بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering Department

Graduation Project

Theoretical Design of Geothermal Assisted Heat Pump System for Barakat Al-Qadi Building in Hebron

Project Team

Ibrahim N. Idais	Hani A. Erfaeiah	Mohmmad J. Anteer

Project Supervisors

Eng. Mohmmad Awad

Hebron – Palestine

June, 2013

Abstract

Geothermal energy is one of the most important ways to conserve energy. The aims of this project is to describe the procedure of theoretical design of Vertical Ground loop Source Heat pump, to obtain a comparison between ordinary heat pump and geothermal heat pump, and to calculate the payback period for the economical feasibility study of the geothermal heat pump compared to chiller system for cooling and heating load.

Local climate conditions and soil properties of Hebron will be used to design the geothermal coil, and coefficient of performance for cooling and heating will be calculated and predicted for the local conditions available.

Table of Contents

List of Tables

List of Figures

CHAPTER ONE

INTRODUCTION

1.1 Introduction

1.2 Project Outline

1.3 The Objectives and Scope

1.4 Time Schedule

Chapter One

Introduction:

1.1 Introduction

Conventional energy sources based on oil, coal, and natural gas are harmful to environment, to economical progress, and to human life. These traditional fossil fuel-based energy sources are facing an increasing pressure on a host of environmental fronts, with the most serious challenge confronting the future use of coal being the Kyoto Protocol greenhouse gas reduction targets. Renewable energy sources currently supply around 15% of world's total energy demand in 2008. The supply is dominated by traditional biomass, mostly fuel wood used for cooking and heating, especially in developing countries [1].

The potential of renewable energy resources is enormous as they can in principle meet many times the world's energy demand. Renewable energy sources such as small hydropower, wind, solar, biomass, and geothermal can provide sustainable energy services, based on the use of routinely available, indigenous resources. It is time for transition to renewable-based energy systems, taking into consideration the costs of solar and wind power systems which have dropped substantially in the past 30 years, and continue to decline, unlike the prices of oil and gas which continue to fluctuate, in fact each moving in opposite directions [2].

Geothermal Energy is one of the renewable energy resources which is a clean low cost energy based on the idea of using the ground as a heat source/sink (which is defined as the Medium where heat is absorbed/rejected without changing its temperature) to reduce the cost of heating or cooling or for getting high temperature from the earth below the crust for producing steam and thus generate electricity.

Geothermal energy in both cases is a sustainable renewable energy resource because it reduces the energy consumed. and thus reduces the emissions and the use of the resources, this way it is a sustainable energy resource and sustainable way of using resources keeping in mind meeting our needs without compromising the needs of the future generations. So it has an economical dimension (reducing costs), ecological dimension (maintaining the environment, maintaining the resources, and reduce the emissions), Social dimension (human being health, human prosperity, and human development) with the fact those future generations was taken into consideration by acting this way, and that is the basis of the sustainable economies that are modeled now days in Sweden, Canada, and many countries in the world [3].

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, Chapter 2; it talks about geothermal energy, Chapter 3; it talks about heat pump, Chapter 4; it talks about geothermal heat pump, Chapter 5; design and calculation.

1.3 The Objectives and Scope

1. To design and modeling a vertical loop Ground Source Heat pump.
2. To obtain a comparison between ordinary heat pump and geothermal heat pump.
3. To find the effect of the heat sink temperature on the performance of the heat pump.
4. To use renewable and clean energy in air conditioning.

1.4 Time Schedule

Table 1.1: Project time-schedule for first semester

Week No Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Literature survey	🟦	🟦	🟦	🟦	🟦											
Collect the information about problem				🟦	🟦											
Geothermal energy						🟦	🟦									
Heat pump							🟦	🟦								
Geothermal heat pump								🟦	🟦							
Writing Documentation									🟦	🟦	🟦	🟦	🟦			
Printing and finishing														🟦	🟦	🟦

Table 1.2: Project time-schedule for second semester

Week No Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Calculation of heating and cooling loads for building	🟥	🟥	🟥	🟥	🟥											
Design the GHP system					🟥	🟥	🟥	🟥	🟥							
Planning by AutoCAD and Selection							🟥	🟥	🟥	🟥						
Writing Documentation										🟥	🟥	🟥	🟥	🟥	🟥	🟥

CHAPTER TWO

GEOTHERMAL ENERGY

Content:

2.1 What is Geothermal Energy ?

2.2 Temperature Variation with Depth

2.3 Earth's Structure

2.4 Sources of Geothermal Heat

2.5 Uses of Geothermal Energy

Chapter Two

Geothermal Energy

2.1 What is Geothermal Energy ?

Geothermal energy is energy that comes from deep inside of Earth. The word geothermal comes from the Greek words geo (meaning "earth") and thermal (meaning "heat"). Geothermal power is a clean, renewable energy source that may someday provide a significant portion of the world's energy.

At the center of Earth about 4,000 miles (6,400 kilometers) below the surface is a very hot core. Some scientists estimate its temperature at about 7600 Fahrenheit (4200 Celsius). The center of the core is solid. The heat from this part of the core is powerful enough to melt rock into a hot liquid called magma. This molten (melted) rock forms the outer core. The heat from magma rises through Earth's mantle. The mantle is the layer that surrounds the core (see Figure 2.1) [5].

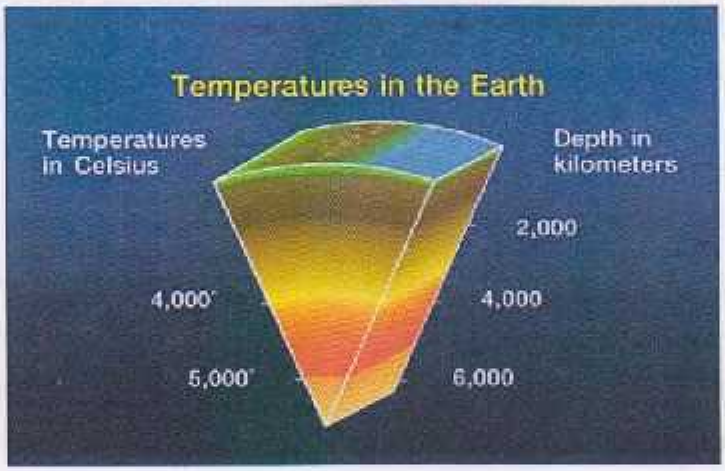


Figure 2.1: Temperature Variation with Dept

2.2 Temperature Variation with Depth

Considering that 46% of sun's energy is absorbed by the earth as shown in (Figure 2.2), because the ground transport heat slowly and has a high heat storage capacity, its temperature change slowly on the order of months or even years, heat absorbed by the earth during the summer effectively gets used in the winter.

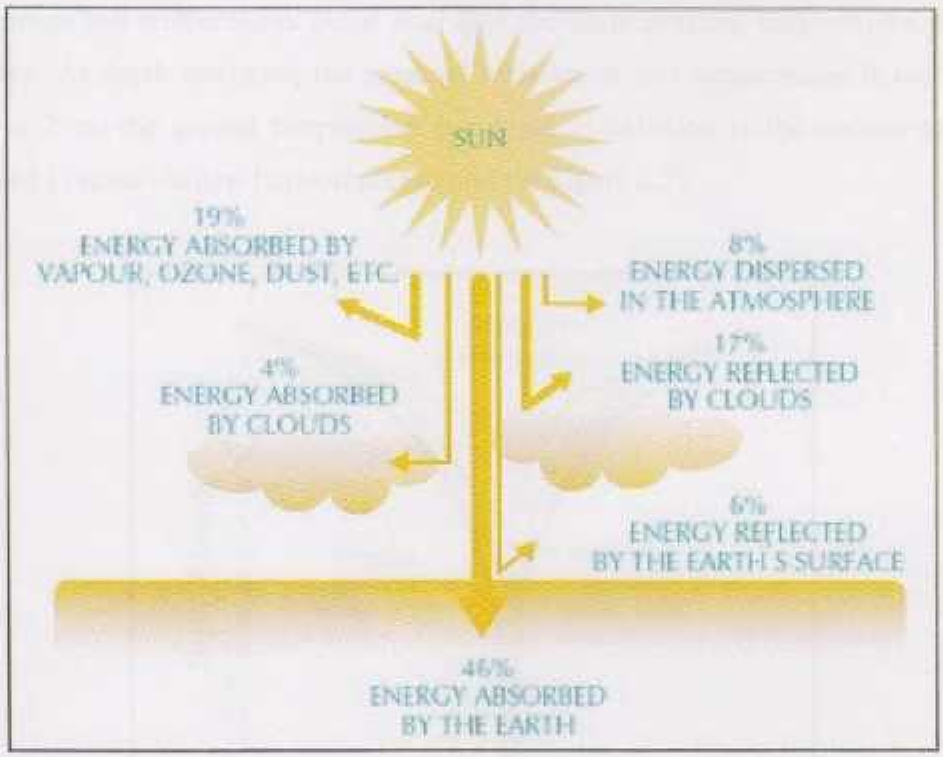


Figure 2.2: Solar Energy Distribution

Along with the Earth's structure and composition, irregular the temperature distribution within the Earth has been one of the fundamental research problems that impact our understanding of the evolution of the Earth. The present-day temperature distribution inside the Earth depends on (i) the original temperature distribution shortly after formation, (ii) the distribution and intensity of heat sources, both of which are time-dependent, and (iii) the mechanism of internal heat transfer conduction, convection or both.

A thorough investigation into the ground properties of a proposed site is vital to designing an appropriate geothermal installation. The ground temperature is one of the most important factors, since it is the difference between this and the fluid temperature which drives the heat transfer. At depths below 2 m, the minimum and maximum soil temperatures occur later than the corresponding temperatures at the surface. As depth increases, the seasonal variation in soil temperatures is reduced. Above 2 m, the ground temperature is subject to radiation at the surface and is utilized in some shallow horizontal systems (see Figure 2.3).

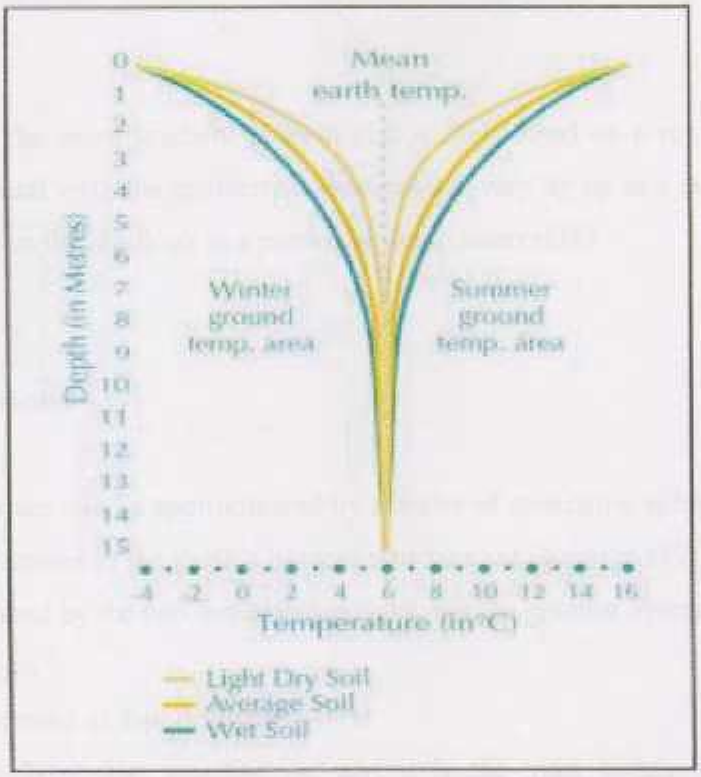


Figure 2.3: Typical Soil Temperature Variation

2.2.1 Temperature gradient

It is possible to estimate temperatures at 100 m depth by applying Fourier's Law of heat conduction: [14]

$$\frac{q}{A} = -k * \frac{dt}{dz} \tag{2.1}$$

where q = heat flow (W/m^2), k = thermal conductivity (W/m.K) and dt/dz = temperature gradient (K/m). Thermal conductivity has been taken as the thermal conductivity of the bedrock geology (i.e. the rock below the soil and superficial deposits layers). The calculated temperature gradient has been added to the estimate of the mean annual air temperature to generate the estimate of temperature at 100 m depth.

The variation in the mean gradient is from (1.5 – 5°C/100m) on a regional basis. Within an individual well, the geothermal gradient can vary by up to a factor of 5 or more, depending on the lithology in a particular depth interval.[6]

2.3 Earth's Structure

The Earth's structure can be approximated by a series of concentric spherical shells. The large-scale features of the Earth`s internal structure are shown in (**Figure 2.4**). The core, constituted by the two innermost regions, has the greatest average density, exceeding 10^4 kg.m^{-3}.

The Earth is composed of four different layers:

1. Crust: is the layer that you live on, and it is the most widely studied and understood. the crust is only about 25 miles (32 kilometers) thick under the continents.

2. Mantle: is much hotter and has the ability to flow.
3. Outer Core: is so hot that the metals in it are all in the liquid state, is composed of the melted metals of nickel and iron.
4. Inner Core: has temperatures and pressures so great that the metals are squeezed together, and are forced to vibrate in place like a solid.

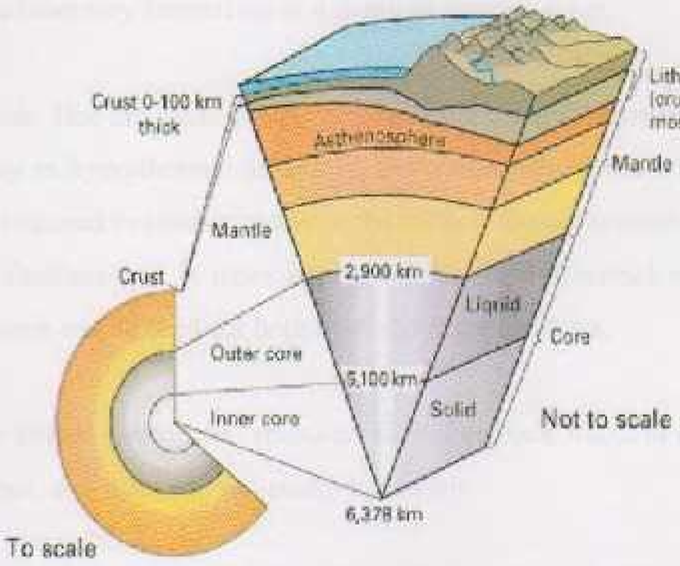


Figure 2.4: The Earth Structure

2.4 Sources of Geothermal Energy

70% comes from the decay of radioactive nuclei with long half lives that are embedded within the Earth. Some energy is from residual heat left over from Earths formation. The rest of the energy comes from meteorite impacts.

There are four types of geothermal resources:

1. Hydrothermal: when hot water or steam is formed in fractured or porous rock at shallow to moderate depths (100m to 4.5km) as a result of either the intrusion in

the earth's crust of molten magma from the earth's interior, or the deep circulation of water through a fault or fracture. they are more suited for space heating than for electricity production [7].

2. Geopressured: geothermal resources consist of hot brine saturated with methane, found in large, deep aquifers under high pressure. The water and methane is trapped in sedimentary formations at a depth of about 3-6 km.

3. Hot Dry Rock: Hot dry rock (HDR) is a heated geological formation formed in the same way as hydrothermal resources, but containing no water as the aquifers or fractures required to conduct water to the surface are not present. This resource is virtually limitless and is more accessible than hydrothermal resources, This type of resource can be used for both heat and for natural gas.

4. Magma: the largest geothermal resource, is molten rock found at depths of 3-10 km and deeper, and therefore not easily accessible.

2.5 Uses of Geothermal Energy

Geothermal energy can be used for electricity production, for commercial, industrial, and residential direct heating purposes, and for efficient home heating and cooling through geothermal heat pumps, the three main uses of geothermal energy are:

1. Direct Use and District Heating System: 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 °F). Geothermal power plants are generally built where geothermal reservoirs are located within a mile or two of the surfaces.

3. Geothermal Heat Pumps: use stable ground or water temperature near the earth's surface to control building temperature above ground.

2.5.1 Direct Use of Geothermal Energy

Hydrothermal resources of low to moderate temperature (20-150 °C) are utilized to provide direct heating for a range of applications.

Geothermal heat is used directly, without involving a power plant or a heat pump, for a variety of applications such as space heating and cooling, food preparation, hot spring bathing and spas (balneology), agriculture, aquaculture, greenhouses, and industrial processes. Uses for heating and bathing are traced back to ancient Roman times.

2.5.2 Geothermal Power Plants

Geothermal power plant use hydrothermal resources which have two common ingredients: water (hydro) and heat (thermal). Its require high temperature (300 to 700 °F), 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.
There are three basic types of geothermal power plants:

1. Dry Steam Power Plants: Dry steam plants use hydrothermal fluids that are primarily steam. The steam travels directly to a turbine, which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine (also eliminating the need to transport and store fuels). These plants emit only excess steam and very minor amounts of gases. Steam technology is still effective today at currently in use at The Geysers in northern California, the world's largest single source of geothermal power. [8]

2. Flash Steam Power Plants: Flash steam plants are the most common type of geothermal power generation plants in operation today. Fluid at temperatures greater than 360°F (182°C) is pumped under high pressure into a tank at the surface held at a much lower pressure, causing some of the fluid to rapidly vaporize, or "flash." The vapor then drives a turbine, which drives a generator. If any liquid remains in the tank, it can be flashed again in a second tank to extract even more energy.

3. Binary Cycle Power Plants: This system passes moderately hot geothermal water past a liquid, usually an organic fluid, that has a lower boiling point. The resulting steam from the organic liquid drives the turbines. This process does not produce any emissions and the water temperature needed for the water is lower than that needed in the Flash Steam Plants (250-360^{0}F).

2.5.3 Geothermal Heat Pump

People also harness geothermal energy by using heat-pump systems. These systems take advantage of stable temperatures beneath Earth's surface. No matter what season it is, a few feet underground, the temperature is about 50-60°F (10-15°C).

Heat-pump systems include three parts: what is called an Earth connection, the heat pump itself, and a heat distribution system. The Earth connection is a loop of pipes buried in the ground near or beneath a building. A fluid circulates in the loop of pipes. The fluid is water or a mixture of water and antifreeze. The fluid picks up heat from within Earth. The heat pump removes heat from the fluid and sends it to the building. Then, pipes distribute the heat through the building. When it is warm out, heat-pump systems can be used backwards for cooling. The system pulls warm air from the building and sends it underground [8].

CHAPTER THREE

HEAT PUMP

Content:

Chapter Three

Heat Pump

3.1 Introduction

Heat pumps are generally more expensive to purchase and install than other heating systems, but they save money in the long run in some areas because they lower the heating bills. Despite their relatively higher initial costs, the popularity of heat pumps is increasing. About one-third of all single-family homes built in the United States in the last decade are heated by heat pumps.

The most common energy source for heat pumps is atmospheric air (air to- air systems), although water and soil are also used. The major problem with air-source systems is frosting, which occurs in humid climates when the temperature falls below 2 to 5°C. Heat pumps and air conditioners have the same mechanical components. Therefore, it is not economical to have two separate systems to meet the heating and cooling requirements of a building. One system can be used as a heat pump in winter and an air conditioner in summer. This is accomplished by adding a reversing valve to the cycle. [9]

3.2 Basic of Heat Pump

A heat pump is a devise which allows transport of heat from a lower temperature level to a higher one, by using external energy (e.g. to drive a compressor). This occurs in a closed-cycle process in which the working fluid is constantly undergoing a change of state (evaporation, compression, condensation and expansion).

A heat pump system consists of heat pumps and piping work; system components include heat exchangers, heat source, heat sink, and controls to provide effective and energy-efficient heating and cooling operations. HCFC-22, HFC-134a, and HFC-407C are the most widely used refrigerants in heat pumps [10].

The thermodynamic principle behind a compression heat pump is the fact that a gas becomes warmer when it is compressed into a smaller volume. This effect is common experience e.g. for cyclists when adjusting air pressure in the tires: The air pump gets warmer in the process.

3.3 Heat Pump Operation

In a heat pump, a medium with low boiling point ("refrigerant") is evaporated by the ground heat, the resulting vapor (gas) is compressed (by using external energy, typically electric power) and thus heated, and then the hot gas can supply its heat to the heating system. Still being in the high pressure part, the vapor now condenses again to a liquid after the useful heat has been transferred. Finally, the fluid enters back into the low-pressure part through an expansion valve, gets very cold and can be evaporated again to continue the cycle (see Figure 3.1).

In General, a fully hermetic compressor (piston or scroll for extremely quiet operation) with built-in, internal overload protection is used in these heat pumps. Stainless steel flat plate heat exchangers or other types like shell and tube or coaxial are used for the evaporator and condenser. Other items in the refrigerant cycle are the expansion valve and possibly a sight glass accumulator and a filter/drier. The refrigeration cycle (Figure 3.1) should be fully insulated against thermal losses and prevent condensation inside the heat pump. For heating/cooling reversible operation.

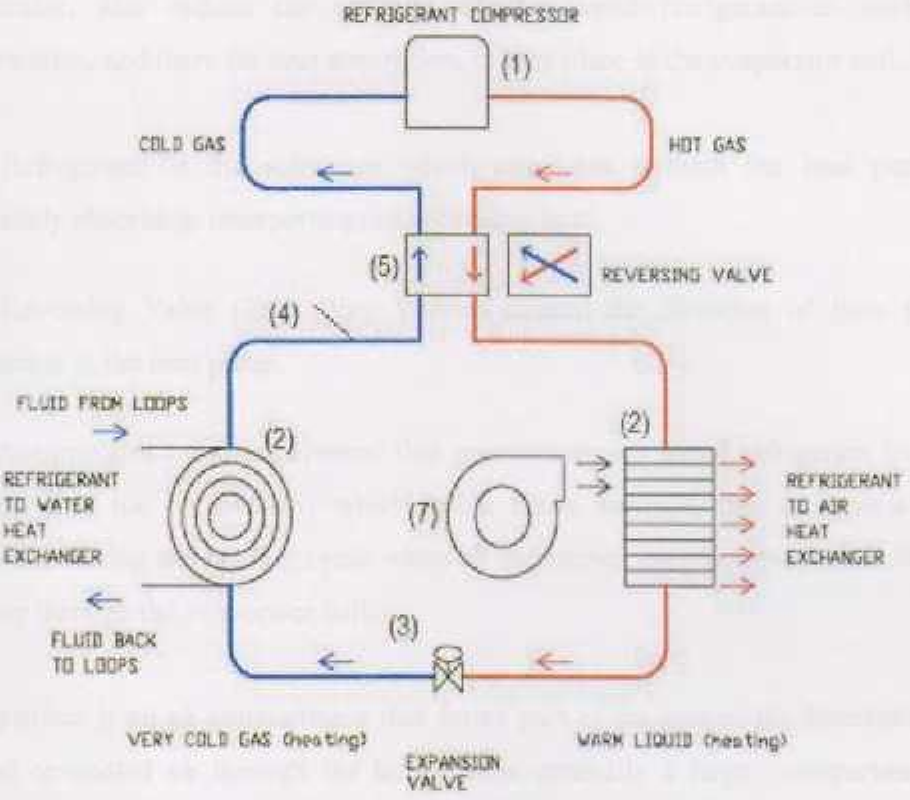


Figure 3.1: Schematic of a vapor compression heat pump

3.3.1 Heat Pump Components

1. The Compressor: draws the refrigerant from the evaporator then compresses it. Compression adds energy to the refrigerant by raising the pressure and temperature to a desired level .

