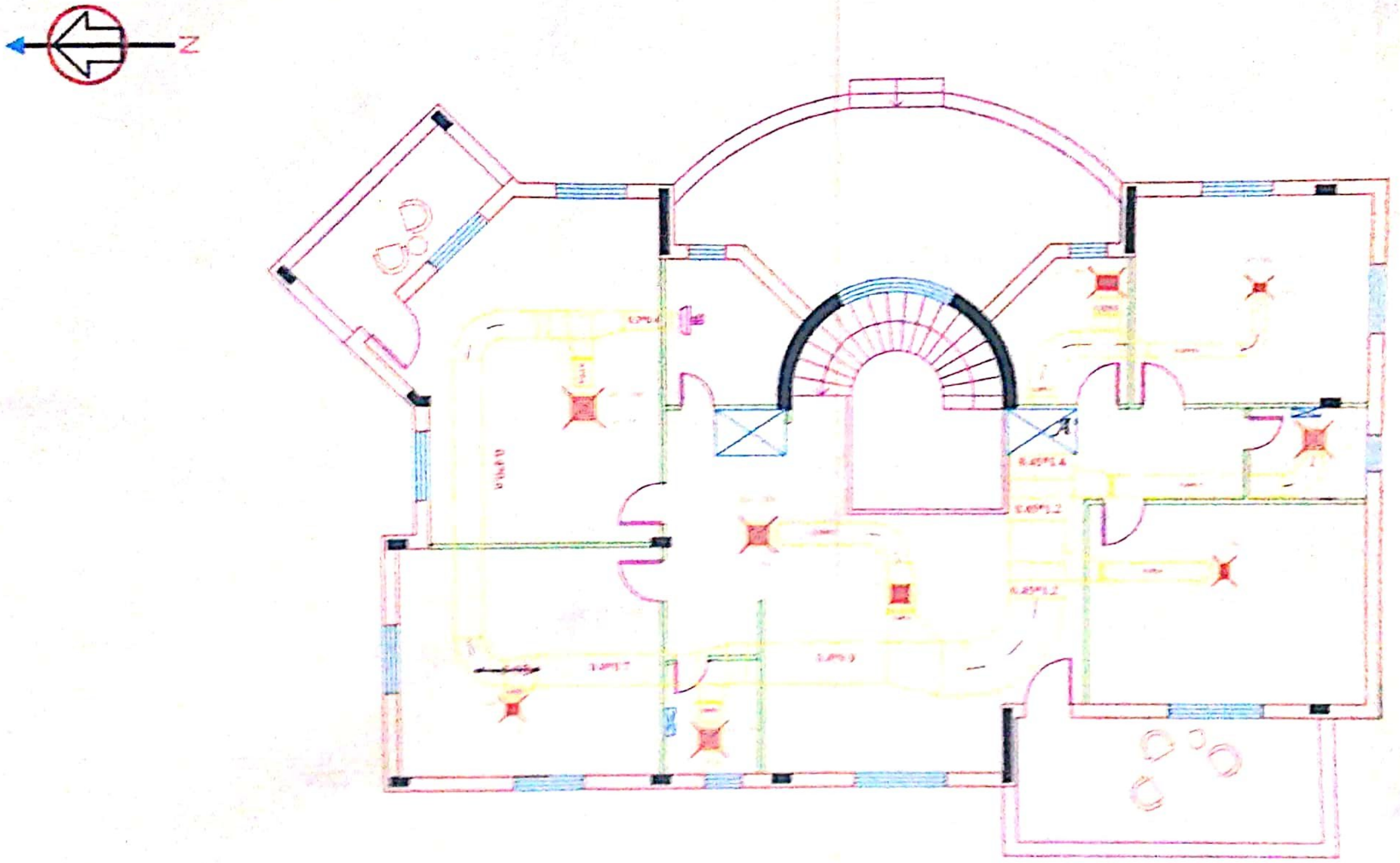

Palestine Polytechnic University
Graduation Project
Drawing Name
Drawing Scale

Figure A43



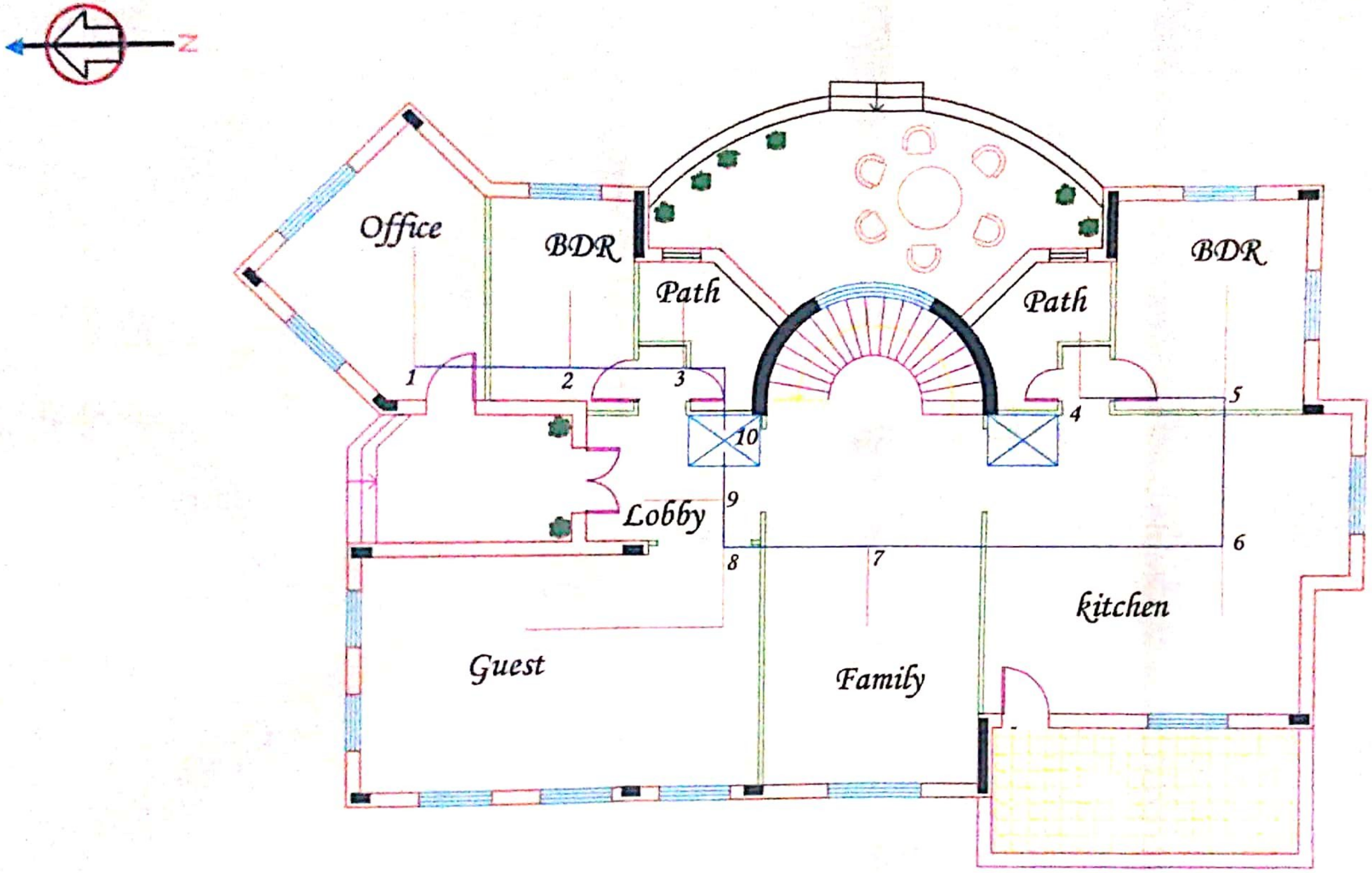
Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Ground Floor Duct and supply air*	D 6
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-44