2. Heat Exchanger Coils: The Evaporator and Condenser are coils that absorb or reject heat between two mediums of different temperature; because a heat pump can reverse its function (cooling or heating).

3. Expansion Valve: meters or regulates the flow of liquid refrigerant to the evaporator, also reduce the pressure of the liquid refrigerant to enable vaporization, and there for heat absorption, to take place in the evaporator coil.

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

5. The Reversing Valve (Four Way Valve): control the direction of flow the refrigerant in the heat pump.

6. The Accumulator : a storage vessel that prevents excess liquid refrigerant from passing into the compressor, which could cause damage, this is especially important during the heating cycle when all refrigerant may not evaporate after passing through the evaporator coil.

7. The plenum is an air compartment that forms part of the system for distributing heated or cooled air through the house. It is generally a large compartment immediately above or around the heat exchanger.

3.4 Types of Heat Pumps

Heat pumps are often classified according to their heat source. The three principal types used in residential and light commercial heating/ cooling systems are: (1) air-source heat pumps, (2) ground-source heat pumps, and (3) water-source heat pumps.

3.4.1 Air-Source Heat Pumps

An air-source heat pump (also sometimes called an air-to-air heat pump) relies on the outdoor air as the heat source. In other words, it extracts the heat from the outdoor air and transfers it to the rooms and spaces inside the structure. A major technical problem associated with earlier air-source heat pumps was that the temperature of the outdoor air is commonly lowest when heat requirements are highest—that is, during the cold winter months.

Air-source heat pumps operate most efficiently in areas where the winter temperatures usually remain above 0°C. In climates where the winter temperatures frequently drop below freezing, a backup auxiliary heater must be used with an air-source heat pump.

3.4.2 Ground Source Heat Pumps

A ground-source heat pump uses the constant temperature of the earth instead of the outdoor air as the heat-exchange medium (that is, the heat source or heat sink depending on the heating or cooling cycle).

During the summer when cool interior temperatures are required, the fluid circulating through the indoor coil of the heat pump collects the heat from inside the structure and pumps it outdoors into a pipe system located below ground. The heat is then absorbed into the ground through the piping and the fluid is recirculated back to the unit. In the winter, the process is reversed.

The system is based on the principle of heat transfer, whereby heat is transferred from one object (the underground pipe) to another object (the ground) through direct contact (see Figure 3.2). Ground-source heat pumps are more efficient and economical to operate than conventional air-source units in areas with similar heating and cooling loads [11].

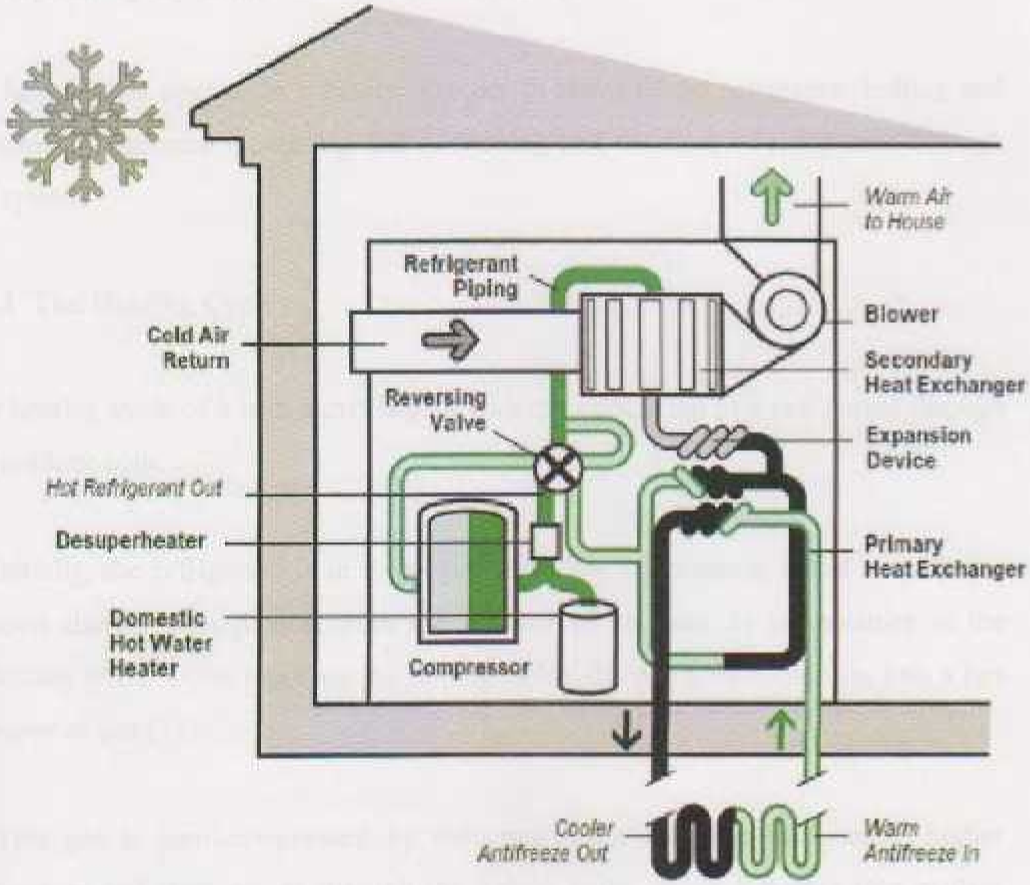


Figure 3.2: Components of a Typical Ground-Source Heat Pump

3.4.3 Water-Source Heat Pumps

Water-source heat pumps use water for both the heat source and the heat sink. The water serves as a direct heat transfer medium in contrast to the heat transfer fluid used in closed-loop systems. The steady cool temperature of the water offsets the seasonal temperature variations by serving as a reservoir of heat in the winter and as a drain of heat in the summer.

3.5 Operating Cycle for Air-Source Heat Pump

All heat pumps operate in a similar manner in terms of the refrigerant boiling and condensing, pressure increasing and decreasing and the flow of refrigerant through the system.

3.5.1 The Heating Cycle

The heating cycle of a heat pump begins with the circulation of a refrigerant through the outdoor coils.

- Initially, the refrigerant is in a low-pressure, low-temperature liquid state, but it soon absorbs enough heat from the outdoor air to raise its temperature to the boiling point. Upon reaching the boiling point, the refrigerant changes into a hot vapor or gas [12].
- This gas is then compressed by the compressor and circulated under higher pressure and temperature through the indoor coils, where it comes into contact with the cooler room air that circulates around the coils. The cooler air causes the gas to cool, condense, and return to the liquid state.
- The condensation of the refrigerant vapor releases heat to the interior of the structure. After the refrigerant has returned to a liquid state, it passes through a special pressure-reducing device (an expansion valve) and then back through the outdoor coils where the heating cycle begins all over again.
- The temperature of the room air that originally cooled the higher-temperature refrigerant vapor is itself increased by the process of heat transfer and recirculated throughout the room to provide the necessary heat.

3.5.2 The Cooling Cycle

- In the cooling cycle, the reversing valve causes the flow of the refrigerant to be reversed. As a result, the compressor pumps the refrigerant in the opposite direction so that the coils that heat the building or space in cold weather cool it in warm weather (See Figure 3.3).

- In other words, the heat is extracted from the interior, cycled through the heat pump, and then expelled outside the building or space during the condensation of the refrigerant (that is, its change from a gaseous to a liquid state).

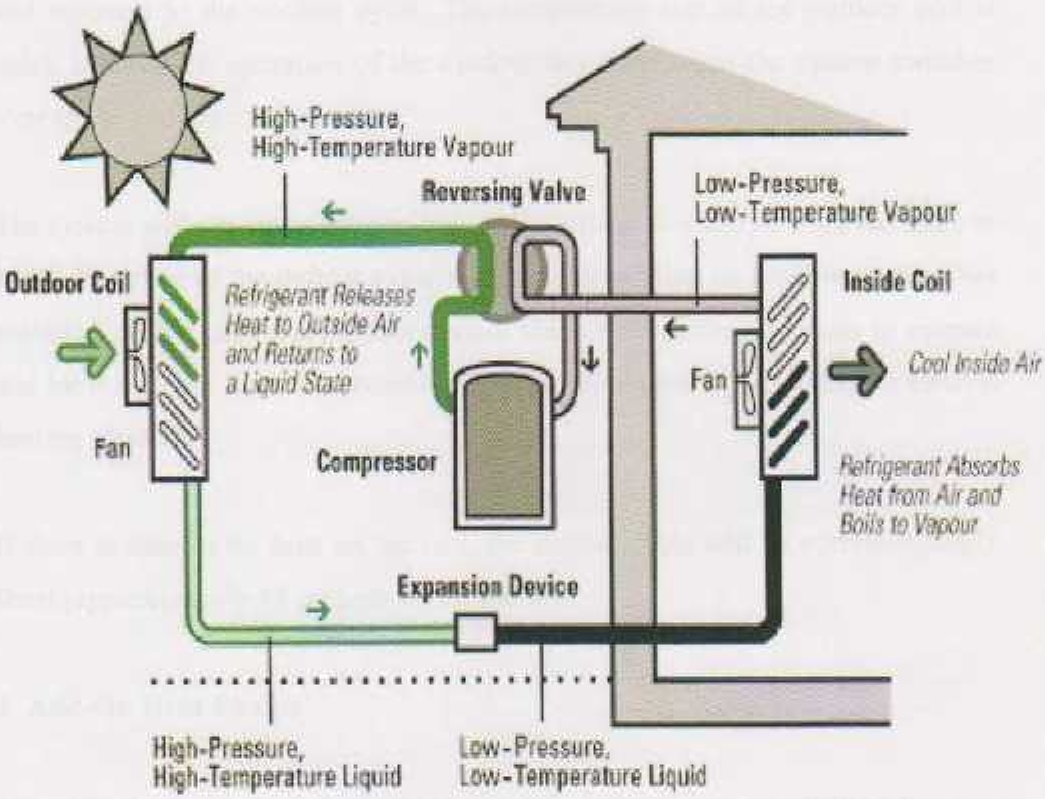


Figure 3.3: Components of an Air-source Heat Pump (Cooling Cycle)

3.5.3 The Defrost Cycle

- Applies only to air-source heat pump.

- Because the outdoor air is relatively cool when the heat pump is on the heating cycle, and the outdoor coil is acting as an evaporator, frost forms on the surface of the coil under certain conditions of temperature and relative humidity, and it must be removed. This is accomplished by putting the heat pump through a defrost cycle.

- In the defrost cycle, the action of the heat pump is reversed at certain intervals and returned to the cooling cycle. The temperature rise of the outdoor coil is quick because the operation of the outdoor fan stops when the system switches over to the cooling cycle.

- The system will remain in the cooling cycle until the coil temperature has risen to 14°C. The time of the defrost cycle will vary, depending on how much frost has collected on the coil. During this period, the indoor motor continues to operate and blow cool air. This cold condition can be eliminated by installing an electric heating element.

- If there is little or no frost on the coil, the defrost cycle will be correspondingly short (approximately 45 seconds to 1 minute).

3.5.4 Add-On Heat Pumps

An air-source heat pump can be added to new or existing gas- or oil-fired furnaces (See Figure 3.4). This unit, typically called an add-on, dual-fuel, or hybrid heat pump, normally operates as a conventional heat pump. During extremely cold weather, the refrigerant circuit is turned off and the furnace provides the required space heating. These add-on heat pumps share the air distribution system with the warm-air furnace. The indoor coil may be either parallel to or in series with the furnace. However, the furnace should never be upstream of the indoor coil if both systems are operated together. Special controls are available that prevent simultaneous operation of the heat pump and furnace in this configuration. This operation raises the refrigerant condensing temperature, which could cause compressor failure.

In applications where the heat pump and furnace operate simultaneously, the following conditions must be met: (1) the furnace and heat pump indoor coil must be arranged in parallel, or (2) the furnace combustion and flue passages must be designed to avoid condensation-induced corrosion during cooling operation. [13]

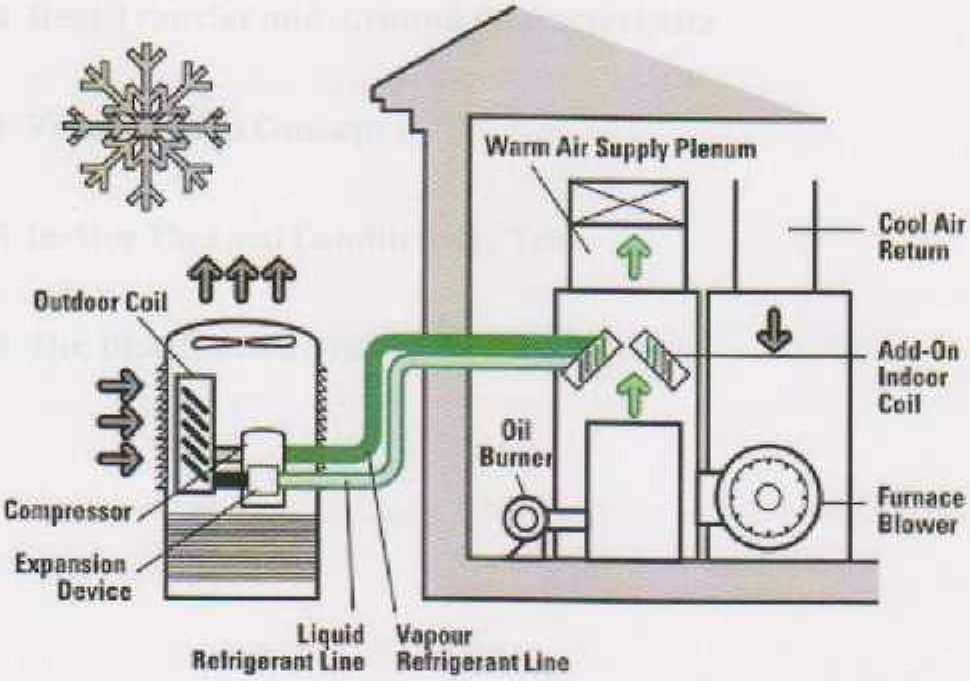


Figure 3.4: Add-On Heat Pump

CHAPTER FOUR

GEOTHERMAL HEAT PUMP SYSTEM

Content:

Chapter Four

Geothermal Heat Pump System

4.1 Overview of Ground-Source Heat Pump Systems

Ground-source heat pump (GSHP) systems (also referred to as geothermal heat pump systems, earth energy systems, and Geo Exchange systems) have received considerable attention in the recent decades as an alternative energy source for residential and commercial space heating and cooling applications. GSHP applications are one of three categories of geothermal energy resources as defined by ASHRAE (1995). These categories are:

1. high-temperature (>150 °C) electric power production.
2. intermediate- and low-temperature (<150 °C) direct-use applications.
3. GSHP applications (generally <32 °C). The GSHP applications are distinguished from the others by the fact that they operate at relatively low temperatures.

The term "ground-source heat pump" has become an all-inclusive term to describe a heat pump system that uses the earth, ground water, or surface water as a heat source and/or sink. GSHP systems consist of three loops or cycles as shown in (Figure 4.1).

1. The first loop is on the load side and is either an air/water loop or a water/water loop, depending on the application.
2. The second loop is the refrigerant loop inside a water- source heat pump.
3. The third loop in the system is the ground loop in which water or an antifreeze solution exchanges heat with the refrigerant and the earth.

Efficiencies of GSHP systems are much greater than conventional air-source heat pump systems. A higher COP (coefficient of performance) can be achieved by a GSHP because the source/sink earth temperature is relatively constant compared to air temperatures.

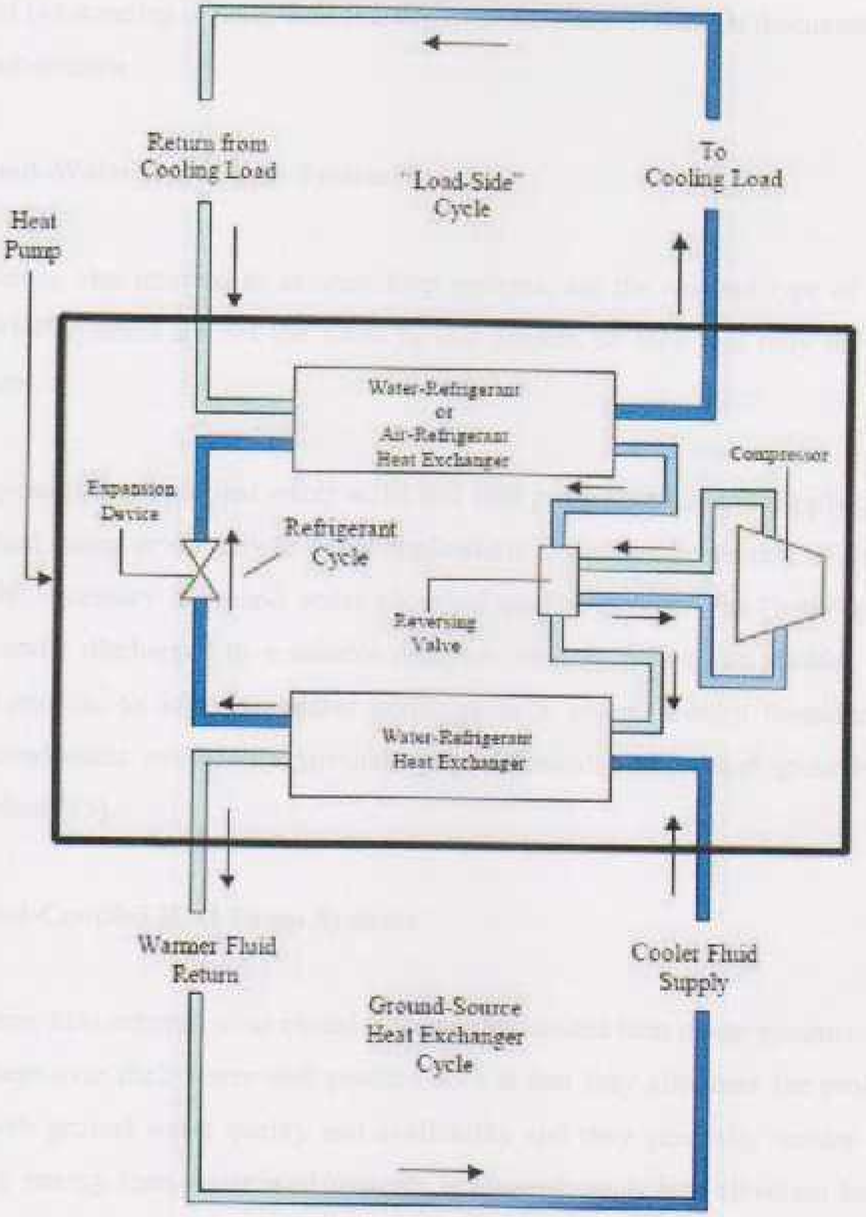


Figure 4.1: Schematic of cycles in a GSHP system in cooling mode

4.2 Types of Geothermal Heat Pump System

According to ASHRAE (1995) groups GSHP systems included into three categories based on the heat source/sink used. A fourth category is added here for the sake of completeness. These categories are: (1) ground-water heat pump (GWHP) systems, (2) ground-coupled heat pump (GCHP) systems, (3) surface water heat pump (SWHP) systems, and (4) standing column well (SCW) systems. Each of these is discussed in the following subsections.

4.2.1 Ground-Water Heat Pump Systems

GWHP systems, also referred to as open-loop systems, are the original type of GSHP system. GWHP systems are not the focus of this project, so they will only be briefly described here.

In GWHP systems, conventional water wells and well pumps are used to supply ground water to a heat pump or directly to some application. Corrosion protection of the heat pump may be necessary if ground water chemical quality is poor. The "used" ground water is typically discharged to a suitable receptor, such as back to an aquifer, to the unsaturated zone a, to a surface-water body, or to a sewer. Design considerations include: ground-water availability, ground-water chemical quality, and ground-water disposal method [15].

4.2.2 Ground-Coupled Heat Pump Systems

GCHP systems, also referred to as closed-loop ground-source heat pump systems. Their main advantage over their water-well predecessors is that they eliminate the problems associated with ground water quality and availability and they generally require much less pumping energy than water well systems because there is less elevation head to overcome.

In GCHP systems, heat rejection/extraction is accomplished by circulating a heat exchange fluid through a piping system buried in the earth. This fluid is either pure water or an antifreeze solution and is typically circulated through high-density polyethylene (HDPE) pipe installed in vertical boreholes or horizontal trenches as shown in (Figure 4.2, Figure 4.3). These systems are further subdivided into vertical GCHP systems and horizontal GCHP systems.

4.2.2.1 Vertical Ground-Coupled Heat Pump Systems

Vertical borehole GCHP systems are the primary focus of this entire research. Therefore, they are described in some detail here and their design challenges are explained, laying the foundation for the motivation of this study.

In vertical borehole GCHP systems, ground heat exchanger configurations typically consist of one to tens of boreholes each containing a U-shaped pipe through which the heat exchange fluid is circulated. A number of borehole to borehole plumbing arrangements are possible. Typical U-tubes have a diameter in the range of (19 to 38 mm) and each borehole is typically (30.5 to 122 m) deep with a diameter ranging from (76 to 127 mm). The borehole annulus is generally backfilled with a material that prevents contamination of ground water (see Figure 4.2) [4].

The advantages of the vertical GCHP are that it (1) requires relatively small plots of ground, (2) is in contact with soil that varies very little in temperature and thermal properties, (3) requires the smallest amount of pipe and pumping energy, and (4) can yield the most efficient GCHP system performance. Disadvantages are (1) typically higher cost because of expensive equipment needed to drill the borehole and (2) the limited availability of contractors to perform such work.

Figure 4.2: A schematic of a vertical borehole ground-coupled heat pump system

4.2.2.2 Horizontal Ground-Coupled Heat Pump Systems

In horizontal GCHP systems, ground heat exchanger configurations typically consist of a series of parallel pipe arrangements laid out in dug trenches or horizontal boreholes about (0.91 to 1.83 m) deep. A number of piping arrangements are possible. "Slinky" configurations (as in Figure 4.3) are popular and simple to install in trenches and shallow excavations. In horizontal boreholes, straight pipe configurations are installed. Typical pipes have a diameter in the range of (19 to 38 mm) and about (121.9 to 182.9 m) of pipe is installed per ton of heating and cooling capacity [13].

The thermal characteristics of horizontal GCHP systems are similar to those of vertical ones. The main difference is that horizontal ground-loop heat exchangers are more affected by weather and air temperature fluctuations because of their proximity to the earth's surface.

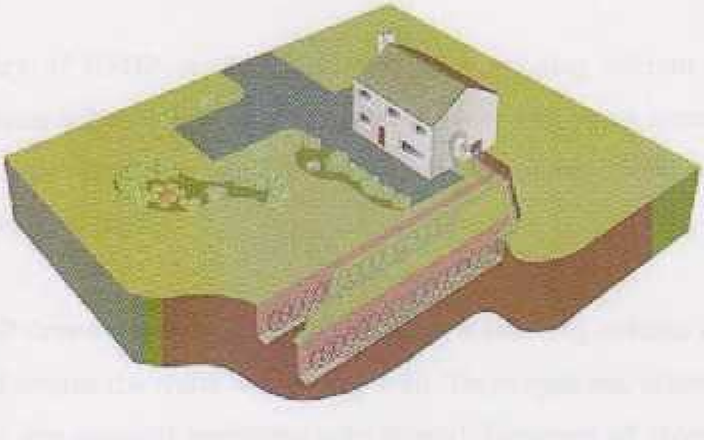


Figure 4.3: A schematic of a horizontal borehole ground-coupled heat pump system

4.2.3 Surface-Water Heat Pump Systems

The third category of GSHP systems is the surface-water heat pump (SWHP) system. A schematic of a SWHP system is shown in (Figure 4.4). The surface-water heat exchanger can be a closed-loop or open-loop type. Typical closed-loop configurations are the Slinky coil type or the loose bundle coil type. In the closed-loop systems, heat rejection/extraction is accomplished by circulating a heat exchange fluid through HDPE pipe positioned at an adequate depth within a lake, pond, reservoir, or other suitable open channel.

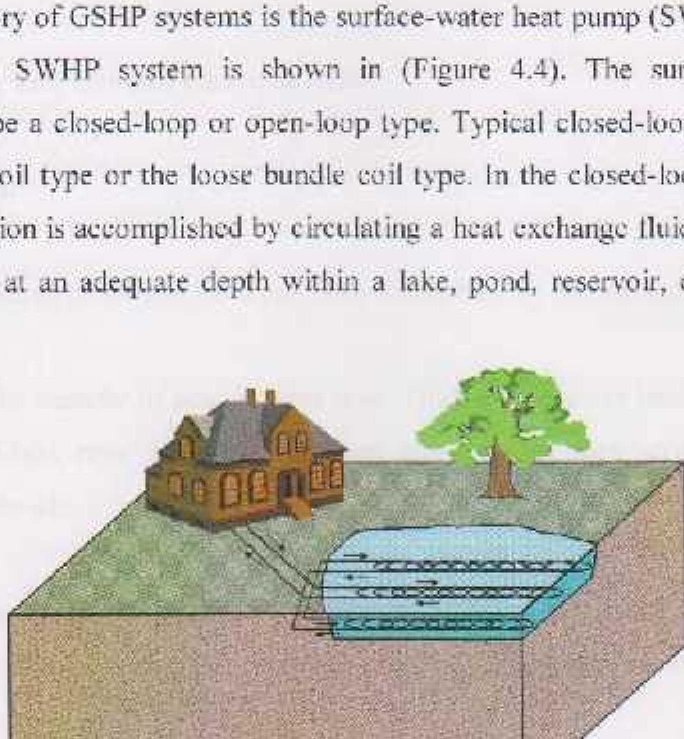


Figure 4.4: A schematic of a surface-water heat pump system.

4.2.4 Standing Column Well Systems

The fourth category of GSHP systems is known as a standing column well (SCW) system. These systems are about as old as the ground-water heat pump systems, but are recently receiving much attention. Since these are not the subject of this research, they are only briefly discussed here.

This type of GSHP draws water to a heat pump from a standing column of water in a deep well bore and returns the water to the same well. These systems, primarily installed in hard rock areas, use uncased boreholes with typical diameters of about (15.24 cm) and depths up to (457.2 m). The uncased borehole allows the heat exchange fluid to be in direct contact with the earth and allows ground water infiltration over the entire length of the borehole.

4.3 Heat Transfer and Ground Characteristics

4.3.1 Heat Transfer

Heat may be transferred or moved from one body to another by one of three methods:

1. Radiation: is the transfer of heat by heat rays. The earth receives heat from the sun by radiation. Light rays from the sun turn into heat as they strike opaque or translucent materials.

2. Conduction: is the flow of heat between parts of a substance by molecular vibrations. The flow can also be from one substance to another substance in direct contact.

3. Convection: is the movement of heat from one place to another by way of fluid or air. [17].

4.3.2 Ground Characteristics

The definition of geothermal energy is subject to variation, in some cases it is considered to be heat below 15-20m in the ground while in others simply all energy stored as heat beneath the earth's surface. Regardless of definition this relatively constant store can be utilized by a heat pump for heating and cooling applications since in winter the ground temperature will be above the average air temperature while in the summer it is likely to be below it (see Figure 4.5).

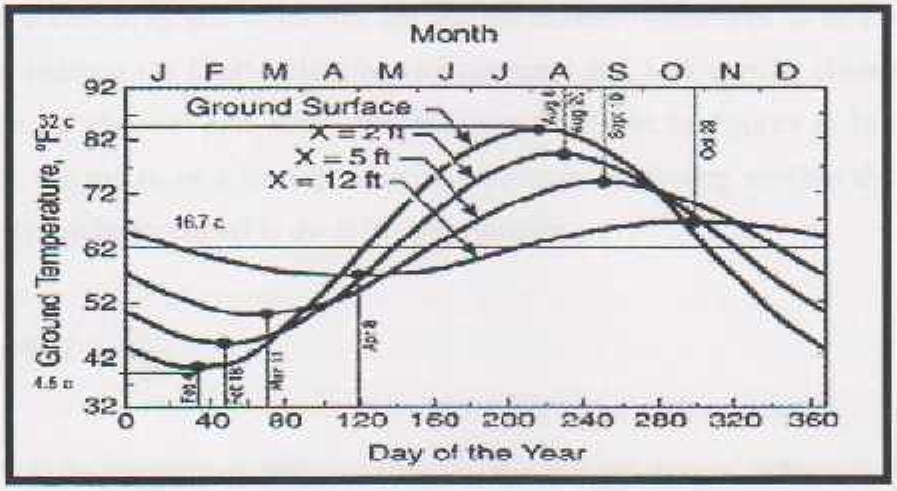


Figure 4.5: Typical Ground Temperature change around the year

The capacity of the GSHP for heating and cooling will depend on not just the size of the system but also the thermal properties of the ground system performance is significantly affected by the material in which the ground heat exchanger (loop) is laid. Factors which will determine performance are :

1. Subsurface temperature.

2. Thickness and nature of superficial deposits i.e. soil.

3. Rock properties i.e. stratigraphy (formation) and lithology (type).
   These will determine strength and conductivity.

4. Hydrological issues, depth to groundwater, seasonal variations in Groundwater temperature, flow direction etc. For vertical type geothermal heat pumps "In general groundwater flow improves heat exchange", when significant flow is present, at 4-10°C heat exchange occurs through a dual mechanism of conduction in the aquifer material and convection in the groundwater itself.

Thermal conductivity and diffusivity are two parameters which need to be clarified in order to estimate the likely subsurface temperatures and heat transfer characteristics. Based on the classical heat conduction equation developed by Fourier in 1822 which considers the soil to be a homogeneous and isotropic conducting medium the thermal diffusivity can be expressed in the following equation:

$$\alpha \nabla^2 T = \frac{dT}{dt} \tag{4.1}$$

Where T is the temperature (°K), t is time (s), and α is the thermal diffusivity (m^2/s) of the conducting medium and defined by

$$\alpha = \frac{k}{\rho\, C_p} \tag{4.2}$$

Where k is the thermal conductivity (W/(m.°K), ρ is the density (kg/m^3). And C_p is the mass specific heat capacity (J/(kg.°K). The higher the value of α the faster the propagation of heat within the medium [16].

4.3.2.1 Thermal conductivity (k)

Thermal conductivity is the quantity of rate of heat transmitted per unit area, per unit temperature gradient under steady state conditions. By Multiplying this factor by the thermal gradient will give the heat flow within the ground.

Generally rocks have higher k values than soils. Variability in the latter is explained due to mixing of mineral and organic particles and their associated thermal characteristics. Furthermore in dry soils air is trapped, and since this has a low k value, saturation will raise the conductivity of soils; "Low conductivity soil may require as much as 50% more collector loop than highly conductive soil" [17].

4.3.2.2 Thermal Diffusivity

Thermal diffusivity is the ground thermal conduction in relation to thermal capacity. This links thermal conductivity, specific heat (Cp) and density (ρ). Density is multiplied by specific heat is termed volumetric heat capacity. A high thermal diffusivity value is desirable since this means the material will quickly adjust temperature to that of the surrounding environment since heat is conducted rapidly relative to thermal mass.

4.4 Vertical Loop Concept

4.4.1 Formulas and Concept

One of the fundamental tasks in the design of a reliable GCHP system is properly sizing the ground-coupled heat exchanger length (i.e. depth of boreholes).

The task of sizing the ground-loop heat exchanger was accomplished using rules of thumb (i.e. 250 feet of bore length per ton of heating or cooling capacity) according to ASHREA but this is of course depends on several things of which, the location, the depth and size of the excavation, the time of the year, the soil diffusivity of heat, the heat pump design conditions, the fluid, the pipes type and thermal properties, the flow type and velocity which is relevant to the pump selection of flow and head, the ground water, the percentage of water content in soil, and many other factors.

To design the loop underground several factors were taken into consideration of which:

A. The fluid used was water because it has high heat capacity. From tables of properties of refrigerant R410a which is used in the heat pump, it can be seen that the condenser unit rejects the heat at 75 ° C in summer and absorbers heat in the vicinity of the evaporator at 2-4 °C because the outdoor design temperature is 35 °C for cooling in summer and 0 °C for heating in winter. The outdoor temperature should be less than 35° C in summer and more than 0 °C in winter to achieve better performance.

   Water is excellent for applications that are above freezing point and below boiling point. But in cold weathers fluids will have to withstand a temperature below freezing point of water, in this case adding antifreeze will be the solution and the performance will drop a little bit but the system will not be damaged because of freezing the water in the heat exchanger. Antifreeze should be added to the water in case of lower temperature which is not our case. Table 4.1 below shows several types of solutions that can be added to water to prevent freezing [18].

   Using the formula:

$$Q[kW] = \dot{m}\left[\frac{L}{s}\right] * Cp\left[\frac{kJ}{kg°C}\right] * \rho\left[\frac{kg}{L}\right] * \Delta T[°C] \qquad (4.3)$$

Table 4.1: Densities and Specific Heats for Various Solutions

	% by Weight	Mean Temp (°C)	Freezing Point (°C)	Density (kg/m^3)	Specific Heat (kJ/°K*kg)
Pure Water	100	25	0	999.6	4.184
Methanol Solution	13.6	25	-9.4	980.2	4.232
	10.0	30	-6.7	904.2	4.274
	6.3	35	-3.9	989.0	4.296
	2.0	40	-1.1	989.4	4.275
Ethylene Glycol Solution	20.0	25	-9.4	1034.4	3.848
	14.6	30	-6.7	1024.4	3.975
	8.8	35	-3.9	1017.3	4.100
	2.5	40	-1.1	1002.9	4.190
Propylene Glycol Solution	23.5	25	-9.4	1024.5	4.023
	18.3	30	-6.7	1017.3	4.065
	12.9	35	-3.9	1012.5	4.107
	5.9	40	-1.1	1005.3	4.149
Sodium Chloride Solution	13.3	25	-9.4	1103.6	3.627
	10.1	30	-6.7	1077.2	3.688
	6.4	35	-3.9	1048.4	3.847
Calcium Chloride Solution	14.3	25	-9.4	1134.7	3.332
	11.3	30	-6.7	1103.6	3.499

B. Pipe Type: Pipes are either steel for vertical design, or High density polyethylene for horizontal design, for leakage problems steel pipes are not used. HDPE pipes are defined by their pressure ratings which can be measured by the Standard Dimension Ratio – SDR [19].

It is common to use the SDR as method of rating pressure piping as seen in the Figure (4.6) where S is the thickness of the pipe and D is the outer diameter of the pipe. Then SDR is:

$$SDR = \frac{D}{S} = \frac{Diameter}{Thickness} \tag{4.4}$$

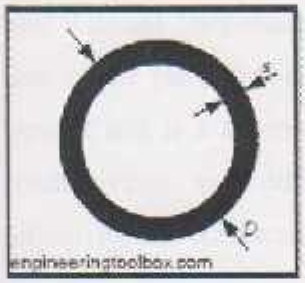


Figure 4.6: Standard Dimension Ratio descriptions

All properties for the pipe are now known such as thickness, material, so the heat conducted through pipes is now known as in Tables (4.2) [20].

Table 4.2: Minimum Required Flow Rate (L/min) for Non laminar Flow Re>3000

Fluid (% by weight)	**T = -1 ° C**				**T = 10 ° C**			
	Nominal Diameter SDR 11 Pipe				**Nominal Diameter SDR 11 Pipe**			
	3/4 in. (20	**1 in. (25 mm)**	**1 1/4 in. (32**	**1 1/2 in. (37.5 mm)**	**3/4 in. (20 mm)**	**1 in. (25 mm)**	**1 1/4 in. (32**	**1 1/2 in. (37.5 mm)**
20% Ethanol	14.3	18.2	22.7	26.1	9.8	12.1	15.1	17.4
20% Ethylene Glycol	9.5	11.7	14.8	17.0	6.8	8.4	10.6	11.7
20% Methanol	11.0	13.6	17.0	19.7	7.6	9.5	11.7	13.2
20% Propylene Glycol	12.9	15.9	20.4	23.1	8.7	10.6	13.6	15.5
20% Calcium Chloride	8.6	11.0	13.6	15.5	5.3	7.6	8.4	9.7
Water	--	--	--	--	4.2	5.3	6.5	7.6

C. Soil: Ground temperature is changing according to the geographical location, the time of the year, time after being disturbed, type and the depth in the ground. The type of soil is a determinant factor because different soils have different thermal conductivities and different thermal diffusivity. Moisture content affects the diffusivity and conductivity all this is shown in table (4.3) and table (4.4) [20].

Table 4.3: Thermal Properties of Rocks at 25°C

Rock Type	**% Occurrence in Earth's Crust***	**k - All** Thermal Conductivity** (W/m.K)	**k - 80%*** Thermal Conductivity** (W/m.K)	**c p Specific Heat** (J/kg.K)	**ρ Density** (kg/m^3)	α(k/ρCp) **Thermal Diffusivity** m^2/day
Dense Rock	--	3.46	--	840	3200	0.111
Average Rock	--	2.42	--	840	2800	0.089
Dense Concrete	--	1.73	--	840	2400	0.073
Heavy soil, Saturated	--	2.42	--	840	3200	0.078
Solid	--	1.3	--	880	2290	0.056
Heavy soil, Damp	--	1.3	--	960	2100	0.056
Heavy soil, Dry	--	0.87	--	840	2000	0.045
Light soil, Damp	--	0.87	--	1050	1600	0.045
Light soil, Dry	--	0.35	--	840	1440	0.024

*** Percentage of sedimentary rocks is higher near the surface.**

**** "All" represents the conductivity range of all samples tested.**

***** "80%" represents the mid-range for samples of rock.**

Table 4.4: Thermal Conductivity and Diffusivity of Sand and Clay Soils

Soil Type	Dry Density (kg/m^3)	5% Moist		10% Moist		15% Moist		20% Moist	
		k (W/m K)	α (m^2/day)	k (W/m K)	α (m^2/day)	k (W/m K)	α (m^2/day	k (W/m K)	α (m^2/day)
Coarse 100% Sand	1900	2.1-3.3	0.089-0.14	2.4-3.5	0.086-0.12	2.8-3.8	0.085-0.11	-	-
	1600	1.4-2.4	0.072-0.12	2.1-2.6	0.089-0.11	2.3-2.8	0.083-0.10	2.4-2.9	0.078-0.093
	1300	0.9-1.9	0.056-0.12	1.0-1.9	0.056-0.10	1.0-2.1	0.047-0.093	1.2-2.1	0.048-0.083
Fine Grain 100% Clay	1900	1.0-1.4	0.045-0.060	1.0-1.4	0.037-0.049	1.4-1.9	0.043-0.059	-	-
	1600	0.9-1.0	0.045-0.054	0.9-1.0	0.037-0.045	1.0-1.2	0.034-0.045	1.0-1.4	0.038-0.051
	1300	0.5-0.9	0.033-0.056	0.6-0.9	0.033-0.047	0.7-0.95	0.032-0.044	0.7-1.0	0.028-0.042

* Values indicate ranges predicted by five independent methods. k = Thermal Conductivity, α = Thermal Diffusivity, Coarse Grain= 0.075 to 5mm - Fine Grain less than 0.075mm (0.075mm = #200 U.S. Standard Sieve

A vertical GCHP (see Figure 4.7) generally consist of two small-diameter, high-density polyethylene (HDPE) tubes placed in a vertical borehole that is subsequently filled with a solid medium. The tubes are thermally fused at the bottom of the bore to a close return U-bend. Vertical tubes range from 20 to 40 mm nominal diameter. Bore depths range from 15 to 180 m, depending on local drilling conditions and available equipment. Boreholes are typically 100 to 150 mm in diameter for single and double loop.

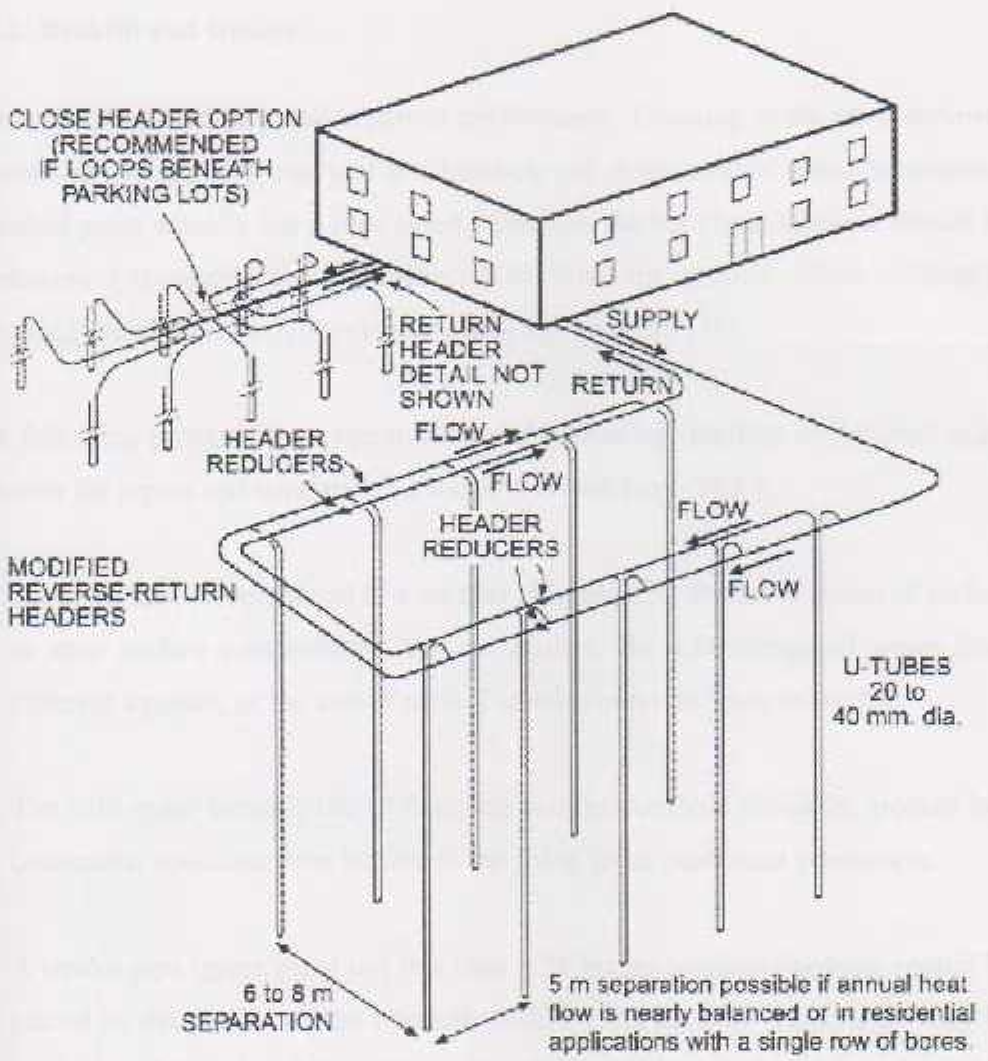


Figure 4.7: Vertical Ground-Coupled Heat Pump Piping

To reduce thermal interference between individual bores, a minimum borehole separation distance of 6 m is recommended when loops are placed in a grid pattern. This distance may be reduced when bores are placed in a single row, the annual ground load is balanced (i.e., energy released in the ground is approximately equal to the energy extracted on an annual basis), or water movement or evaporation and subsequent recharge mitigates the effect of heat build-up in the loop field [13].

4.4.2 Backfill and Grouts

The backfill also plays a major part in performance. Grouting is the most common material for backfill. It can seal the borehole off from surface water penetration. Standard grout actually has a poor conductivity, so the bore hole diameter should be minimized (Approximately 5" diameter) to limit the grout's affect. Thermally enhanced grouts have been developed to address this issue [21].

The following provisions are recommended for grouting (sealing) of the void space between the piping and borehole of a Vertical closed-loop (VCL):

1. Grouting is to be completed in a manner that prevents the introduction of surface or near surface contaminants into an aquifer, the interchange of water from different aquifers, or the loss of natural artesian pressure from an aquifer.

2. The void space between the VCL piping and the borehole should be grouted in a continuous operation from bottom to top using grout placement procedures.

3. A tremie pipe (grout pipe) not less than 1.25 inches nominal diameter should be placed to the bottom of the borehole before grouting. The tremie pipe may be used to push the closed-loop piping into the borehole and should be retracted as grouting proceeds.
4. Grout should be pumped through the tremie pipe until the density of the grout flowing from the borehole at the ground surface equals the density of the grout being pumped in.

5. Grout manufacturers' product specifications should be followed when mixing and pumping grout.

4.5 In-Situ Thermal Conductivity Tests

Ground testing provide 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 a provide a price with less of a hedge in it.

The test are generally connected by drilling a bore hole and adding a loop. Hot water from portable eclectic heater is circulated as shown in Figure 4.8.