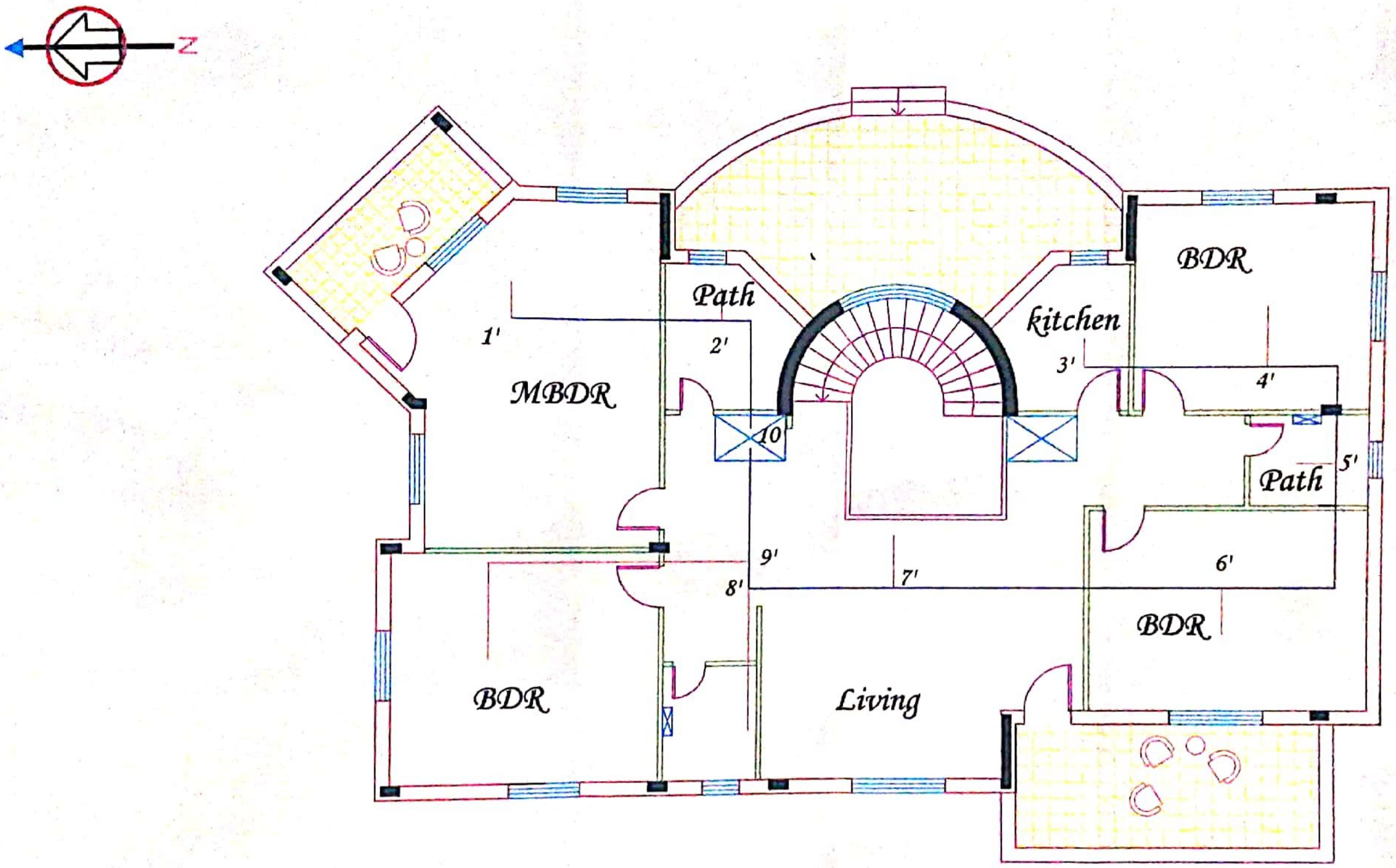
Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*First Floor Duct and supply air*	D 7
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-45