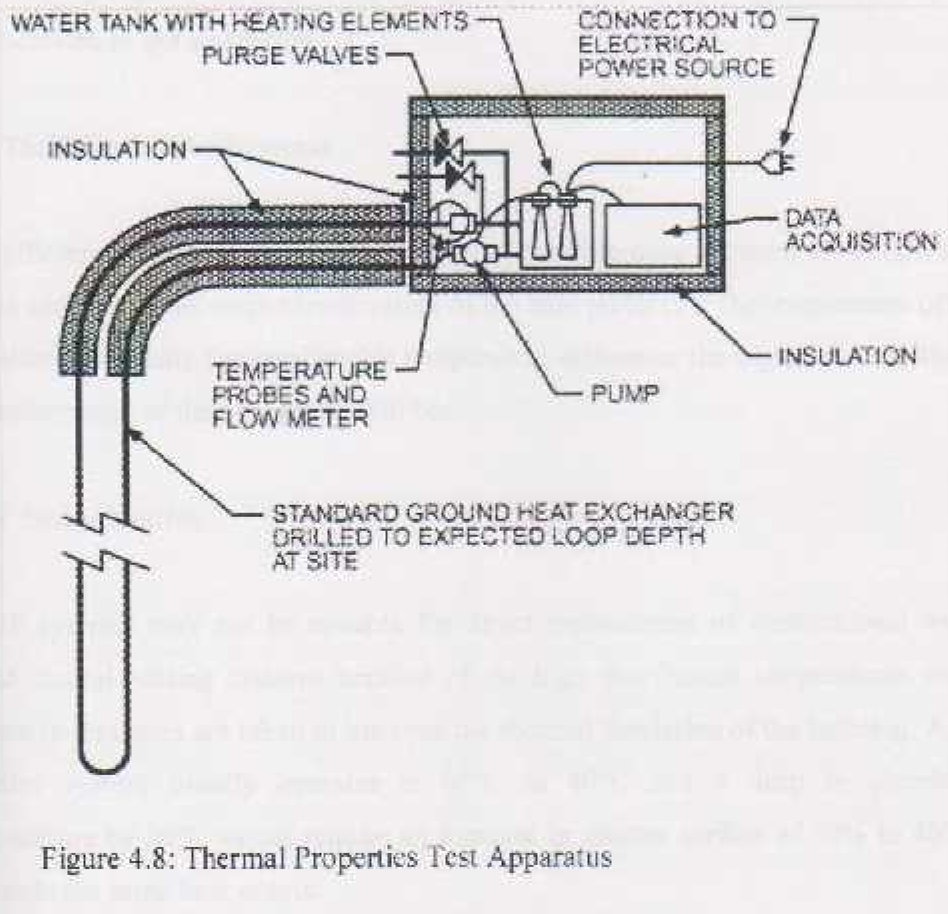


Figure 4.8: Thermal Properties Test Apparatus

We take a specifications to enhance reported accuracy, that are include [22]:

- Test duration should be 36 to 48 hours.
- Heat input rate should be 15 to 25 W for each foot of borehole depth.
- The input electric power to the heater should have a standard deviation of less than ±1.5% of the average value and the peaks less than ±10% of the average.
- After the ground loop is installed with grout, a five-day waiting period should elapse before starting a test in low-thermal conductivity soils [k<1.0 Btu/hr-ft-°F(1.7 W/m.°C)]. In more conductive soils a three-day waiting period is recommended.
- At the end of the waiting period the ground temperature should be measured by inserting a probe inside the liquid-filled ground heat exchanger at three vertical locations to get an average.

4.6 The Distribution Systems

The efficiency of a heat pump is a function of the difference between the temperature of the source and the output temperature of the heat pump (i.e. the temperature of the distribution system).The smaller this temperature difference the higher the coefficient of performance of the heat pump will be.

4.6.1 Space heating

GSHP systems may not be suitable for direct replacement of conventional water-based central heating systems because of the high distribution temperatures unless extensive measures are taken to improve the thermal insulation of the building. A wet radiator system usually operates at 60°C to 80°C and a drop in circulating temperature by 20°C would require an increase in emitter surface of 30% to 40% to maintain the same heat output.

Table 4.5 shows the supply temperatures required for a range of domestic heating distribution systems.

Table 4.5: Typical delivery temperatures for various heating distribution systems

Distribution system	**Delivery temperature °C**
Underfloor heating	30-45
Low temperature radiators	45-55
Conventional radiators	60-90
Air	30-50

For new housing where high insulation levels result in low heating demand, low temperature air distribution systems, low temperature water-based systems or under floor heating are all possible options. The most efficient type of space heating to use with a GSHP system is underfloor heating.

The thermal capacity of the distribution system is important. If it is too low the heat pump may suffer from artificially long off periods at times of light load. This effect is partly due to the presence of a restart delay (designed to reduce wear on the compressor by preventing rapid on/off cycling) in the heat pump.

4.6.2 Space Cooling

Most water-to-air heat pumps are reversible so a forced air distribution system can readily be adapted to provide cooling as well as heating. A reversible water-to-water heat pump coupled to an under floor distribution system can also be designed to supply space cooling in summer. Even with water-to-water heat pumps designed for heating only, a limited amount of 'passive' summer cooling can be provided by direct use of the ground loop for example by by-passing the heat pump, and circulating fluid from the ground coil through a fan convector.

CHAPTER FIVE

THEORITICAL DESIGN AND CALCULATIONS

Content:

Chapter Five

Theoretical Design And Calculations

5.1 Introduction

The designer must perform his normal tasks, such as zone-by-zone load analysis. In addition, he must also specify the geothermal type, total bore length, minimum separation distance, pipe diameter, U-bend diameter, operating parameters and antifreeze properties. This chapter will provide the designer with some details 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 are taken in august.

$T_i = 24$ °C

$T_{out} = 34$ °C

$$T_{om} = T_{out} - \frac{DR}{2} \qquad (5.1)$$

Where T_i is the room design temperature, T_{out} is the outdoor temperature, T_{om} is the outdoor mean temperature. DR is the daily range temperature. [23]

$DR = T_{ave.max} - T_{ave.min} = 40 - 31.5 = 8.5$ °C

$\rightarrow T_{om} = (34 - \frac{8.5}{2}) = 29.75$ °C

5.2.2 Heat Gain Through Sunlit Walls

Construction of the wall:

(Stone) + (Concrete) + (Insulation) + (Plastering) see Figure & Table (5.1).

Calculation of overall heat transfer coefficient (U) for external wall as follow:

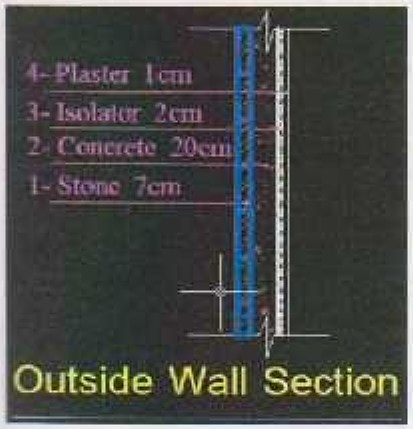


Figure 5.1: Outside wall section

k W/m.°C	Thickness m	Layer
2.2	0.07	Hard Stone (1)
1.75	0.20	Concrete (2)
0.034	0.02	Polystyrene (3)
0.72	0.01	Cement plaster(4)

Table 5.1: Outside wall Component

$$U = \frac{1}{\left(\frac{1}{hfin}\right) + \left(\frac{\Delta x}{ks}\right) + \left(\frac{\Delta x}{kc}\right) + \left(\frac{\Delta x}{ki}\right) + \left(\frac{\Delta x}{kp}\right) + \left(\frac{1}{hfout}\right)} \tag{5.2}$$

Where ks Thermal conductivity of stone, kc is thermal conductivity of concrete, kp is thermal conductivity of cement plaster, ki is thermal conductivity of polystyrene, hf_{in} is the convection coefficient of inside air, hf_{out} is the convection coefficient of outside air.

So:

$$U = \frac{1}{\left(\frac{1}{8.33}\right) + \left(\frac{0.07}{2.2}\right) + \left(\frac{0.2}{1.75}\right) + \left(\frac{0.02}{0.034}\right) + \left(\frac{0.01}{0.72}\right) + \left(\frac{1}{16.66}\right)}$$

$U = 0.96$ W/m.°C

$$\dot{Q} = U * A * \Delta T \tag{5.3}$$

Where A is the area of the wall and ΔT is the total equivalent temperature difference, 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 taken from Table (A-2) needs to be corrected and can be calculated from the following equation:

$$(\mathrm{CLTD})_{corr} = (\mathrm{CLTD} + \mathrm{LM})k + (25.5 - T_i) + (T_{am} - 29.4)f \tag{5.4}$$

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 $k = 1$ for dark colored roof, $k = 0.5$ for permanently light colored roofs, $k = 0.65$ for permanent light color walls, and the factor f is attic fan factor such that $f = 1$, if there is no attic or roof fan; $f = 0.75$, if there is an attic or roof fan.

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

$$\dot{Q} = U * A * (\mathrm{CLTD})_{corr} \tag{5.5}$$

And we can show these calculations for ground floor, first, second, and third floor in Table (5.2), means we have the same combination of internal, and external walls for each floor, for details about building see Figure (A-35), and (A-36).

Table 5.2: Ground, first, second, and third floor (Wall)

Component	Direction	LM	CLTD	(CLTD)corr.	A(m^2)	$\dot{Q}(W)$
BDR1	N	-1.1	0	1.135	10.04	11.39
BDR1	W	0.0	1	2.5	9.95	24.87
Bath1	N	-1.1	0	1.135	4.7	6.34

Component	Direction	LM	CLTD	(CLTD)corr.	A(m^2)	$\dot{Q}(W)$
Bath1	E	0.0	12	9.65	7.5	72.37
BDR2	W	0.0	1	2.5	9.95	24.87
BDR3	W	0.0	1	2.5	9.95	24.87
BDR3	S	0.5	9	8.025	11.08	100
Bath2	S	0.5	9	8.025	4.7	37.7
Bath2	E	0.0	12	9.65	6.9	66.58
Lobby	S	0.5	9	8.025	6.51	52.24
Kitchen	W	0.0	1	2.5	7.5	18.75
Kitchen	S	0.5	9	8.025	9.58	76.9
Kitchen	E	0.0	12	9.65	9.88	95.34
Dining	E	0.0	12	9.65	6.3	60.8
Salon	S	0.5	9	8.025	2.4	19.26
Salon	E	0	12	9.65	11.38	109.8
Salon	N	-1.1	0	1.135	8.38	9.51
Bath3	N	-1.1	0	1.135	3.2	3.63
Bath3	W	0.0	1	2.5	7.5	18.75

5.2.3 Heat Gain Through Ceiling ($\dot{Q}_{ce}$) and Floor ($\dot{Q}_f$)

$$\dot{Q}_f = U_{floor} * A * \Delta T \tag{5.6}$$

$$\dot{Q}_{ce} = U_{ce} * A * (CLTD)_{corr} \tag{5.7}$$

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

$T_{ground} = 27.5$ °C

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

$U_{floor} = 2.328\ W/m^2.°C$ this value taken from Table (A-15)

$U_{ce} = 1.08\ W/m^2.°C$ this value taken from Table (A-16)

Tables (5.3) shows these calculations for ground and third floor because there is no ground or ceiling for first, and second floor.

Table 5.3: Ground and Third floor (Floor, Ceiling)

Component	A (m^2)	$\dot{Q}_{floor}$ (W)	$(CLTD)_{corr}$	$\dot{Q}_{cei}$ (W)
BDR1	19.6	159.7	16	338.7
Bath1	9.25	75.37	16	159.84
BDR2	17.6	143.4	16	304.13
BDR3	18.4	150	16	317.95
Bath2	3.91	31.86	16	67.56
Lobby	21.45	174.8	16	370.65
Kitchen	19.8	161.3	16	342.14
Dining	11.05	90	16	190.94
Salon	20	163	16	345.6
Bath3	3	24.4	16	51.84

5.2.4 Heat Transmitted Through Glass

5.2.4.1 Construction of the glass

Selection data:

- Double glass
- Regular double
- $U_{gl} = 3.2\ W/m^2.°C$ this value taken 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:

$$\dot{Q}_{tr} = A(SHG)(SC)(CLF) \tag{5.8}$$

Where A is the area of the glass, (SHG) is the solar heat gain factor and can be taken from Table (A-5). (SC) is the cooling load factor and can be taken from Table (A-6). (CLF) is the cooling load factor and can be taken from Table (A-7) [33].

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

$$\dot{Q}_{conv} = U * A * (CLTD)_{corr.} \tag{5.9}$$

Where CLTD is the value of the cooling load temperature difference for the glass and can be taken from Table (A-2).

Table (5.4) shows these calculations for ground, first, second, and third floor are the same as follows:

Table 5.4: Ground, First, Second, and Third floor (Glass)

Comp.	Direction	A(m^2)	(CLTD)$_{corr.}$	SHG	SC	CLF	$\dot{Q}_{tr}$	$\dot{Q}_{conv.}$	$\dot{Q}_{total}$
BDR1	N	3	7.75	117	0.51	0.86	153.5	74.4	228.35
BDR1	W	2.25	8.85	691	0.51	0.53	420.25	63.72	483.97
Bath1	N	0.45	7.75	117	0.51	0.86	23.1	11.16	34.36
BDR2	W	2.25	8.85	691	0.51	0.53	420.25	63.72	483.97
BDR3	W	2.25	8.85	691	0.51	0.53	420.25	63.72	483.97
BDR3	S	3	9.35	350	0.51	0.68	364.14	89.76	453.9
Bath2	S	0.45	9.35	350	0.51	0.68	364.14	13.46	377.6
Lobby	S	2.25	9.35	350	0.51	0.68	364.14	67.32	431.46
Kitchen	S	3.15	9.35	350	0.51	0.68	364.14	94.25	458.4

Comp.	Direction	A(m^2)	$(CLTD)_{corr}$	SHG	SC	CLF	$\dot{Q}_{tr}$	$\dot{Q}_{cond}$	$\dot{Q}_{total}$
Kitchen	E	3.15	8.85	691	0.51	0.22	244.22	89.21	333.43
Salon	E	3.15	8.85	691	0.51	0.22	244.22	89.21	333.43
Salon	N	3.15	7.75	117	0.51	0.86	161.64	78.12	239.76
Bath3	N	0.45	7.75	117	0.51	0.86	23.1	11.16	34.26

5.2.5 Heat Gain Through Ventilation, Light, and Door

5.2.5.1 For Ventilation ($\dot{Q}_{vent}$)

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 ($\dot{Q}_{light}$)

$$Q_{light} = P_l * A * (CLF)_{Lt} \tag{5.10}$$

Where P_l is the lamp rated power in watts, A is the area of room, $(CLF)_{Lt}$ is the light cooling load factor. Table (A-10) gives the light cooling load factor for two types of fixture arguments. [23]

5.2.5.3 For Door ($\dot{Q}_{door}$)

$\dot{Q} = UA\Delta T$

$U = 7\ W/m^2.°C$ this value taken from Table (A-18)

$\Delta T = 34 - 24 = 10°C$

Table (5.5) shows these calculations for ground, first, second, and third floor are the same as follows:

Table 5.5: Each Floor (Ventilation, Light, Door)

Component	$\dot{Q}_{vent}$(W)	$\dot{Q}_{light}$ (W)	$\dot{Q}_{door}$ (W)
BDR1	—	405.7	141.7
Bath1	1620	84	—
BDR2	—	385	—
BDR3	—	381	—
Bath2	1620	73	—
Lobby	—	444	141.7
Kitchen	570	434	—
Dining	—	229	189
Salon	—	414	—
Bath3	1540	56	—

5.2.6 Heat Gain Through Occupants and Equipment

5.2.6.1 For Equipment ($\dot{Q}_{equip}$)

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

5.2.6.2 For Occupants ($\dot{Q}_{occup}$)

The heat gain through Occupants can be calculated from equation:

$$\dot{Q}_{occup} = n * \dot{Q}_s * CLF_{occup} + n * \dot{Q}_L \tag{5.11}$$

Where $\dot{Q}_s$ is the sensible heat and can be taken from Table (A-14), n is the number of person, CLF_{occup} is the cooling load factor and can be taken from Table (A-11), $\dot{Q}_L$ is the latent heat. [23]

Table (5.6) shows all these calculations for ground, 1st, 2nd, and 3rd floor.

Table 5.6: Each Floor (Equipment, Occupants)

Component	$\dot{Q}_{equip}$(W)	$\dot{Q}_{occup}$(W)
BDR1	1245	267.4
Bath1	1465	86
BDR2	995	258
BDR3	650	258
Bath2	1065	86
Lobby	250	687
Kitchen	3190	344
Dining	—	514
Salon	—	258
Bath3	—	86

5.2.7 Heat Gain Through Infiltration ($\dot{Q}_{inf}$)

The cooling load due to infiltration is given by the following equation:

$$\dot{Q}_{inf} = \rho * C_p * \dot{V}_f * (T_{out} - T_{in}) \tag{5.12}$$

Where $\dot{V}_f$ is the volumetric flow rate of infiltration air, C_p is the specific heat at constant pressure, and ρ is the density of infiltration air. [23]

If the density of air which is 1.25 kg/m^3, and its specific heat at constant pressure 1000 J/kg.K are substituted eq. (5.12), then

$$\dot{Q}_{inf} = \left(\frac{1250}{3600}\right) * \dot{V}_f * (T_{in} - T_{out}) \tag{5.13}$$

$\Delta T = 34 - 24 = 10°C$

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

Where V is the volume of the room, and Air changes per hour is given in Table (A-17).

Table (5.7) shows all these calculations for ground, 1st, 2nd, and 3rd floor.

Table 5.7: Each Floor (Infiltration)

Component	$V(m^3)$	Air Change/hour	$\dot{Q}_{inf}$ (W)
BDR1	58.8	1.5	306.25
Bath1	52.8	1	183.3
BDR2	55.2	1.5	287.5
BDR3	11.73	2	81.2
Bath2	64.35	2	446.5
Lobby	59.35	2	412.5
Kitchen	33.15	2	230.5
Dining	60	2	416.7
Salon	9	3	93.7
Bath3	12.75	3	133

5.2.8 Total Cooling Load

5.2.8.1 Total Cooling Load of Ground Floor

$$\dot{Q}_{Total} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{floor} + \dot{Q}_{inf} + \dot{Q}_{door} + \dot{Q}_{v} + \dot{Q}_{l} + \dot{Q}_{equ} + \dot{Q}_{oc} \quad (5.14)$$

Table (5.8) shows all these calculations for ground floor.

Table 5.8: Ground Floor Total

Component	$\dot{Q}_{sens}$(W)	$\dot{Q}_{laten}$(W)	$\dot{Q}_{total}$(W)
BDR1	2518.4	272	2790.4
Bath1	3594.6	32	3626.6
BDR2	2676.47	64	2738.47
BDR3	2518.9	64	2582.9

Component	$\dot{Q}_{sens}$(W)	$\dot{Q}_{laten}$(W)	$\dot{Q}_{total}$(W)
Bath2	3808	32	3840
Lobby	2588.6	96	2684.6
Kitchen	5282	630	5912
Dining	1378.8	120	1498.8
Salon	1883.1	—	1883.1
Bath3	1774	32	1806
Sum	28026.3	1342	29368.3

5.2.8.2 Total Cooling Load of First and Second Floor

$$\dot{Q}_{Total} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{inf} + \dot{Q}_{door} + \dot{Q}_{v} + \dot{Q}_{l} + \dot{Q}_{equ} + \dot{Q}_{oc} \qquad (5.15)$$

Table (5.9) shows all these calculations for first floor, and the same total for second floor.

Table 5.9: First Floor Total

Component	$\dot{Q}_{sens}$(W)	$\dot{Q}_{laten}$(W)	$\dot{Q}_{total}$(W)
BDR1	2358.66	272	2630.66
Bath1	3519.1	32	3551.1
BDR2	2531.1	64	2595.1
BDR3	2368.9	64	2432.9
Bath2	3776	32	3808
Lobby	2418.8	96	2514.8
Kitchen	5120.7	630	5750.7
Dining	1288.8	120	1408.8
Salon	1720	—	1720
Bath3	1749.6	32	1781.6
Sum	26851.66	1342	28193.66

5.2.8.3 Total Cooling Load of Third Floor

$$\dot{Q}_{Total} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{ciel} + \dot{Q}_{inf} + \dot{Q}_{door} + \dot{Q}_{v} + \dot{Q}_{l} + \dot{Q}_{equ} + \dot{Q}_{oc} \qquad (5.16)$$

Table (5.10) shows all these calculations for third floor.

Table 5.10: Third Floor Total

Component	$\dot{Q}_{sens}$(W)	$\dot{Q}_{laten}$(W)	$\dot{Q}_{total}$(W)
BDR1	2697.4	272	2969.4
Bath1	3679	32	3711
BDR2	2835	64	2899
BDR3	2686.8	64	2750.8
Bath2	3853.5	32	3875.5
Lobby	2789.5	96	2885.5
Kitchen	5462.8	630	6092.8
Dining	1479.7	120	1599.7
Salon	2065.6	—	2065.6
Bath3	1801.4	32	1833.4
Sum	29340.72	1342	30682.72

$$\begin{aligned}\dot{Q}_{tot}\ Cooling\ of\ Building &= \dot{Q}_{tot1} + +\dot{Q}_{tot2} + \dot{Q}_{tot3} + \dot{Q}_{tot4}\\ &= 29368.3 + 28193.66 + 28193.66 + 30682.72\\ &= 116438.34\ \text{W}\end{aligned}$$

$$\begin{aligned}\dot{Q}_{tot}\ Design\ of\ Building &= 116438.34 * 1.1\\ &= 128082.17\ \text{W}\end{aligned}$$

5.3 Heating load

5.3.1 Heat Loss Through Walls

We can calculate the heat loss through walls by:

$$\dot{Q}_{wall} = UA\Delta T \tag{5.17}$$

Where U is the over heat transfer coefficients (0.96W/m^2.°C) which is calculated in equation (5.2), A is the area of the wall and ΔT is the total temperature difference .

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

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

$\Delta T = 24 - 4 = 20°C$

Table (5.11) shows all these calculations for ground, 1st, 2nd, and 3rd floor.

Table 5.11: Ground, 1st, 2nd, and 3rd floor (Wall)

Component	Direction	Area (m^2)	$\dot{Q}_{wall}$(W)
BDR1	W	9.95	199
BDR2	W	9.95	199
BDR3	W	9.95	199
BDR3	S	11.08	236
Bath2	S	4.7	94
Bath2	E	6.9	138
Lobby	S	6.51	130.2
Kitchen	W	7.5	150
Kitchen	S	9.58	191.6
Kitchen	E	9.88	197.6
Dimming	E	1.46	29.2
Salon	E	11.38	227.6
Salon	N	8.38	167.6
Bath3	N	3.2	64

Component	Direction	Area (m^2)	$\dot{Q}$ (W)
Lobby	N	5.82	116.4
Bath1	N	4.7	94
BDR1	N	10.04	200.8
Salon	S	2.4	48
Bath	E	7.5	150
Bath3	W	7.5	150

5.3.2 Heat Loss Through Glass

The total heating load due to exposed glass area is:

$$\dot{Q}_{glass} = UA\Delta T \tag{5.18}$$

Where U is the overall heat transfer coefficients (3.2 $W/m^2.°C$)

$\Delta T = 24 - 4 = 20°C$

Table (5.12) shows all these calculations for ground, 1^{st}, 2^{nd}, and 3^{rd} floor.