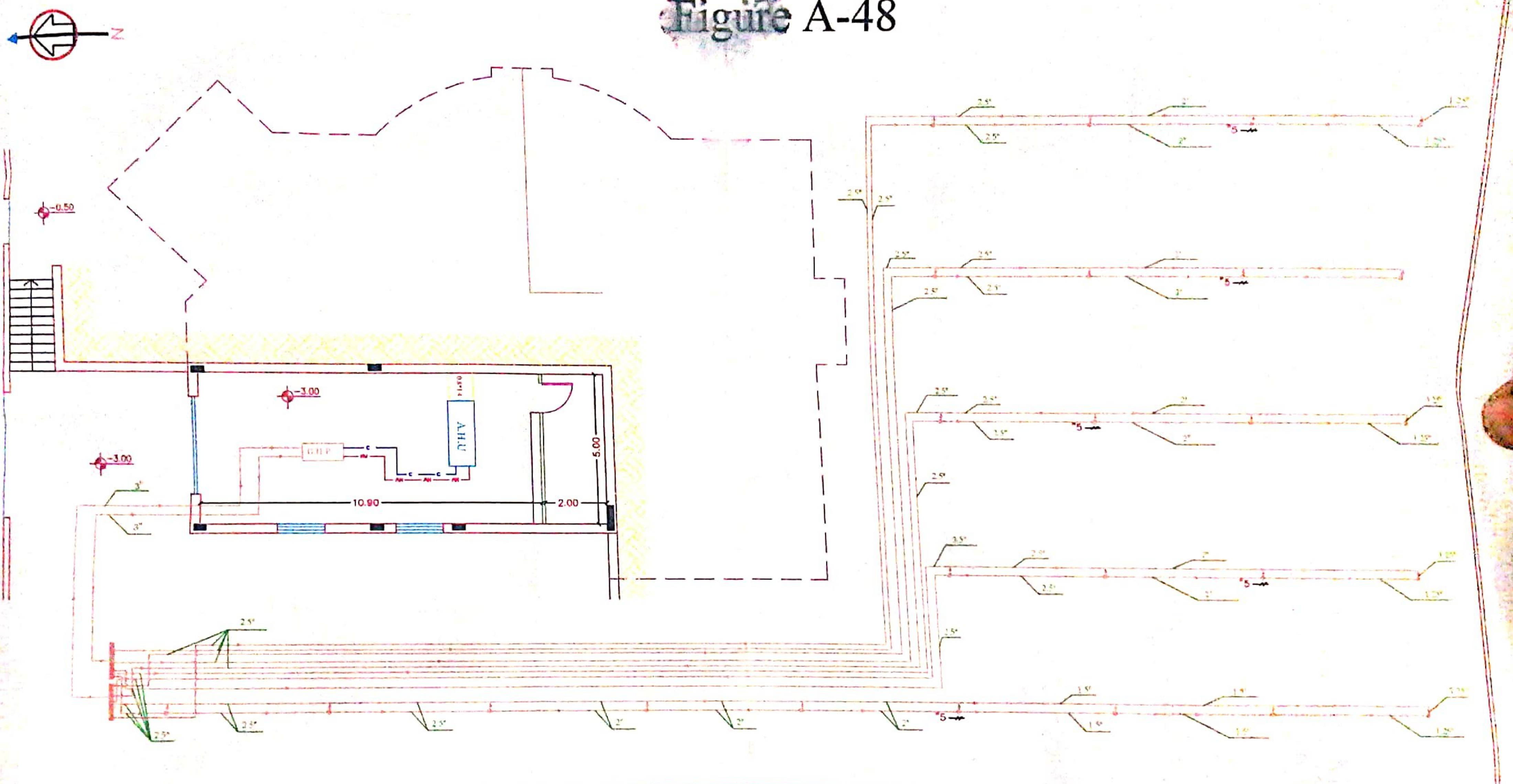
Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Ground Floor Return Duct line*	D 8
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-46



Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*First Floor Return Duct line*	D 9
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-48