Table 5.12: Ground, 1^{st}, 2^{nd}, and 3^{rd} floor (Glass)

Component	Direction	Area (m^2)	$\dot{Q}$(W)
BDR1	W	2.05	131.2
BDR2	W	2.05	131.2
BDR3	W	2.05	131.2
BDR3	S	2.72	174.08
Bath2	S	0.4	25.6
Lobby	S	2.05	131.2
Kitchen	S	3.02	193.28
Kitchen	E	3.02	193.28
Salon	E	3.02	193.28
Salon	N	3.02	193.28
Bath3	N	0.4	25.6
Bath1	N	0.4	25.6
BDR1	N	2.72	174.08

5.3.3 Heat Loss Through Floor and Ceiling

$$\dot{Q}_f = U_f * A * \Delta T_f \quad (5.19)$$

$$\dot{Q}_{ce} = U_{ce} * A * \Delta T_{cei} \quad (5.20)$$

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

$T_{out} = 10\ °C$

$\Delta T_f = 24 - 10 = 14\ °C$

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

$\quad = 24 - 10 = 14\ °C$

$U_f = 2.328\ W/m^2.°C$ this value taken from Table (A-15)

$U_{ce} = 1.08\ W/m^2.°C$ this value taken from Table (A-16)

Table (5.13) shows these calculation for ground and third floor because there is no ground or ceiling for first, and second floor.

Table 5.13: Ground and Third floor (Floor, Ceiling)

Component	Area (m^2)	$\dot{Q}_{floor}$ (W)	$\dot{Q}_{ceiling}$ (W)
BDR1	19.6	456.3	423.36
Bath1	4.25	98.94	91.8
BDR2	17.6	409.73	380.16
BDR3	18.4	428.35	397.44
Bath2	3.91	91.03	84.45
Lobby	21.45	499.35	463.32
Kitchen	19.8	460.94	427.68
Dining	11.05	257.24	238.68
Salon	20	465.6	432
Bath3	3	69.84	64.8

5.3.4 Heat Loss Through Infiltration

The heat load due to infiltration is given by the following equation:

$$\dot{Q}_{inf} = \left(\frac{1250}{3600}\right) * \dot{V}_f * (T_{in} - T_{out}) \qquad (5.21)$$

$\Delta T = 24 - 4 = 20°C$

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

Table (5.14) shows all these calculations for ground, 1st, 2nd, and 3rd floor.

Table 5.14: Ground, 1st, 2nd, and 3rd floor (Infiltration)

Component	V (m^3)	Air Change/hour	ΔT°C	$\dot{Q}_{inf}$ (W)
BDR1	58.8	1.5	20	612.5
Bath1	12.75	3	20	265.6
BDR2	52.8	1	20	366.64
BDR3	55.2	1.5	20	574.96
Bath2	11.73	2	20	162.9
Lobby	64.35	2	20	896
Kitchen	59.4	2	20	824.94
Dining	33.15	2	20	460.38
Salon	60	2	20	833.28
Bath3	9	3	20	187.48

5.3.5 Heat Loss Through Door

$$Q_{door} = UA\Delta T \qquad (5.22)$$

$U = 7\ W/m^2.°C$ this value taken from Table (A-18)

$\Delta T = 24 - 4 = 20°C$

Table (5.15) shows these calculations for ground, first, second, and third floor are the same as follows:

Table 5.15: Each Floor (Door)

Component	Direction	A (m^2)	$\dot{Q}_{door}$ (W)
Lobby	S	2.02	283.5
Dining	E	2.7	378
Lobby	N	2.4	336
BDR1	N	2.02	283.5

5.3.6 Total Heating Load

5.3.6.1 Total Heating Load of Ground Floor

$$\dot{Q}_{Total} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{floor} + \dot{Q}_{inf} + \dot{Q}_{door} \tag{5.23}$$

Table (5.16) shows all these calculations for ground floor.

Table 5.16: Ground Floor Total

Component	$\dot{Q}_{total}$ (W)
BDR1	2057.38
Bath	634.14
BDR2	1106.57
Bath3	1743.6
Bath2	511.53
Lobby	2276.25
Kitchen	2211.64
Dining	1124.82
Salon	2128.64
Bath3	496.92
Sum	14291.5

5.3.6.2 Total Heating Load of First Floor

$$\dot{Q}_{Total} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{inf} + \dot{Q}_{door} \qquad (5.24)$$

Table (5.17) shows all these calculations for first floor, and the same total for second floor.

Table 5.17: First Floor Total

Component	$\dot{Q}_{total}$ (W)
BDR1	1601.8
Bath	535.2
BDR2	696.84
Bath3	1315.25
Bath2	420.5
Lobby	1776.9
Kitchen	1750.67
Dining	867.58
Salon	1663.04
Bath3	427.08
Sum	11079.1

5.3.6.3 Total Heating Load of Third Floor

$$\dot{Q}_{Total} = \dot{Q}_{wall} + \dot{Q}_{Glass} + \dot{Q}_{inf} + \dot{Q}_{door} + \dot{Q}_{ceil} \qquad (5.25)$$

Table (5.18) shows all these calculations for third floor.

Table 5.18: Third Floor Total

Component	$\dot{Q}_{total}$ (W)
BDR1	2024.44
Bath	627
BDR2	1077
Bath3	1712.7

Component	$\dot{Q}_{total}\ (W)$
Bath2	504.95
Lobby	2240.22
Kitchen	2178.35
Dining	1106.26
Salon	2095.04
Bath3	491.88
Sum	14057.8

$$\dot{Q}_{tot}\ heat\ of\ Building = \dot{Q}_{tot1} + +\dot{Q}_{tot2} + \dot{Q}_{tot3} + \dot{Q}_{tot4}$$
$$= 14291.5 + 11079.1 + 11079.1 + 14057.8$$
$$= 50507.5\ W$$

$$\dot{Q}_{tot}\ Design\ of\ Building = 50507.5 * 1.1$$

$$= 55558.25\ \mathrm{W}$$

5.4 Duct Design

5.4.1 Warm and Cool Air Quantities

The calculated heating load and cooling load for a given space must be met by introducing sufficient amount of warm and cool air into that space, according to the following relation. [23]

$$\dot{Q}_s = \rho C_p \dot{V}(T_s - T_i) \qquad (5.26)$$

$$\rightarrow \dot{V} = \frac{\dot{Q}_s}{\rho C_p (T_s - T_i)}$$

Where $\dot{Q}_s$ is the room sensible heat or cool heat, 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 room air, respectively.

$\rho = 1.25\ kg/m^3$

$C_p = 1.01\ kJ/kg.K$

$T_i = 24\ ^\circ C$

$T_{s\,heating} = 55\ ^\circ C$

$T_{s\,cooling} = 14\ ^\circ C$

$\dot{Q}_{s\,cooling} = 116.438\ kW$

$\dot{Q}_{s\,heating} = 50.6075\ kW$

$\rightarrow \dot{V}_{cooling} = 9.22\ m^3/s\quad Used\ to\ design\ the\ duct$

$\rightarrow \dot{V}_{s\,heating} = 1.53\ m^3/s$

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

5.4.2 Duct Sizing

The relation beteen 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-33).

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

$$\dot{V} = \frac{\pi}{4} d^2 * v \tag{5.27}$$

Four different methods are used to size ducts:

1. The Assumed Velocity Method.
2. The Equal Pressure Drop Method.
3. Balanced Pressure Drop Method.
4. Static Pressure Regain Method.

By using the assumed velocity method to size the duct from fan to diffuser and from return grille to fan, the velocity is assumed in main duct and branches related to Table (A-19) as follows:

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

$V_{branch} = (2.5\ to\ 3.5)\ m/s$

By using equation (5.26)

$d_{main\ duct} = 1.532m$

From Figure (A-37):

$\Delta P/El = 0.16\ Pa/m$

5.4.2.1 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. (5.27), then the Table (A-20) gives the equivalent of rectangular ducts for equal pressure drop and equal flow rate.

In Table (5.19), (5.20), and (5.21) show all calculations of the supply duct sizing with non-circular duct for ground, first, and third floor, where the second floor have the same duct size because it have the same load [25].

The line and components for ground floor, 1st, 2nd, and 3rd are the same design because of symmetry (repeated) in building shows in Figure (A-37).

Table 5.19: Supply duct for Ground floor with non-circular size

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
A-B	2.236	0.263	4.5	0.795	400	1400
B-C	1.957	0.285	4.5	0.744	400	1250
C-D	1.753	0.256	4	0.729	400	1200
D-E	0.661	0.309	3.5	0.473	400	500
E-F	0.491	0.242	3	0.456	400	450
D-G	1.092	0.217	3.5	0.630	400	850

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
G-H	0.879	0.248	3.5	0.565	400	700
H-I	0.411	0.172	2.5	0.457	350	500
H-J	0.411	0.257	3	0.418	350	450
J-K	0.292	0.334	3	0.352	300	350
BDR1	0.221	0.253	2.5	0.335	300	300
Bath 1	0.270	0.223	2.5	0.371	300	400
BDR2	0.170	0.297	2.5	0.294	250	250
BDR3	0.204	0.266	2.5	0.322	300	300
Bath 2	0.279	0.219	2.5	0.377	300	400
Lobby	0.213	0.259	2.5	0.329	300	300
Kitchen	0.411	0.172	2.5	0.457	350	500
Dining	0.119	0.372	2.5	0.246	200	250
Salon	0.149	0.323	2.5	0.276	250	250
Bath 3	0.143	0.331	2.5	0.270	250	250

Table 5.20: Supply duct for First & second floor with non-circular size

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
A'-B'	2.229	0.263	4.5	0.794	400	1400
B'-C'	1.929	0.287	4.5	0.739	400	1250
C'-D'	1.7365	0.258	4	0.725	400	1200
D'-E'	0.6945	0.287	3.5	0.502	400	500
E'-F'	0.489	0.243	3	0.455	400	450
D'-G'	1.042	0.224	3.5	0.615	400	800
G'-H'	0.843	0.255	3.5	0.554	400	650
H'-I'	0.455	0.162	2.5	0.481	350	550
H'-J'	0.388	0.28	3	0.406	350	400
J'-K'	0.277	0.345	3	0.343	300	350
BDR1	0.208	0.262	2.5	0.325	300	300
Bath 1	0.281	0.281	2.5	0.378	300	400
BDR2	0.2055	0.264	2.5	0.323	300	300

BDR3	0.1926	0.275	2.5	0.313	300	300
Bath 2	0.3	0.209	2.5	0.391	300	400
Lobby	0.199	0.27	2.5	0.318	300	300
Kitchen	0.455	0.162	2.5	0.481	350	550
Dining	0.111	0.388	2.5	0.238	250	200
Salon	0.136	0.342	2.5	0.263	250	250
Bath 3	0.141	0.334	2.5	0.268	250	250

Table 5.21: Supply duct for third floor with non-circular size

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
A'''-B'''	2.5068	0.139	5	0.798	400	1450
B'''-C'''	2.1998	0.265	4.5	0.788	400	1400
C'''-D'''	1.9828	0.283	4.5	0.749	400	1250
D'''-E'''	0.8377	0.356	4	0.516	400	550
E'''-F'''	0.529	0.339	3.5	0.438	400	400
D'''-G'''	1.145	0.294	4	0.603	400	750
G'''-H'''	0.917	0.242	3.5	0.577	400	700
H'''-I'''	0.482	0.245	3	0.452	400	450
H'''-J'''	0.4351	0.261	3	0.43	400	400
J'''-K'''	0.3085	0.323	3	0.362	350	350
BDR1	0.235	0.243	2.5	0.346	300	300
Bath 1	0.2939	0.212	2.5	0.387	350	350
BDR2	0.3088	0.2 05	2.5	0.396	350	350
BDR3	0.217	0.256	2.5	0.332	300	300
Bath 2	0.307	0.206	2.5	0.395	350	350
Lobby	0.228	0.248	2.5	0.34	300	300
Kitchen	0.482	0.156	2.5	0.495	350	600
Dining	0.1266	0.357	2.5	0.254	250	250
Salon	0.1635	0.305	2.5	0.288	250	250
Bath 3	0.145	0.328	2.5	0.271	250	250

5.4.3 Supply Air Ceiling Diffuser

From Table (A-22) we are give the information of supply air ceiling diffuser, Tables (5.22), (5.23), and (5.24) shows the information of supply air ceiling diffuser (see Figure (A-39) & (A-40)). [13]

Table 5.22: Ground floor Diffuser

Component	$\dot{V}$ m^3/s	ΔP In w.g	Size in*in	Type of Diffuser	CFM
BDR1	0.221	0.1	12*12	4SNOD	500
Bath 1	0.270	0.14	12*12	4SNOD	600
BDR2	0.17	0.067	12*12	4SNOD	400
BDR3	0.204	0.1	12*12	4SNOD	450
Bath 2	0.279	0.14	12*12	4SNOD	600
Lobby	0.213	0.1	12*12	4SNOD	500
Kitchen	0.468	0.1	18*18	4SNOD	1125
Dining	0.119	0.1	9*9	4SNOD	280
Salon	0.149	0.039	12*12	4SNOD	300
Bath 3	0.143	0.039	12*12	4SNOD	300

Table 5.23: First and second floor Diffuser

Component	$\dot{V}$ m^3/s	ΔP In w.g	Size in*in	Type Diffuser	CFM
BDR1	0.208	0.1	12*12	4SNOD	500
bath1	0.281	0.067	15*15	4SNOD	624
BDR2	0.205	0.100	12*12	4SNOD	500
BDR3	0.192	0.067	12*12	4SNOD	400
bath2	0.300	0.039	18*18	4SNOD	675
Lobby	0.199	0.1	12*12	4SNOD	500
Kitchen	0.455	0.1	18*18	4SNOD	1125
Dining	0.111	0.1	9*9	4SNOD	280
Salon	0.136	0.039	12*12	4SNOD	300
Bath3	0.141	0.039	12*12	4SNOD	300

Table 5.24: Third floor Diffuser

Component	$\dot{V}$ m^3/s	ΔP In w.g	Size in*in	Type Diffuser	CFM
BDR1	0.235	0.1	12*12	4SNOD	500
bath1	0.294	0.067	15*15	4SNOD	624
BDR2	0.309	0.039	18*18	4SNOD	675
BDR3	0.217	0.1	12*12	4SNOD	500
bath2	0.307	0.1	15*15	4SNOD	780
Lobby	0.228	0.1	12*12	4SNOD	500
Kitchen	0.482	0.1	18*18	4SNOD	1125
Dining	0.126	0.039	12*12	4SNOD	300
Salon	0.163	0.067	12*12	4SNOD	400
Bath3	0.145	0.039	12*12	4SNOD	300

5.4.4 Design of Return Ducts

The design of return ducts are based on using the above described methods. By using the assumed velocity method. For the return duct system, air flows through the branches into the main duct and back to the fan. [23]

Table (5.25), (5.26), and (5.27) show all calculations of the return duct with non-circular size for 1st, 2nd, and 3rd floor, where the second floor have the same duct size because it have the same load.

The line and components for ground floor, 1st, 2nd, and 3rd are the same design because of symmetry (repeated) in building shows in Figure (A-38).

Table 5.25: Return duct for Ground floor with non-circular size

Line & Component	V m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
1-2	0.491	0.244	3	0.456	400	450
4-3	0.483	0.246	3	0.452	400	450
3-2	0.653	0.3	3.5	0.487	400	500
2-5	1.144	0.213	3.5	0.645	400	900
5-6	1.357	0.267	4	0.657	400	1000
7-6	0.292	0.686	4	0.304	300	250
6-8	1.649	0.237	4	0.724	400	1200
8-9	1.768	0.305	4.5	0.707	400	1150
9-10	2.236	0.343	5	0.754	400	1300
BDR1	0.221	0.254	2.5	0.335	300	300
Bath 1	0.270	0.225	2.5	0.370	300	400
BDR2	0.170	0.3	2.5	0.294	300	300
BDR3	0.204	0.267	2.5	0.322	300	300
Bath 2	0.279	0.22	2.5	0.377	300	400
Lobby	0.213	0.26	2.5	0.329	300	300
Kitchen	0.411	0.173	2.5	0.457	350	500
Dining	0.119	0.374	2.5	0.246	250	200
Salon	0.149	0.325	2.5	0.275	250	250
Bath 3	0.143	0.334	2.5	0.269	250	250

Table 5.26: Return duct for First and second floor with non-circular size

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
1'-2'	0.489	0.243	3	0.455	400	450
4'-3'	0.4926	0.242	3	0.457	400	450
3'-2'	0.6981	0.286	3.5	0.504	400	500
2'-5'	1.187	0.207	3.5	0.657	400	950
5'-6'	1.386	0.262	4	0.664	400	1000
7'-6'	0.277	0.705	4	0.267	300	250

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
6'-8'	1.663	0.234	4	0.727	400	1200
8'-9'	1.774	0.302	4.5	0.708	400	1150
9'-10'	2.23	0.342	5	0.753	400	1300
BDR1	0.208	0.262	2.5	0.325	300	300
Bath 1	0.281	0.218	2.5	0.378	300	400
BDR2	0.205	0.264	2.5	0.323	300	300
BDR3	0.192	0.275	2.5	0.313	300	300
Bath 2	0.300	0.209	2.5	0.391	300	400
Lobby	0.199	0.27	2.5	0.318	300	300
Kitchen	0.455	0.162	2.5	0.481	350	550
Dining	0.111	0.388	2.5	0.237	250	200
Salon	0.136	0.342	2.5	0.263	250	250
Bath 3	0.141	0.334	2.5	0.268	250	250

Table 5.27: Return duct for Third floor with non-circular size

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
1'''-2'''	0.530	0.233	3	0.474	400	450
4'''-3'''	0.524	0.234	3	0.471	400	450
3'''-2'''	0.833	0.36	4	0.515	400	550
2'''-5'''	1.363	0.226	4	0.658	400	950
5'''-6'''	1.599	0.324	4.5	0.672	400	1000
7'''-6'''	0.308	0.476	3.5	0.334	300	350
6'''-8'''	1.900	0.292	4	0.733	400	1200
8'''-9'''	2.027	0.28	4.5	0.757	400	1300
9'''-10'''	2.507	0.321	5	0.798	400	1450
BDR1	0.235	0.243	2.5	0.346	300	300
Bath 1	0.294	0.212	2.5	0.387	350	350
BDR2	0.309	0.207	2.5	0.396	350	350
BDR3	0.217	0.257	2.5	0.332	300	300
Bath 2	0.307	0.208	2.5	0.395	350	350

Line & Component	$\dot{V}$ m^3/s	$\Delta P/EL$ Pa/m	v (m/sec)	d (m)	High	Width
Lobby	0.228	0.25	2.5	0.34	300	300
Kitchen	0.482	0.157	2.5	0.495	350	600
Dining	0.126	0.36	2.5	0.254	250	250
Salon	0.164	0.307	2.5	0.288	250	250
Bath 3	0.145	0.331	2.5	0.271	250	250

5.4.5 Return Air Grille

From Table (A-23) we take the information of return air grille, Table (5.28), (5.29), and (5.30) show the information of Return Air Grille.

Table 5.28: Ground floor (Grille)

Component	$\dot{V}$ m^3/s	ΔP In w.g	Size in*in	Type of Grille	CFM
BDR1	0.221	0.022	12*12	7145H	540
bath1	0.270	0.016	12*16	7145H	620
BDR2	0.170	0.010	12*12	7145H	360
BDR3	0.204	0.016	12*12	7145H	450
bath2	0.279	0.016	12*18	7145H	685
Lobby	0.213	0.016	12*12	7145H	450
Kitchen	0.468	0.022	14*20	7145H	1110
Dining	0.119	0.022	12*6	7145H	252
Salon	0.149	0.022	10*10	7145H	360
Bath3	0.143	0.022	10*10	7145H	366

Table 5.29: First and second floor (Grille)

Component	$\dot{V}$ m^3/s	ΔP In w.g	Size in*in	Type of Grille	CFM
BDR1	0.208	0.016	12*12"	7145H	450
bath1	0.281	0.010	12*16"	7145H	496
BDR2	0.205	0.016	12*12"	7145H	450
BDR3	0.192	0.016	12*12"	7145H	450
bath2	0.300	0.016	12*16"	7145H	620
Lobby	0.199	0.016	12*12"	7145H	450
Kitchen	0.455	0.016	16*20"	7145H	1050
Dining	0.111	0.022	12*6"	7145H	252
Salon	0.136	0.016	10*10"	7145H	305
Bath3	0.141	0.016	10*10"	7145H	305

Table 5.30: Third floor (Grille)

Component	$\dot{V}$ m^3/s	ΔP In w.g	Size in*in	Type of Grille	CFM
BDR1	0.235	0.022	12*12"	7145H	540
bath1	0.294	0.016	14*14"	7145H	620
BDR2	0.308	0.022	14*14"	7145H	744
BDR3	0.217	0.016	12*12"	7145H	450
bath2	0.307	0.022	14*14"	7145H	744
Lobby	0.228	0.022	12*12"	7145H	540
Kitchen	0.482	0.016	14*24"	7145H	1050
Dining	0.126	0.016	10*10"	7145H	305
Salon	0.163	0.022	10*10"	7145H	360
Bath3	0.145	0.016	10*10"	7145H	305

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.[25]

From Table (A-24) selected model AHU 200 with air CFM = 20000.

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

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

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

$\Delta P_{supply\ air\ duct} = \Delta P_{A\to K'''} + \Delta P_{fitting}$

$\Delta P_{A\to A'} = 0.16 * (3.75 + 1.5 + 6) = 1.8\ Pa$

$\Delta P_{A'\to A''} = 0.16 * (3.75 + 1.5 + 6) = 1.8\ Pa$

$\Delta P_{A''\to A'''} = 0.16 * (3.75 + 1.5 + 6) = 1.8\ Pa$

$\Delta P_{A'''\to B'''} = 0.139 * (0.81 + 1.5 + 6) = 1.155\ Pa$

$\Delta P_{B'''\to C'''} = 0.266*(0.52+1.5+6)=2.125\ Pa$

$\Delta P_{C'''\to D'''} = 0.283 * (3.9 + 1.5 + 6) = 3.22\ Pa$

$\Delta P_{D'''\to G'''} = 0.294 * (3.56 + 1.5 + 6) = 3.25\ Pa$

$\Delta P_{G'''\to H'''} = 0.292 * (2.51 + 1.5 + 6) = 2.42\ Pa$

$\Delta P_{H'''\to J'''} = 0.261 * (1.72 + 1.5 + 6) = 2.4\ Pa$

$\Delta P_{J'''\to K'''} = 0.323 * (3.52 + 1.5 + 6) = 3.55\ Pa$

$\Delta P_{K'''\to Bath3} = 0.328(1.1 + 1.5 + 6) = 2.82\ Pa$

$\Delta P_{Supply\ air\ duct} = 26.34\ Pa$

$\Delta P_{return\ duct} = \Delta P10 \to 4'''$

$\Delta P_{10\to 10'} = 0.16 * (3.75 + 1.5 + 6) = 1.8\ Pa$

$\Delta P_{10'\to 10''} = 0.16 * (3.75 + 1.5 + 6) = 1.8\ Pa$

$\Delta P_{10''\to 10'''} = 0.16 * (3.75 + 1.5 + 6) = 1.8\ Pa$

$\Delta P_{10'''\to 9'''} = 0.321 * (3.6 + 1.5 + 6) = 3.56\ Pa$

$\Delta P_{4'''\rightarrow 8'''} = 0.28 * (3.73 + 1.5 + 6) = 3.14\ Pa$

$\Delta P_{8'''\rightarrow 6'''} = 0.292 * (1.84 + 1.5 + 6) = 2.72\ Pa$

$\Delta P_{6'''\rightarrow 5'''} = 0.324 * (3.12 + 1.5 + 6) = 3.44\ Pa$

$\Delta P_{5'''\rightarrow 2'''} = 0.226 * (5.76 + 1.5 + 6) = 2.99\ Pa$

$\Delta P_{2'''\rightarrow 3'''} = 0.36 * (0.6 + 1.5 + 6) = 2.91\ Pa$

$\Delta P_{3'''\rightarrow 4'''} = 0.234 * (4.34 + 1.5 + 6) = 2.77\ Pa$

$\Delta P_{4'''\rightarrow RDR3} = 0.257 * (3.04 + 1.5 + 6) = 2.7\ Pa$

$\sum \Delta P_{\text{return duct}} = 29.63\ Pa$

$$\Delta P_{\text{Dynamic}} = \left(\frac{V}{1.29}\right)^2 = \left(\frac{5}{1.29}\right)^2 = 15\ Pa$$

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

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

ΔP_{coil} , ΔP_{Filter} , $\Delta P_{\text{fan inlet}}$, $\Delta P_{\text{fan outlet}}$, given from Table (A-25).