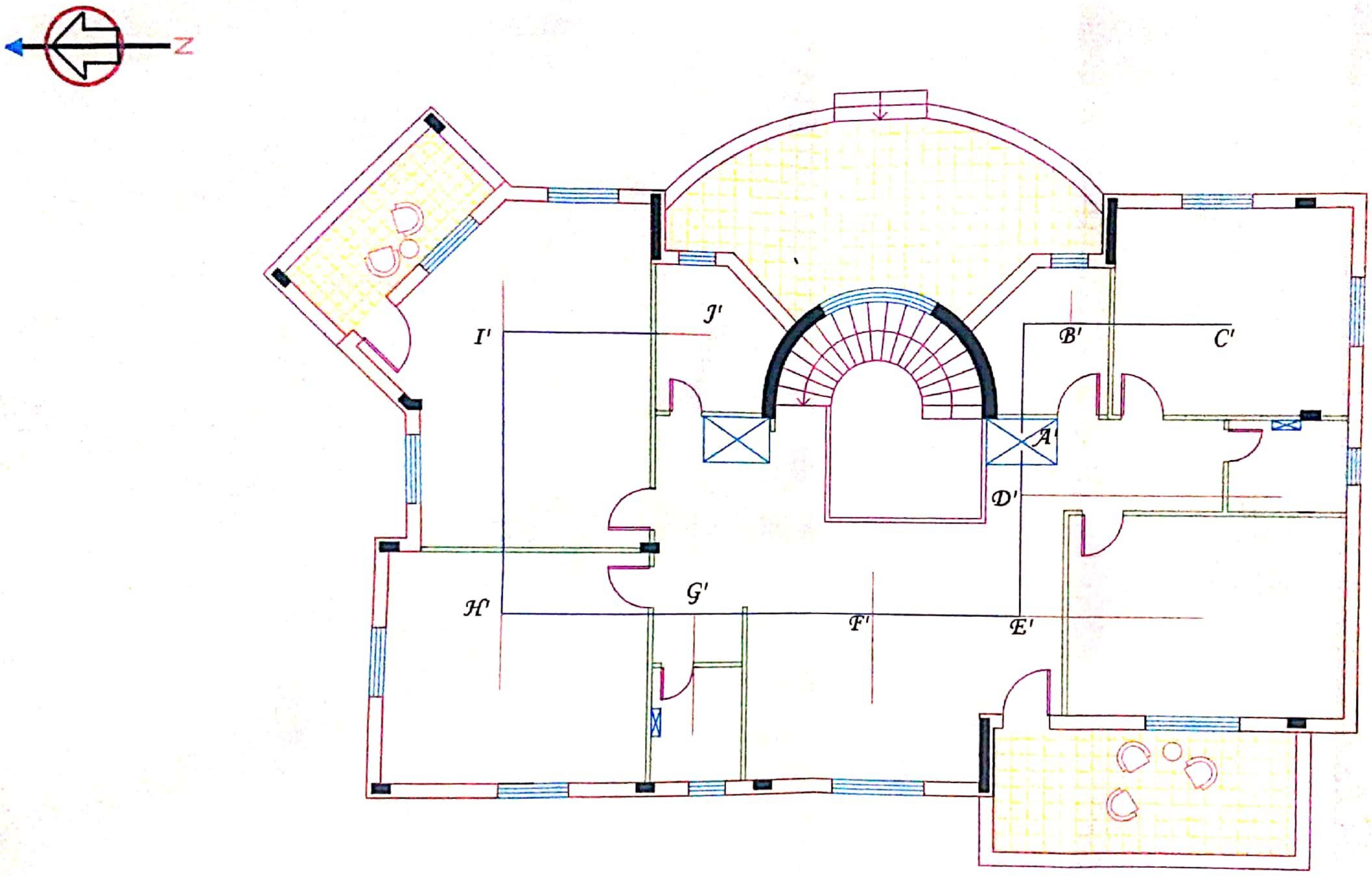


alestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Basement Floor Plan & line GHP*	D 10
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-47

alestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*Sections*	D 11
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004

Figure A-42



Palestine Polytechnic University	name:	Mahmoud & Safwan	Drawing Name:	*First Floor Duct line*	D 5
Graduation Project	sub. to:	Eng. Mohammad Awad	Drawing Scale:	1 : 100	Date: 6/11/2004