$\Delta P_{\text{coil}} = 0.328\ in\ of\ H2O = 81.7\ Pa$

$\Delta P_{\text{Filter}} = 0.68\ in\ of\ H2O = 169.4\ Pa$

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

$\Delta P_{\text{fan outlet}} = 60\ Pa$

$\Delta P_{\text{fan}} = 25.8 + 29.27 + 15 + 17 + 4.5 + 81.7 + 169.4 + 80 + 60 = 483.57$ Pa

$$\text{Power} = \frac{V * \Delta P}{\eta} \tag{5.28}$$

$$Power = \frac{9.22 * 482.67}{0.9 * 1000} = 4.95\ kW$$

5.6 Summer Air Conditioning and Winter Warm Air Heating System

5.6.1 Traditional Air Conditioning System (Chiller) Selection:

We select Variable Water Volume System (VWV) from Petra company since:

The system offers large savings in energy and initial costs. The system may be used in multi-story buildings, office complexes, hotels, or any other type of project where high-energy savings are required. The system is comprised of air-cooled water chillers (cooling + heating), indoor units with three way valves, a control package, pumps, expansion tanks, storage tanks, water piping and integrated complete system control.

5.6.2 Selection model

Total cooling load = $128.1kW$

So we select RWC Model 530 from Petra company Table (A-26).

Cost of this model = $135000\ NIS$

5.6.2.1 General Data

Cooling capacity = $129.4\ kW$

Heating capacity = $121.5\ kW$

Compressor: Hermetically Sealed Scroll

Number of Compressor: 4

Refrigerant: R-22

Water connection size = $3\ in$

Number of fans = 2

Air flow rate = $14805\ l/s$

5.6.2.2 Electrical Data

Power $supply\ = 380/420\ volt$

$3Phase,\ 50Hz$

Total Consumption Power = $37kW$

5.6.3 Annual power consumption

$$\text{Annual Power Consumption} = (\text{Load [kW]}/\text{COP}) * \text{No.of month per year} * \text{No.of day per month} * \text{No. of hour per day} * \text{Price of electricity} \quad (5.29)$$

$$\text{COP}_{cooling} = \frac{129.4}{37} = 3.497$$

$$\text{COP}_{heating} = \frac{121.5}{37} = 3.284$$

$$\text{Annual Power Consumption for Cooling} = \left(\frac{128.1}{3.497}\right) * 5 * 30 * 16 * 0.61$$
$$= 53628.4\ NIS$$

$$\text{Annual Power Consumption for Heating} = \left(\frac{55.56}{3.284}\right) * 5 * 30 * 16 * 0.61$$
$$= 24768.5\ NIS$$

$$\text{Total Annual Power Consumption} = 78397\ NIS$$

5.7 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.

5.7.1 Vertical Heat Exchanger length Design

To find the required vertical heat exchanger length of bore, it takes the following equation for heating:[13]

$$L_h = \frac{q_a * R_{ga} + (C_{fh} * q_{lh}) * (R_b + PLF_m * R_{gm} + R_{gd} * F_{sc})}{t_p + \frac{t_{wi} + t_{wo}}{2} - t_g} \tag{5.30}$$

And takes the following equation for cooling:[13]

$$L_c = \frac{q_a * R_{ga} + (C_{fc} * q_{lc}) * (R_b + PLF_m * R_{gm} + R_{gd} * F_{sc})}{t_p + \frac{t_{wi} + t_{wo}}{2} - t_g} \tag{5.31}$$

Where L_c is the length of bore required for cooling (m), L_h is the bore reqired for heating (m), q_a net annual average heat transfer to the ground (kW), C_{fh} heat pump correction factor for heating, C_{fc} heat pump correction factor for cooling, q_{lh} building design heating load (kW), q_{lc} building design cooling load (kW), R_b thermal resistivity of bore, R_{ga} effective thermal resistivity of the ground annual pulse (m·K/kW), R_{gm} effective thermal resistivity of the ground monthly pulse (m·K/kW), 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 (°C), t_p temperature penalty for interference of adjacent bores (°C), t_{wi} liquid temperature at heat pump inlet (°C), and t_{wo} liquid temperature at heat pump outlet(°C) [13].

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:

$$q_a = \frac{C_{fc} q_{lc} EFLhours\ c + C_{fh} q_{lh} EFLhours\ c}{8760} \tag{5.32}$$

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-28) and everything is plugged into the above equation for net annual heat transfer.

$C_{fc} = 1.2$

$C_{fh} = 0.8$

q_{lc} =128082.17 kW = 437327.09 Btu

q_{lh} =55.558 kW = 189698.679 Btu

EFL hours $_c$ = 2400 h

EFL hours $_h$ = 2400 h

$$q_a = \frac{(1.2*397568.93*2400) + (0.8*189698.67*2400)}{8760}$$

$$= 185356.56 \ Btu/h$$

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:
$\tau_1 = 3650$ (10 years); $\tau_2 = 3680$ (1 month); $\tau_f = 3680.25$ (6 hours) [13].

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

$$F_{01} = \frac{4\alpha(\tau_f - \tau_1)}{d^2} \tag{5.33}$$

$$F_{02} = \frac{4(\tau_f - \tau_2)}{d^2} \tag{5.34}$$

$$F_{0f} = \frac{4\alpha\tau_f}{d^2} \tag{5.35}$$

Where α is thermal diffusivity, and d is diameter of pipe.[24]

Using the values of F_0 find the G values associated with each of these Fourier values if found form a logarithmic fit of Figure (A-31):[26]

$$G = 0.0769\, Ln(F0) + 0.0901 \tag{5.36}$$

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

$$R_{ga} = \frac{G_f - G_1}{k_g} \tag{5.37}$$

$$R_{gm} = \frac{G_1 - G_2}{k_g} \tag{5.38}$$

$$R_{gd} = \frac{G_2}{k_g} \tag{5.39}$$

Where k_g the thermal conductivity of earth.

$\alpha = 0.8$ ft^2/day

$k_g = 1.19\, Btu/h\, ft$ °F

$d = 32$ mm$= 0.105$ ft

- $Gf = 1.1575$
- $G1 = 0.7884$
- $G2 = 0.4196$

$R_{ga} = 0.3\ (h\ ft.°F/Btu)$

$R_{gm} = 0.3099\ (h\ ft.°F/Btu)$

$R_{gd} = 0.3526\ (h\ ft.°F/Btu)$

Next, a specific type of pipe needs to be assumed for use in the heat exchanger. A commonly used pipe for this purpose is 32mm diameter polyethylene tube (SDR11).

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:

$$R_b = R_{bf} + R_p \tag{5.40}$$

Where R_{bf} is the backfill resistivity, and $R_b$thermal resistivity of pipe.

R_{bf} = 0.7 h ft.°F/Btu

R_p = 0.075 h ft.°F/Btu

R_b = 0.7 + 0.075 = 0.775 h ft °F/Btu

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

$Fsc = 1.03$

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

$$PLF_m = \left(\frac{load * Hours}{Peakload * 24h}\right) * \left(\frac{DaysOccupiedPerMonth}{DaysPerMonth}\right) \tag{5.41}$$

$$PLF_m = \frac{116.438 * 16}{128.082 * 24} * \frac{27}{31} = 0.528$$

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 3 degrees higher than t_g in cooling, and 10 to 20 degrees lower than t_g in heating (both in °F). [25]

$t_{wi\,c}$ = 29 °C = 84.2 °F

$t_{wo\,c}$ = 32.22 °C = 90 °F

$t_{wi\,h}$ = 11 °C = 52 °F

$t_{wo\,h}$= 8.8 °C= 47.84 °F

Finally, the temperature penalty due to bores affecting one another t_p , see Table (A-29) can be used to estimate this value. Interpolation can be done with values not exactly matching the chart.

t_p = 2.6 °C = 36.68°F

With all of these values determined, equations (5.30), and (5.31) can be used to solve for the bore length required for heating and cooling.

$$L_h = \frac{185356.56*0.31+(0.8*189698.667)*(0.775+0.528*0.3099+0.3526*1.03)}{36.68+\frac{52+47.84}{2}-63.2}$$

$$L_h = \frac{255020.94}{23.4} = 10898.33\,ft = 3322.66\,m$$

$$L_c = \frac{185356.56*0.31+(1.2*437327.09)*(0.775+0.528*0.3099+0.3526*1.03)}{36.68+\frac{84.2+90}{2}-63.2}$$

$$L_c = \frac{740638.1494}{60.58} = 12225.786\,ft = 3727.01\,m$$

We depend in design bore length on L_c because L_c is larger than L_h .

$$\text{Number of Bores} = \frac{Bore\ Length}{deep\ of\ each\ Bore}$$

$$\text{Number of Bores} = \frac{3727.01}{100} = 37.01 \approx 37\ \text{Bores}$$

Length of Heat exchanger (polyethylene pipe) $= 2 * L_c = 7454.02\ m$

5.7.2 Circulation Pump Selection

To select the pump must be know the friction loss in pipes and the friction loss in coil of heat pump, so we use the Table (A-30) to calculate the friction in pipes, and use the Table (A-28) to know the value of friction in heat pump coil :

Total Equivalent Length of Pipe $= 7454.02 * 1.5$

$= 11181.3$ m

Take the pressure drop in pipe is 6 kPa/100m.

Friction loss in pipes $= 11181.3 * \frac{6}{100} = 670.9\ kPa$

Friction loss in heat pump coil $= 23.2\ ft.of\ water = 69.35\ kPa$

And the total friction loss$= 670.9 + 69.35 = 740.25\ kPa$

Also the required flow rate in heat pump coil to achieve the required amount of heat is = 90 gpm see Table (A-27) .

Based on the water flow rate and the friction loss in pipes we selected the type of Pump TPE Series 1000 from Grundfoss Company see Figure (A-32).

5.7.3 Water Volume in the Heat Exchanger

The water amount in ground heat exchanger can be calculated from the following equation:

$$V_{water} = \frac{\pi * d^2}{4} * L \qquad (5.42)$$

Where A is the cross section area of pipe (m^2), L is the length of pipe (m), d is the diameter of pipe.

We should take that require flow rate in SDR11 is 11 l/min per Ton Refrigeration from Ground Loop Design Software. [24]

We have a different diameter start from geothermal heat pump to borehole in different length see Figure (A-43) then the calculation as follow:

$d_1 = 32\ mm\ , d_2 = 37.5\ mm\ , d_3 = 50\ mm\ , d_4 = 75\ mm$

$L_1 = 7525\ m.\ L_2 = 140\ m\ , L_3 = 196\ m, L_4 = 3.4\ m$

$$V_1 = \frac{\pi * (0.032)^2}{4} * 7525 = 6.05\ m^3$$

$$V_2 = \frac{\pi * (0.0375)^2}{4} * 140 = 0.154\ m^3$$

$$V_3 = \frac{\pi * (0.05)^2}{4} * 196 = 0.385\ m^3$$

$$V_4 = \frac{\pi * (0.075)^2}{4} * 3.4 = 0.015\ m^3$$

$$\text{Total water volume in heat exchanger} = 6.05 + 0.154 + 0.385 + 0.015 = 6.604\ m^3$$

5.7.4 Geothermal Heat pump Selection

We select heating and cooling heat pump model WRA-420 from Daikin-McQuay see Table (A-27) and (A-28).

5.7.4.1 Selection Model

Total Cooling Load = 128.1 kW = 437008 BTU

Total Heating Load = $55.56\ kW\ =\ 189698.7\ BTU$

5.7.4.2 General Data

Cooling capacity = $443177 BTU/h = 129.9\ kW$

Heating capacity = $491495 btu/h = 144.05\ kW$

Number of Compressor scroll type = 2

Refrigerant: R-410a

Water Connection = $3\ in\ pipe$

Water Flow Rate = $90\ gpm$

5.7.4.3 Electrical Data

Power Supply = $380V, 3PH, 50Hz$

Total consumption for cooling= $19.838\ kW$

Total consumption for heating= $30.141\ kW$

5.7.5 Cost of Geothermal Heat Pump Equipment

Cost of Heat Pump = $32400\ \$ = 118260\ NIS$

Cost of Pipe = $7455 * 3.65 = 27211\ NIS$

Cost of Drilling = $37 * 1000 * 3.65$

$= 135050\ NIS$

Cost of Centrifugal Pump = $2000\ \$ = 7300\ NIS$

SO the Initial cost for Geothermal heat pump = $118260 + 27211 + 135050 + 7300$

$= 287821\ NIS$

5.7.6 Annual power Consumption for Heat Pump

$$COP_{cooling} = \frac{129.9}{19.838} = 6.5$$

$$COP_{heating} = \frac{144.05}{30.141} = 4.78$$

$$\text{Annual Power Consumption for Cooling} = \left(\frac{128.1}{6.5}\right) * 5 * 30 * 16 * 0.61$$

$$= 28852.1\ NIS/year$$

$$\text{Annual Power Consumption For Heating} = \left(\frac{55.56}{4.78}\right) * 5 * 30 * 16 * 0.16$$

$$= 17016.7\ NIS/year$$

5.8 System Comparison and Payback Period

Initial cost difference between two system

$= (initial\ cost\ of\ GHP) - (initial\ cost\ of\ Traditional\ system)$

$= 287821 - 135000 = 152821$ NIS

Annual Power Consumption difference between two system

= Annual Power C. of Traditional S. – Annual Power C. of GHP

$= 78397 - 45868.8 = 32528.2\ NIS$/year

The number of years necessary to offset the cost difference used simple Payback method:

$$\text{Payback Period} = \frac{\text{Initial cost difference}}{\text{Annual Power Consumption difference}}$$

$$= \frac{152821}{32528.2} = 4.7\ years$$

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, in this project the payback period is not exceed the typical period of geothermal heat pump system (3-6 years), so we recommend apply it in an individual buildings because it sufficient.

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 government to motivate the owners of companies and enterprises use GHP in the process of air conditioning and refrigeration, this is because it reduces the power consumption.

REFRENCES

[1] ASHRAE, 1995. Commercial/Institutional Ground-Source Heat Pump Engineering Manual. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA.

[2] A.K. Akella and etl Social, Economical and environmental impacts of renewable energy systems, Renewable Energy 34 (2009) 390–396.

[3] Robert W. Kates, Thomas M. Parris, and Anthony A. Leiserowitz, What is sustainable development, pages,. 8–21, Volume 47, Number 3,Environment: Science and Policy for Sustainable Development, c, 2005. http://www.heldref.org/env.php

[4] Test Done By Mena Geothermal Company, 2008.

[5] Jon Busbyla, Melinda Lewis2, Helen Reeves1, Russell Lawley1, " Initial geological considerations before installing ground source heat pump Systems", British Geological Survey, Crowmarsh Gifford, Wallingford, OX10 8BB.

[6] Harsh Gupta, Geothermal Energy: An Alternative Resource For The 21st Century, Hyderabad, India, India, 2007.

[7] James, Z.2001. Ground Coupled Heat Pump Algorithm.

[8] Alan Wachtel, Geothermal Energy, Chelsea House Publishers, New York, 2010.

[9] Y. A. Cengel and M. A. Boles, Thermodynamics An Engineering Approach, 5th ed. McGraw-Hill, 2006.

[10] Retscreen. International. Canada-Ground Sourse Heat Pump Project Analysis, 2005.

[11] James E. Brumbaugh, Audel HVAC Fundamentals, Volume 3: Air-Conditioning, Heat Pumps, and Distribution Systems, 4th Ed, Wiley Publishing, Inc., Canada, 2004.

[12] Karl Ochsner, Geothermal Heat Pumps. a guide & installing, USA, 2007.

[13] ASHRAE, 2011. ASHRAE Handbook, HVAC Applications. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA.

[14] Jay Egg Brian Clark Howard, Geothermal HVAC Green Heating and Cooling, by The McGraw-Hill Companies, 2011.

[15] http://www1.eere.energy.gov/geothermal.

[16] Allen, Alistair, Low-enthalpy geothermal energy resources from groundwater in fluvioglacial gravels of buried valleys, Elsevie ,Applied Energy 74 (2003) 9–19.

[17] Michelle Kubik, The Future of Geothermal Energy, Massachusetts Institute of Technology, 2006.

[18] Perry, Robert H. and Chilton, Cecil H. Chemical Engineer's Handbook. 5th Ed. New York, McGraw Hill, 1973.

[19] Engineering tools, http://www.engineeringtoolbox.com/

[20] http://www.gaiageo.com/ Copyright 1999-2011. Gaia Geothermal, LLC.

[21] Best Practices for Geothermal Vertical Closed-Loop Installations, Michigan Department, 2010.

[22] Richard A. Beier, "Soil Thermal Conductivity Tests", Oklahoma State University, 2008.

[23] ALsaad,M,Hamad.M.2001.Amman.Heating and Air Conditioning.

[24] Ground Loop Design Software From GAIA Geothermal Company

[25] ASHRAE, 2012. ASHRAE Handbook, HVAC Systems and Equipment. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., Atlanta, GA.

[26] Aristodimos J. Philippacopoulos, "Influence of debonding in ground heat exchangers used with geothermal heat pumps", Published by Elsevier Science Ltd, 2001.

Appendix A

Table A-1 Ground Temperatures

GWT (F)	City	State/Country	GWT (F)	City	State/Country	GWT (F)	City	State
52	Frankfurt	Germany	66	Charleston	South Carolina	65	Birmingham	Alabama
51	Hamburg	Germany	64	Columbia	South Carolina	70	Mobile	Alabama
48	Munich	Germany	62	Greenville	South Carolina	67	Montgomery	Alabama
51	Stuttgart	Germany	51	Sioux Falls	South Dakota	40	Anchorage	Alaska
57	Athens	Greece	61	Knoxville	Tennessee	3	Fairbanks	Alaska
53	Budapest	Hungary	63	Memphis	Tennessee	73	Phoenix	Arizona
83	Jakarta	Indonesia	60	Nashville	Tennessee	64	Little Rock	Arkansas
52	Dublin	Ireland	71	Austin	Texas	65	Fresno	California
63	Jerusalem	Palestine	68	Dallas	Texas	64	Los Angeles	California
50	Genova	Italy	71	Houston	Texas	57	Sacramento	California
57	Milan	Italy	72	San Antonio	Texas	64	San Diego	California
63	Naples	Italy	55	Salt Lake City	Utah	60	San Francisco	California
56	Palermo	Italy	46	Burlington	Vermont	52	Denver	Colorado
61	Rome	Italy	61	Norfolk	Virginia	51	Hartford	Connecticut
58	Torino	Italy	60	Richmond	Virginia	57	Dover	Delaware
58	Trieste	Italy	59	Roanoke	Virginia	70	Daytona Beach	Florida
58	Venice	Italy	57	Washington	DC	71	Jacksonville	Florida
62	Nagoya	Japan	53	Seattle	Washington	78	Miami	Florida
63	Osaka	Japan	49	Spokane	Washington	69	Tallahassee	Florida
51	Sapporo	Japan	58	Charleston	West Virginia	75	Tampa	Florida
54	Tokyo	Japan	48	La Crosse	Wisconsin	62	Atlanta	Georgia
58	Inch'on	Korea	47	Milwaukee	Wisconsin	67	Savannah	Georgia
59	Pusan	Korea	46	Cheyenne	Wyoming	79	Honolulu	Hawaii
57	Seoul	Korea	42	Calgary	Alberta	47	Boise	Idaho
[illegible]	Kuwait City	Kuwait	40	Edmonton	Alberta	51	Chicago	Illinois
[illegible]	Tripoli	Libyan Arab Jamahiriya	53	Vancouver	British Columbia	56	Springfield	Illinois
[illegible]	George Town	Malaysia	40	Winnipeg	Manitoba	53	Fort Wayne	Indiana
[illegible]	Kuala Lumpur	Malaysia	42	Moncton	New Brunswick	55	Indianapolis	Indiana
[illegible]	Acapulco	Mexico	43	Saint John's	Newfoundland	53	Des Moines	Iowa
[illegible]	Mexico City	Mexico	45	Halifax	Nova Scotia	59	Wichita	Kansas
[illegible]	Veracruz	Mexico	45	Ottawa	Ontario	57	Cincinnati	Ohio
[illegible]	Casablanca	Morocco	48	Toronto	Ontario	60	Lexington	Kentucky
[illegible]	Amsterdam	Netherlands	42	Charlottetown	Prince Edward Island	60	Louisville	Kentucky
[illegible]	Auckland	New Zealand	46	Montreal	Quebec	70	New Orleans	Louisiana
[illegible]	Christchurch	New Zealand	39	Regina	Saskatchewan	68	Shreveport	Louisiana
[illegible]	Wellington	New Zealand	64	Buenos Aires	Argentina	46	Caribou	Maine
[illegible]	Oslo	Norway	64	Adelaide	Australia	48	Portland	Maine
[illegible]	Asuncion	Paraguay	72	Brisbane	Australia	57	Baltimore	Maryland
[illegible]	Lima	Peru	67	Canberra	Australia	50	Boston	Massachusetts
[illegible]	Manila	Philippines	59	Melbourne	Australia	50	Worchester	Massachusetts
[illegible]	Krakow	Poland	67	Perth	Australia	50	Detroit	Michigan
[illegible]	Warsaw	Poland	67	Sydney	Australia	49	Flint	Michigan
[illegible]	Porto	Portugal	51	Salzburg	Austria	46	Grand Rapids	Michigan
[illegible]	San Juan	Puerto Rico	50	Vienna	Austria	41	Duluth	Minnesota
[illegible]	Doha	Qatar	80	Manama	Bahrain	47	Minneapolis	Minnesota
[illegible]	Bucharest	Romania	52	Brussels	Belgium	67	Jackson	Mississippi
[illegible]	Riyadh	Saudi Arabia	50	La Paz	Bolivia	58	Kansas City	Missouri
[illegible]	Singapore	Singapore	82	Belem	Brazil	59	St. Louis	Missouri
[illegible]	Barcelona	Spain	80	Brasilia	Brazil	49	Billings	Montana
[illegible]	Madrid	Spain	79	Recife	Brazil	47	Helena	Montana
[illegible]	Sevilla	Spain	70	Sao Paulo	Brazil	53	Omaha	Nebraska
[illegible]	Valencia	Spain	55	Sofia	Bulgaria	80	Las Vegas	Nevada
[illegible]	Stockholm	Sweden	61	Santiago	Chile	50	Reno	Nevada
[illegible]	Geneva	Switzerland	56	Beijing	China	50	Concord	New Hampshire
[illegible]	Damascus	Syria	77	Guangzhou	China	55	Trenton	New Jersey
[illegible]	Taipei	Taiwan	53	Harbin	China	59	Albuquerque	New Mexico
[illegible]	Bangkok	Thailand	77	Hong Kong	China	50	Albany	New York
[illegible]	Tunis	Tunisia	62	Shanghai	China	50	Buffalo	New York
[illegible]	Ankara	Turkey	50	Shenyang	China	52	New York City	New York
[illegible]	Istanbul	Turkey	58	Bogota	Colombia	59	Asheville	North Carolina
[illegible]	Izmir	Turkey	77	Havana	Cuba	62	Charlotte	North Carolina
[illegible]	Abu Dhabi	United Arab Emirates	50	Prague	Czech Republic	60	Greensboro	North Carolina
[illegible]	Dubai	United Arab Emirates	47	Copenhagen	Denmark	62	Raleigh	North Carolina
[illegible]	Aberdeen	United Kingdom	60	Quito	Ecuador	44	Bismarck	North Dakota
[illegible]	Belfast	United Kingdom	78	Aswan	Egypt	42	Fargo	North Dakota
[illegible]	Birmingham	United Kingdom	73	Cairo	Egypt	51	Cleveland	Ohio
[illegible]	Edinburgh	United Kingdom	47	Helsinki	Finland	55	Columbus	Ohio
[illegible]	Liverpool	United Kingdom	61	Bordeaux	France	50	Dayton	Ohio
[illegible]	London	United Kingdom	57	Lyon	France	62	Oklahoma City	Oklahoma
[illegible]	Montevideo	Uruguay	59	Marseille	France	54	Portland	Oregon
[illegible]	Caracas	Venezuela	58	Nantes	France	52	Harrisburg	Pennsylvania
[illegible]	Hanoi	Vietnam	54	Paris	France	55	Philadelphia	Pennsylvania
[illegible]	Belgrade	Yugoslavia	52	Berlin	Germany	52	Pittsburgh	Pennsylvania

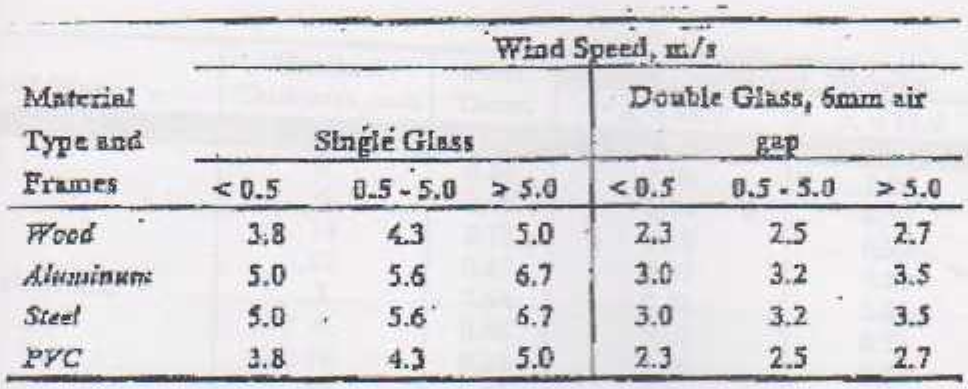
Table A-2 cooling load temperature differences for calculating cooling load from sunlit roofs

Roof No.	Description of Construction	U, W/m^2°C	Solar Time, h																							
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Without Suspended Ceiling																									
1	Steel sheet with 25.4 mm (or 50.8 mm) insulation	1.209 (0.700)	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	0.960	3	2	0	−1	−2	−2	−1	2	5	13	22	29	35	39	41	41	39	35	29	22	15	11	8	5
3	101.6 mm L.W. concrete	1.709	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	32	36	37	37	34	30	25	22	16	12	10
5	25.4 mm wood with 50.8 insulation	0.619	4	0	−2	−3	−4	−4	−4	−2	3	9	16	22	27	32	35	36	35	33	27	20	14	10	6	3
6	152.4 mm L.W. concrete	0.877	17	14	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	15	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 (0.653)	14	12	10	8	7	5	4	4	6	8	11	15	18	22	25	28	29	30	29	27	22	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	22	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	8	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)	2	0	−1	−2	−3	−3	0	5	13	20	28	35	40	43	43	41	37	31	22	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	0.751	10	8	6	4	3	1	0	0	2	6	10	15	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	15	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	22	21	21	20	19	18
10	63.5 mm wood with 50.8 mm insulation	0.409	18	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 Latitude correction factor (LM) for latitude and month applied to walls and roof, north latitudes

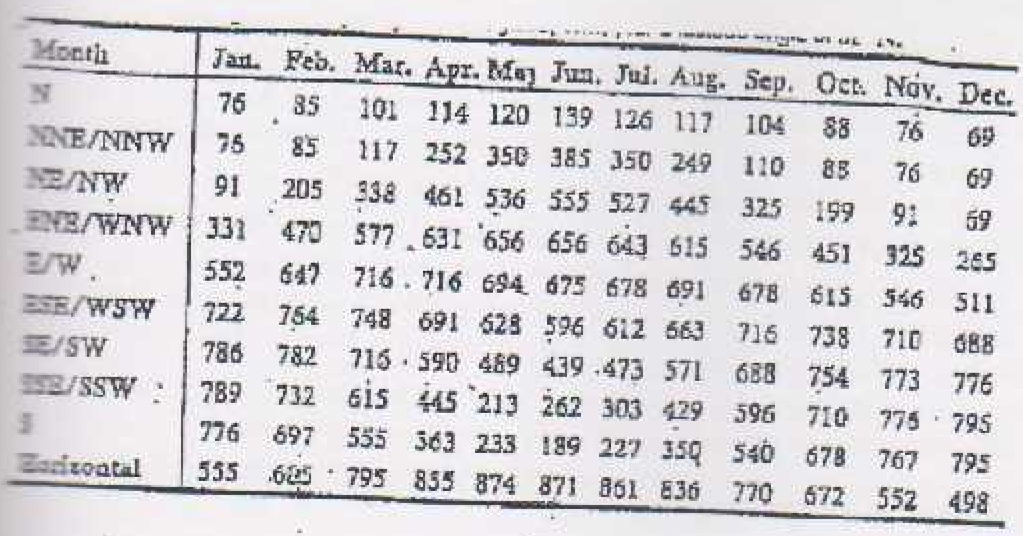
Lat.	Month	N	NNE NNW	NE NW	ENE WNW	E W	ESE WSW	SE SW	SSE SSW	S	Horizontal Roofs
16	December	−2.2	−3.3	−4.4	−4.4	−2.2	−0.5	2.2	5.0	7.2	−5.0
	Jan./Nov.	−2.2	−3.3	−3.8	−3.8	−2.2	−0.5	2.2	4.4	6.6	−3.8
	Feb./Oct.	−1.6	−2.7	−2.7	−2.2	−1.1	0.0	1.1	2.7	3.8	−2.2
	Mar/Sept.	−1.6	−1.6	−1.1	−1.1	−0.5	−0.5	0.0	0.0	0.0	−0.5
	Apr./Aug.	−0.5	0.0	−0.5	−0.5	−0.5	−1.6	−1.6	−2.7	−3.5	0.0
	May/July	2.2	1.6	1.6	0.0	−0.5	−2.2	−2.7	−3.8	−3.8	0.0
	June	3.3	2.2	2.2	0.5	−0.5	−2.2	−3.3	−4.4	−3.8	0.0
24	December	−2.7	−3.8	−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	7.2	−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/July	0.5	1.1	1.1	0.0	0.0	−1.6	−1.6	−2.7	−3.3	0.5
	June	1.6	1.6	1.6	0.5	0.0	−1.6	−2.2	−3.3	−3.3	0.5
32	December	−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	5.0	0.5	−0.5
	May/July	0.5	0.5	0.5	0.0	0.0	−0.5	−0.5	−1.6	−1.6	0.5
	June	0.5	1.1	1.1	0.5	0.0	−1.1	−1.1	−2.2	−2.2	1.1
40	December	−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	−5.0	−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	5.5	−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/July	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5
	June	0.5	0.5	0.5	0.5	0.0	0.5	0.0	0.0	−0.5	1.1
48	December	−3.3	−4.4	−6.1	−7.7	−7.2	−5.5	−1.6	1.1	3.3	−13.8
	Jan./Nov.	−3.3	−4.4	−6.1	−7.2	−6.1	−4.4	−0.5	2.7	4.4	−13.3
	Feb./Oct.	−2.7	−3.8	−5.5	−6.1	−4.4	−2.7	0.5	4.4	6.1	−10.0
	Mar/Sept.	−2.2	−3.3	−3.3	−3.8	−2.2	−0.5	2.2	4.4	6.1	−6.1
	Apr./Aug.	−1.6	−1.6	−1.6	−1.6	−0.5	0.0	2.2	3.3	3.8	−2.7
	May/July	0.0	−0.5	0.0	0.0	0.5	0.5	1.6	1.6	2.2	0.0
	June	0.5	0.5	1.1	0.5	1.1	0.5	1.1	1.1	1.6	1.1

Table A-4 Overall heat transfer coefficient for windows, W/m^2.°C



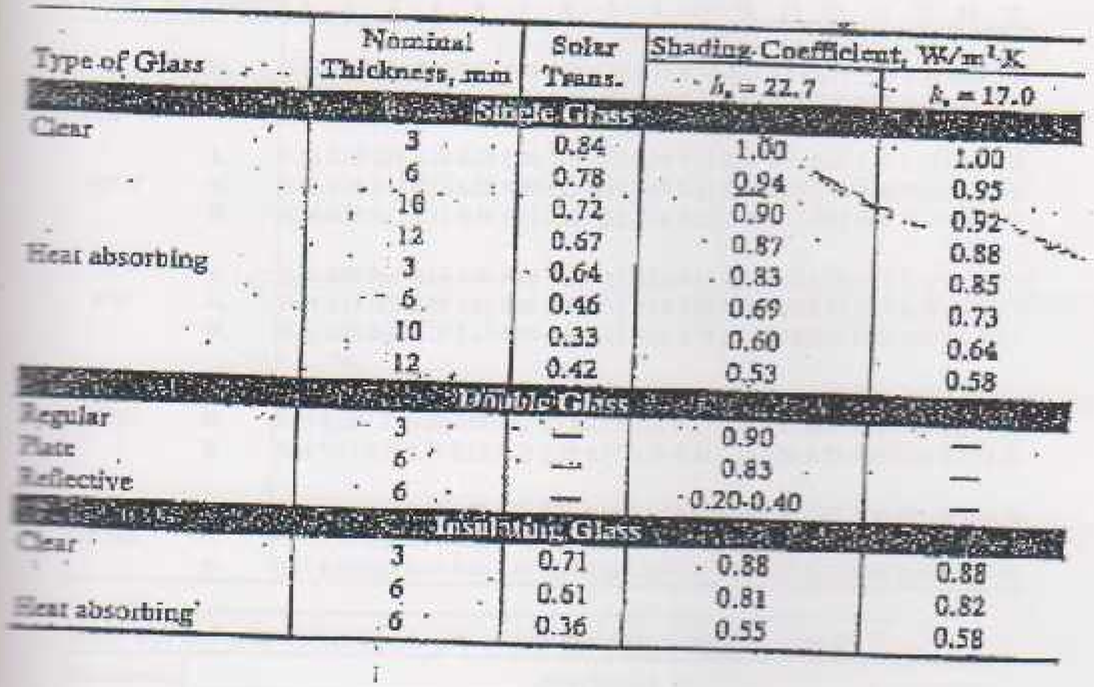
Material Type and Frames	Wind Speed, m/s					
	Single Glass			Double Glass, 6mm air gap		
	< 0.5	0.5 - 5.0	> 5.0	< 0.5	0.5 - 5.0	> 5.0
Wood	3.8	4.3	5.0	2.3	2.5	2.7
Aluminum	5.0	5.6	6.7	3.0	3.2	3.5
Steel	5.0	5.6	6.7	3.0	3.2	3.5
PVC	3.8	4.3	5.0	2.3	2.5	2.7

Table A-5 solar heat gain factor (SHG) W/m^2 , 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	775	795
S	776	697	555	363	233	189	227	350	540	678	767	795
Horizontal	555	605	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/m^2K	
			$h_o = 22.7$	$h_o = 17.0$
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 Cooling load factors for glass without interior shading, north latitudes

Glass Facing	Building Construction	Solar Time, h																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
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
	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	0.53
WNW	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	0.53
	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
	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
NW	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
	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
NNW	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	0.37	0.51
	H	0.14	0.13	0.12	0.11	0.10	0.12	0.15	0.17	0.20	0.23	0.23	0.25	0.28	0.28	0.31	0.38	0.47
	L	0.11	0.09	0.07	0.06	0.05	0.07	0.14	0.24	0.16	0.48	0.58	0.66	0.72	0.74	0.73	0.67	0.59
HORIZ.	M	0.16	0.14	0.12	0.11	0.11	0.13	0.16	0.24	0.13	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	0.16	0.45	0.52	0.59	0.62	0.64	0.62	0.58	0.51

TABLE 9-11 Cooling Load factors (CLF) for glass windows with interior shading, North latitude.

Fenestration Facing	Solar Time, h																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
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	0.36	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 cooling 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 requirement for ventilation

Application	Maximum Occupancy Per 100 m²	Ventilation Air Requirements	
		L/s/Person	L/s/m²
Offices:			
Office space	7	10.0	2.5-10.0
Reception areas	60	8.0	3.5-7.5
Telecomm. Centers	60	10.0	—
Conference rooms	50	10.0	—
Public spaces:			
Corridors	—	—	0.25
Public restrooms	100	25.0	—
Locker and dressing rooms	50	7.5-17.5	5-2.5
Smoking lounge	70	30.0	—
Elevators:	—	7.5	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	—	5L/s/car	7.50
Auto repair rooms	—	—	7.50

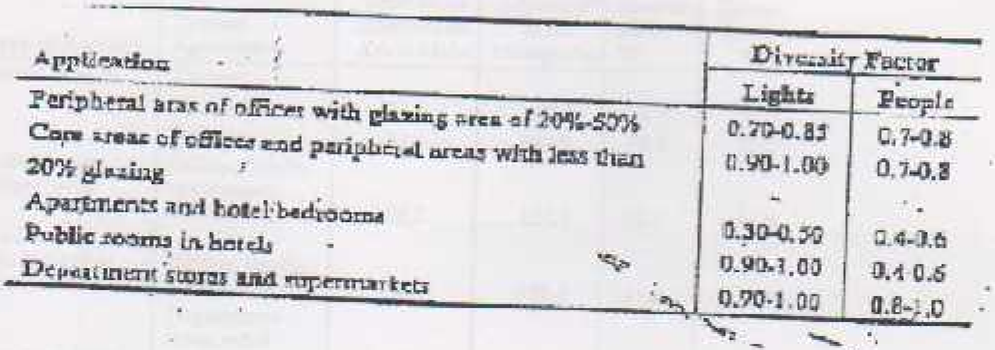
Table A-10 Cooling load factors for lighting

Number of hours after lights are turned On	Fixture X^c hours of operation		Fixture Y^c 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

Table A-11 sensible heat Cooling load factors for people

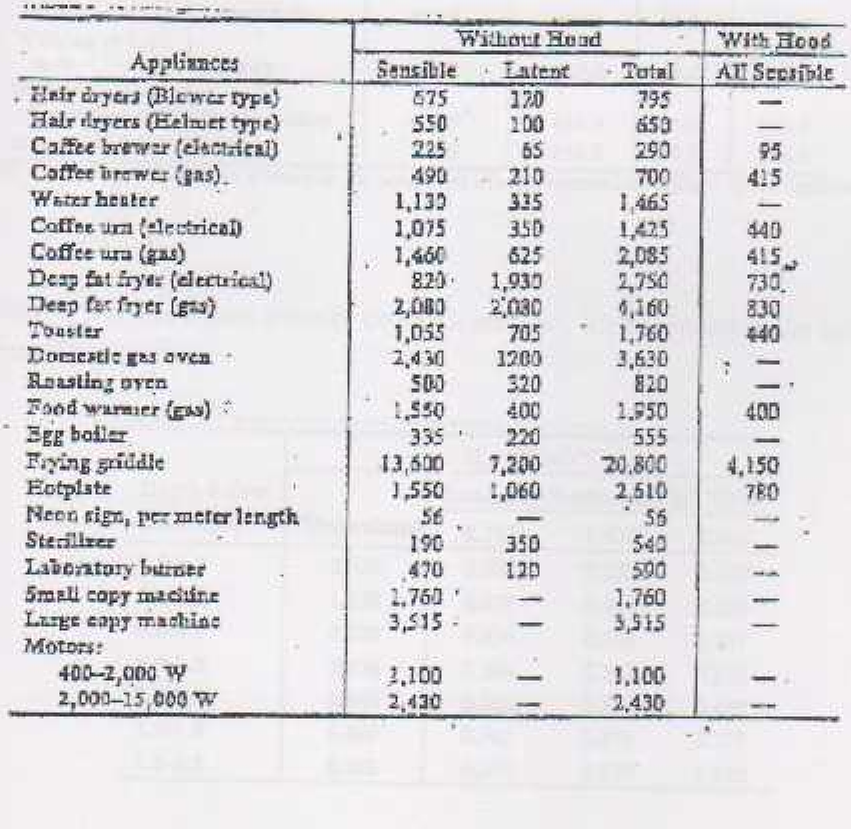
Hours after each entry into space	Total hours in space							
	2	4	6	8	10	12	14	16
1	0.49	0.49	0.50	0.51	0.53	0.55	0.58	0.62
2	0.58	0.59	0.60	0.61	0.62	0.64	0.66	0.70
3	0.17	0.66	0.67	0.67	0.69	0.70	0.72	0.75
4	0.13	0.71	0.72	0.72	0.74	0.75	0.77	0.79
5	0.10	0.27	0.76	0.76	0.77	0.79	0.80	0.82
6	0.08	0.21	0.79	0.80	0.80	0.81	0.83	0.85
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	0.36	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	0.05	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	0.25	0.39

Table A-12 Cooling load factors for occupants



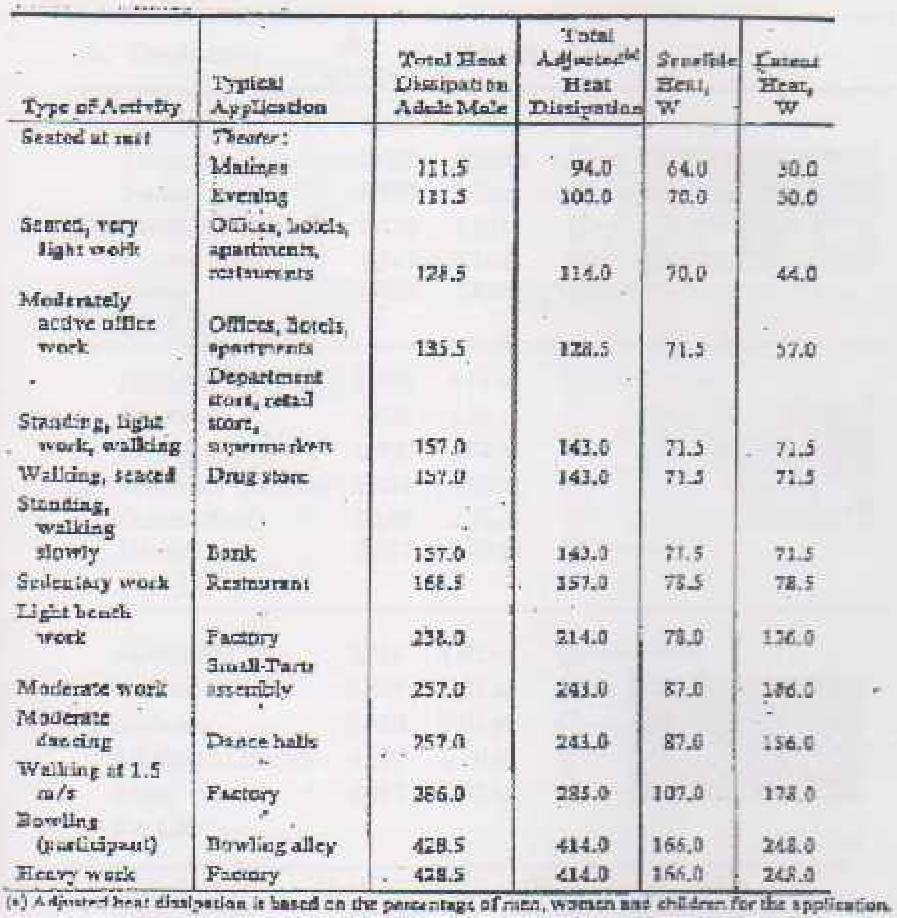
Application	Diversity Factor	
	Lights	People
Peripheral aras of offices with glazing area of 20%-50%	0.70-0.85	0.7-0.8
Core areas of offices and peripheral areas with less than 20% glazing	0.90-1.00	0.7-0.8
Apartments and hotel bedrooms	0.30-0.50	0.4-0.6
Public rooms in hotels	0.90-1.00	0.4-0.6
Department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

Table A-13 Cooling load factors for equipment



Appliances	Without Hood			With Hood
	Sensible	Latent	Total	All Sensible
Hair dryers (Blower type)	675	120	795	—
Hair dryers (Helmet type)	550	100	650	—
Coffee brewer (electrical)	225	65	290	95
Coffee brewer (gas)	490	210	700	415
Water heater	1,130	335	1,465	—
Coffee urn (electrical)	1,075	350	1,425	440
Coffee urn (gas)	1,460	625	2,085	415
Deep fat fryer (electrical)	820	1,930	2,750	730
Deep fat fryer (gas)	2,080	2,080	4,160	830
Toaster	1,055	705	1,760	440
Domestic gas oven	2,430	1200	3,630	—
Roasting oven	500	320	820	—
Food warmer (gas)	1,550	400	1,950	400
Egg boiler	335	220	555	—
Frying griddle	13,600	7,200	20,800	4,150
Hotplate	1,550	1,060	2,610	780
Neon sign, per meter length	56	—	56	—
Sterilizer	190	350	540	—
Laboratory burner	470	120	590	—
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	—	2,430	—

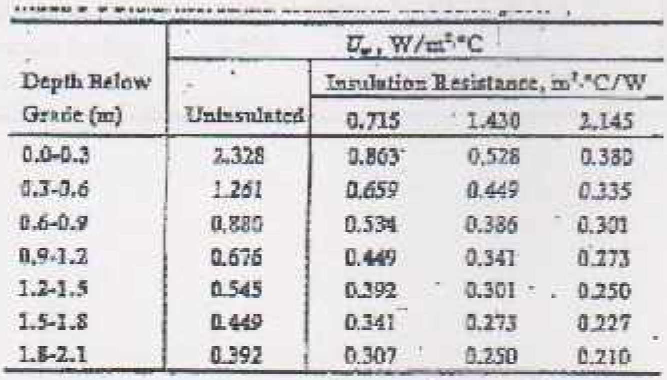
Table A-14 Heat gain from occupants in watt person



Type of Activity	Typical Application	Total Heat Dissipation Adult Male	Total Adjusted[a] Heat Dissipation	Sensible Heat, W	Latent Heat, W
Seated at rest	*Theater:*				
	Matinee	111.5	94.0	64.0	30.0
	Evening	131.5	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, supermarkets	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	234.0	214.0	78.0	136.0
Moderate work	Small-Parts assembly	257.0	243.0	87.0	156.0
Moderate dancing	Dance halls	257.0	243.0	87.0	156.0
Walking at 1.5 m/s	Factory	366.0	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-15 Overall heat transfer coefficients Uw , for basement walls below grade ($W/m^2.°C$).



Depth Below Grade (m)	U_w, $W/m^2\cdot°C$			
	Uninsulated	Insulation Resistance, $m^2\cdot°C/W$		
		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-16 overall heat transfer coefficients for typical ceiling constructions, W/m^2, °C, for $R_0 = 0.03$ m^2 , C/W

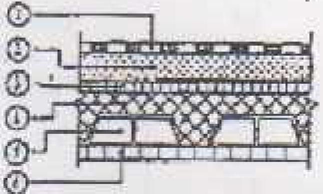
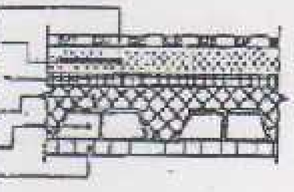
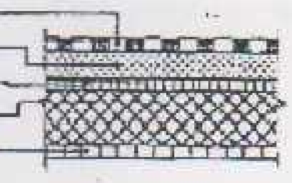
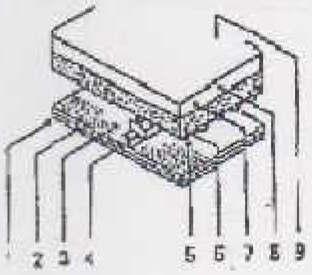
No.	Construction	R_{th} m^2·°C/W	Thickness	Layer
(1)	Asphalt Mix	0.028	0.02 m	① 
	Concrete	0.029	0.05 m	②
	Insulation	0.750	0.03 m	③
	Reinforced Concrete	0.034	0.03 m	④
	Cement Block	0.147	0.14 m	⑤
	Plaster	0.027	0.02 m	⑥
	$U = 0.88$			
(2)	Asphalt Mix	0.028	0.02 m	① 
	Concrete	0.029	0.05 m	②
	Insulation	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
	$U = 1.08$			
(3)	Asphalt Mix	0.028	0.02 m	① 
	Concrete	0.029	0.05 m	②
	Insulation	0.750	0.03 m	③
	Reinforced Concrete	0.057	0.10 m	④
	Plaster	0.017	0.02 m	⑤
	$U = 1.00$			
(4)	Inside Surface	0.110	—	① 
	Metal Lath	0.083	0.02 m	②
	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-17 Air change per hours in residences and commercial application

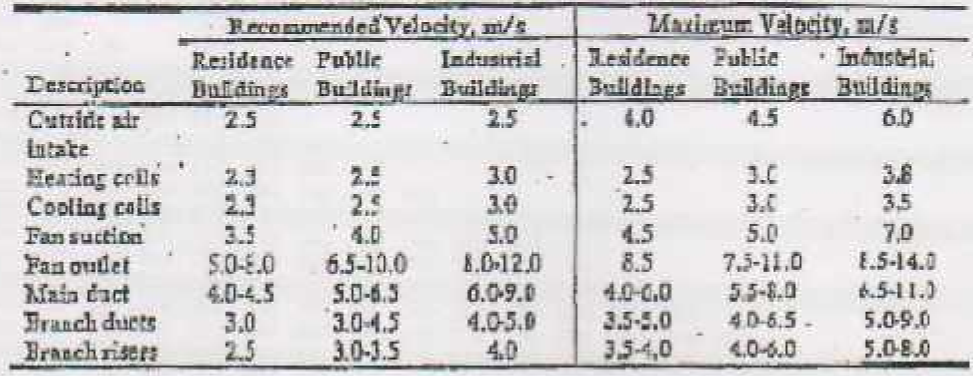
Type of Room or Building	No. of Air Change per Hour
Rooms with no windows or exterior doors	0.5
Rooms with windows or exterior doors on one side only	1.0
Rooms with windows or exterior doors on two sides	1.5
Rooms with windows or exteriors doors on three sides	2.0
Entrance halls	2.0-3.0
Factories, machine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

(1) For rooms with weather stripped windows or storm sash, use 2/3 of these values.

Table A-18 Overall heat transfer coefficients for wood and steel doors, W/m^2.°C

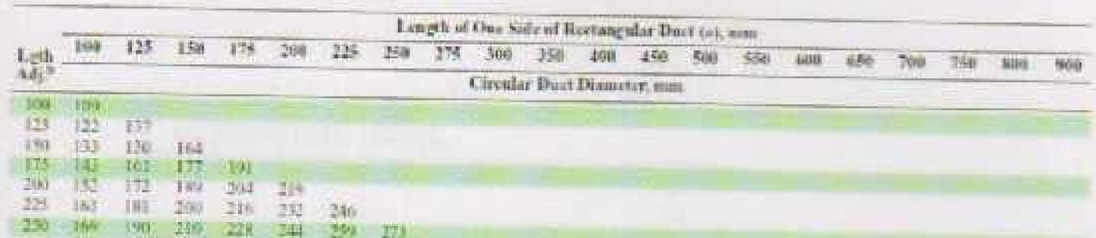
Door Type	Without Storm Door	With Wood Storm Door	With Metal Storm Door
25 mm-wood	3.6	1.7	2.2
35 mm-wood	3.1	1.6	1.9
40 mm-wood	2.8	1.5	1.8
45 mm-wood	2.7	1.5	1.8
50 mm-wood	2.4	1.4	1.7
Aluminum	7.0	—	—
Steel	5.8	—	—
Steel with:			
Fiber core	3.3	—	—
Polystyrene core	2.7	—	—
Polyurethane core	2.3	—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

Table A-19 Recommended and maximum air velocities for warm and cool air systems



Description	Recommended Velocity, m/s			Maximum Velocity, m/s		
	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	3.0	2.5	3.0	3.6
Cooling coils	2.3	2.5	3.0	2.5	3.0	3.5
Fan suction	3.5	4.0	5.0	4.5	5.0	7.0
Fan outlet	5.0-8.0	6.5-10.0	8.0-12.0	8.5	7.5-11.0	8.5-14.0
Main duct	4.0-4.5	5.0-6.5	6.0-9.0	4.0-6.0	5.5-8.0	6.5-11.0
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 risers	2.5	3.0-3.5	4.0	3.5-4.0	4.0-6.0	5.0-8.0

Table A-20 Circular equivalents of rectangular ducts for equal friction and capacity.



Lgth Adj.^{b}	Length of One Side of Rectangular Duct (a), mm																			
	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	650	700	750	800	900
	Circular Duct Diameter, mm																			
100	109																			
125	122	137																		
150	133	150	164																	
175	143	161	177	191																
200	152	172	189	204	219															
225	161	181	200	216	232	246														
250	169	190	210	228	244	259	273													
275	176	199	220	238	256	272	287	301												
300	183	207	229	248	266	283	299	314	328											
350	195	222	245	267	286	305	322	339	354	383										
400	207	235	260	283	305	325	343	361	378	409	437									
450	217	247	274	299	321	343	363	382	400	433	464	492								
500	227	258	287	313	337	360	381	401	420	455	488	518	547							
550	236	269	299	326	352	375	398	419	439	477	511	543	573	601						
600	245	279	310	339	365	390	414	436	457	496	533	567	598	628	656					
650	253	289	321	351	378	404	429	452	474	515	553	589	622	653	683	711				
700	261	298	331	362	391	418	443	467	490	533	573	610	644	677	708	737	765			
750	268	306	341	373	402	430	457	482	506	550	592	630	666	700	732	763	792	820		
800	275	314	350	383	414	442	470	496	520	567	609	649	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
1100	313	358	399	437	473	506	538	569	598	652	703	751	795	838	878	916	953	988	1022	1086
1200	324	370	413	453	490	525	558	590	620	677	731	780	827	872	914	954	993	1030	1066	1133
1300	334	382	426	468	506	543	577	610	642	701	757	808	857	904	948	990	1031	1069	1107	1177
1400	344	394	439	482	522	559	595	629	662	724	781	835	886	934	980	1024	1066	1107	1146	1220
1500	353	404	452	495	536	575	612	648	681	745	805	860	913	963	1011	1057	1100	1143	1183	1260
1600	362	415	463	508	551	591	629	665	700	766	827	885	939	991	1041	1088	1133	1177	1219	1298
1700	371	425	475	521	564	605	644	682	718	785	849	908	964	1018	1069	1118	1164	1209	1253	1335
1800	379	434	485	533	577	619	660	698	735	804	869	930	988	1043	1096	1146	1195	1241	1286	1371
1900	387	444	496	544	590	633	674	713	751	823	889	952	1012	1068	1122	1174	1224	1271	1318	1405
2000	395	453	506	555	602	646	688	728	767	840	908	973	1034	1092	1147	1200	1252	1301	1348	1438
2100	402	461	516	566	614	659	702	743	782	857	927	993	1055	1115	1172	1226	1279	1329	1378	1470
2200	410	470	525	577	625	671	715	757	797	874	945	1013	1076	1137	1195	1251	1305	1356	1406	1501
2300	417	478	534	587	636	683	728	771	812	890	963	1031	1097	1159	1218	1275	1330	1383	1434	1532
2400	424	486	543	597	647	695	740	784	826	905	980	1050	1116	1180	1241	1299	1355	1409	1461	1561
2500	430	494	552	606	658	706	753	797	840	920	996	1068	1136	1200	1262	1322	1379	1434	1488	1589
2600	437	501	560	616	668	717	764	810	853	935	1012	1085	1154	1220	1283	1344	1402	1459	1513	1617
2700	443	509	569	625	678	728	776	822	866	950	1028	1102	1173	1240	1304	1366	1425	1483	1538	1644
2800	450	516	577	634	688	738	787	834	879	964	1043	1119	1190	1259	1324	1387	1447	1506	1562	1670
2900	456	523	585	643	697	749	798	845	891	977	1058	1135	1208	1277	1344	1408	1469	1529	1586	1696

Lgth Adj.[b]	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
	Length One Side of Rectangular Duct (a), mm																			
	Circular Duct Diameter, mm																			
1000	1093																			
1100	1146	1202																		
1200	1196	1256	1312																	
1300	1244	1306	1365	1421																
1400	1289	1354	1416	1475	1530															
1500	1332	1400	1464	1526	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	1889	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	2502	2562	2621	2678	2733				
2600	1715	1808	1896	1980	2061	2139	2213	2285	2355	2422	2487	2551	2612	2672	2730	2787	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	2510	2578	2644	2708	2771	2832	2891	2949	3006	3061	
2900	1800	1898	1992	2081	2167	2250	2329	2406	2480	2552	2621	2689	2755	2819	2881	2941	3001	3058	3115	3170

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

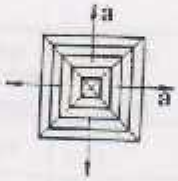
[b] Length adjacent side of rectangular duct (b), mm.

Table A-21 Equivalent length L_e, of various fittings.

commonly used 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-22 Model 4SNOD four-way throw square diffusers.



NECK SIZE Ak	NECK VELOCITY 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	[illegible]
Ak = .13	Throw each side-a	2-3	3-5	4-7	5-9	6-11	7-13	8-15	[illegible]
9"X9"	Total CFM	112	168	224	280	336	392	[illegible]	504
	CFM each side-a	28	42	56	70	84	98	112	126
Ak = .28	Throw each side-a	2-3	3-5	4-8	5-10	6-12	7-14	[illegible]	[illegible]
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 = .5	Throw each side-a	2-4	4-7	5-9	6-11	7-14	[illegible]	[illegible]	[illegible]
15"X15"	Total CFM	312	468	624	780	936	[illegible]	[illegible]	1404
	CFM each side-a	78	117	156	195	235	273	[illegible]	[illegible]
Ak = .79	Throw each side-a	3-5	4-8	5-10	7-13	8-16	[illegible]	[illegible]	[illegible]
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 = 1.13	Throw each side-a	3-5	4-8	5-10	7-13	9-17	[illegible]	[illegible]	[illegible]
21"X21"	Total CFM	612	918	1224	1530	1836	[illegible]	2448	2754
	CFM each side-a	153	229	306	382	459	[illegible]	612	688
Ak = 1.54	Throw each side-a	3-5	4-8	6-11	7-13	[illegible]	[illegible]	[illegible]	[illegible]
24"X24"	Total CFM	800	1200	1600	2000	[illegible]	[illegible]	[illegible]	3600
	CFM each side-a	200	300	400	500	[illegible]	700	[illegible]	900
Ak = 2	Throw each side-a	3-6	5-9	6-12	7-14	[illegible]	[illegible]	[illegible]	[illegible]

Table A-23 Fixed blade Return Air Grille Models 7145H.

Listed Duct Size (inches)	Alternate Size (inches)	Core Area (sq. ft.)	Ak Factor	Core Velocity VP Neg. SP	100 .001 .003	200 .002 .011	300 .006 .025	400 .010 .043	500 .016 .070	600 .022 .101	700 .031 .138	800 .040 .180	900 .050 .228	1000 .062 .281
6 x 6	8 x 4 10 x 4	0.20	0.23	CFM NC	20 –	40 –	60 –	80 –	100 –	120 17	140 22	160 26	180 30	200 34
8 x 6	10 x 5 12 x 4	0.28	0.30	CFM NC	28 –	56 –	84 –	112 –	140 –	168 18	196 23	224 27	252 31	280 35
10 x 6	12 x 5 16 x 4	0.35	0.37	CFM NC	35 –	70 –	105 –	140 –	175 –	210 19	245 24	280 28	315 32	350 36
8 x 8	14 x 5	0.38	0.40	CFM NC	38 –	76 –	114 –	152 –	190 15	228 20	266 25	304 29	342 33	380 37
12 x 6	18 x 4	0.42	0.45	CFM NC	42 –	84 –	126 –	168 –	210 16	252 21	294 25	336 31	378 34	420 38
12 x 8	16 x 6 24 x 4	0.58	0.59	CFM NC	58 –	116 –	174 –	232 –	290 17	348 22	406 26	464 31	522 35	580 39
10 x 10	14 x 7 26 x 4	0.61	0.62	CFM NC	61 –	122 –	183 –	244 –	305 17	366 22	427 27	488 32	549 35	610 39
18 x 8	14 x 8 30 x 4 28 x 4	0.65	0.67	CFM NC	65 –	130 –	195 –	260 –	325 18	390 23	455 28	520 32	585 36	650 39
12 x 10	16 x 8 20 x 6 24 x 5	0.74	0.74	CFM NC	74 –	148 –	222 –	296 –	370 18	444 23	518 28	592 33	666 37	740 40
12 x 12	14 x 10 24 x 6 18 x 8 36 x 4	0.90	0.89	CFM NC	90 –	180 –	270 –	360 –	450 19	540 24	630 29	720 34	810 37	900 40
14 x 14	16 x 12 24 x 8 20 x 10 34 x 6	1.24	1.22	CFM NC	124 –	248 –	372 –	496 –	620 19	744 24	868 29	992 34	1116 38	1240 41
18 x 12	16 x 14 28 x 8 22 x 10 36 x 8	1.37	1.34	CFM NC	137 –	274 –	411 –	548 15	685 20	822 25	959 30	1096 35	1233 38	1370 41
24 x 10	20 x 12 30 x 8	1.52	1.49	CFM NC	152 –	304 –	456 –	608 15	760 20	912 25	1064 30	1216 35	1368 39	1520 42
16 x 16	18 x 14 30 x 8 22 x 12	1.64	1.58	CFM NC	164 –	328 –	492 –	656 16	820 21	984 26	1148 31	1312 36	1476 39	1640 42
24 x 12	18 x 16 30 x 10 20 x 14 36 x 8	1.85	1.78	CFM NC	185 –	370 –	555 –	740 16	925 21	1110 26	1295 31	1480 36	1665 39	1850 42
18 x 18	20 x 16 28 x 12 24 x 14 32 x 10	2.10	2.01	CFM NC	210 –	420 –	630 –	840 16	1050 21	1260 27	1470 32	1680 37	1890 40	2100 43
30 x 12	20 x 18 26 x 14 22 x 16 36 x 10	2.32	2.23	CFM NC	232 –	464 –	696 –	928 17	1160 22	1392 27	1624 32	1856 37	2088 40	2320 44
20 x 20	24 x 18 30 x 14 26 x 16 36 x 12	2.61	2.48	CFM NC	261 –	522 –	783 –	1044 17	1305 22	1566 28	1827 33	2088 38	2349 41	2610 44
22 x 22	24 x 20 30 x 16 28 x 18 36 x 14	3.17	3.00	CFM NC	317 –	634 –	951 –	1268 18	1585 23	1902 29	2219 33	2536 38	2853 41	3170 45
30 x 18	24 x 22 40 x 14 34 x 16	3.54	3.34	CFM NC	354 –	708 –	1062 –	1416 18	1770 23	2124 29	2478 34	2832 39	3186 42	3540 46
24 x 24	26 x 22 32 x 18 28 x 20 36 x 16	3.79	3.56	CFM NC	379 –	758 –	1137 –	1516 18	1895 23	2274 29	2653 34	3032 39	3411 42	3790 46
36 x 18	32 x 20 46 x 14 40 x 16	4.27	4.01	CFM NC	427 –	854 –	1281 –	1708 19	2135 24	2562 30	2989 35	3416 40	3843 43	4270 47
26 x 26	28 x 24 46 x 14	4.47	4.16	CFM NC	447 –	894 –	1341 –	1788 19	2235 24	2682 30	3129 35	3576 40	4023 43	4470 47
30 x 24	26 x 26 36 x 20 32 x 22 40 x 18	4.77	4.46	CFM NC	477 –	954 –	1431 –	1908 20	2385 25	2862 31	3339 36	3816 40	4293 44	4770 48
28 x 28	30 x 26 40 x 20 36 x 22	5.20	4.85	CFM NC	520 –	1040 –	1560 –	2080 20	2600 25	3120 31	3640 36	4160 41	4680 44	5200 48
36 x 24	30 x 28 44 x 20 40 x 22	5.74	5.36	CFM NC	574 –	1148 –	1722 –	2296 20	2870 26	3444 32	4018 36	4592 41	5166 45	5740 49
30 x 30	34 x 26 48 x 20 38 x 24	5.99	5.57	CFM NC	599 –	1198 –	1797 –	2396 20	2995 26	3594 32	4193 37	4792 41	5391 45	5990 49

Table A-24 Air Handling Unit.

Inlet Water Temp. 45°F- Coils are of 8 Fins/inch

MODEL	On Coil		AFR	4 Rows				6 Rows				8 Rows			
	DB °F	WB °F	SCFM	T.CAP BTU/H	S.CAP BTU/H	WFR GPM	WPD FT	T.CAP BTU/H	S.CAP BTU/H	WFR GPM	WPD FT	T.CAP BTU/H	S.CAP BTU/H	WFR GPM	WPD FT
AHU150	75	63	15000	413303	298995	87.0	9.47	483135	355133	113.0	3.83	568688	462601	125.0	3.17
	78	65		450000	287900	90.0	10.09	566726	379140	128.0	4.59	661697	438374	141.0	5.47
	80	67		485000	303610	97.0	11.01	654798	433336	143.0	5.66	757112	458053	158.0	8.00
	85	70		505000	321180	101.0	12.53	800159	470494	168.0	7.66	912115	522507	186.0	10.87
AHU200	75	63	20000	485000	352780	97.0	8.10	653748	475527	149.0	4.24	783895	539201	163.0	6.97
	78	65		495000	358875	99.0	8.42	700183	509489	165.0	5.37	889331	577189	187.0	7.66
	80	67		505000	354510	101.0	8.74	866249	543271	190.0	6.70	1018791	615350	209.0	9.43
	85	70		515000	375930	103.0	9.36	1073248	630775	221.0	9.07	1199800	696150	236.0	12.02
AHU250	75	63	25000	510000	415140	102.0	11.85	820021	598039	176.0	7.04	960280	675951	195.0	11.06
	78	65		515000	408910	103.0	12.10	902524	637822	193.0	9.26	985000	683600	197.0	11.27
	80	67		520000	403480	104.0	12.32	1000000	630000	200.0	9.71	1020000	665200	204.0	12.02
	85	70		525000	429450	105.0	12.54	1020000	664020	204.0	10.66	1060000	734000	212.0	12.91
AHU320	75	63	32000	520000	484120	104.0	11.83	950000	723000	190.0	8.27	1020000	779280	204.0	11.54
	78	65		525000	477730	105.0	12.05	995000	724380	199.0	9.12	1050000	773850	210.0	12.17
	80	67		535000	472940	107.0	12.47	1050000	726700	210.0	10.08	1070000	763980	214.0	12.60
	85	70		545000	511755	109.0	12.91	1070000	789330	214.0	10.44	1090000	808780	218.0	13.04
AHU400	75	63	40000	585000	562975	117.0	14.14	975000	820950	195.0	8.37	1050000	855150	210.0	11.71
	78	65		600000	579000	120.0	14.81	1000000	815000	200.0	8.77	1070000	875250	214.0	12.12
	80	67		625000	577380	125.0	15.90	1050000	815850	210.0	9.50	1090000	864370	218.0	12.54
	85	70		650000	631150	130.0	17.15	1085000	877785	217.0	10.20	1110000	925700	222.0	12.96

Notes:

- AFR: Air flow rate (SCFM). SCFM: Standard value of Air Flow Rate at sea level, where:
  - Air Density= 1.2 kg/m³ (0.075 lb/ft³)
  - Elevation= Zero (Std.)
- DB: Dry bulb
- WB: Wet bulb
- S.CAP: Sensible cooling capacity (MBH)
- T.CAP: Total capacity (MBH)
- WFR: Water flow rate (U.S. gallons per minute)
- WPD: Water pressure drop (Feet of H_2O)
- For other conditions please refer to the nearest Petra sales office

Table A-25 "PAH" Static pressure drop.

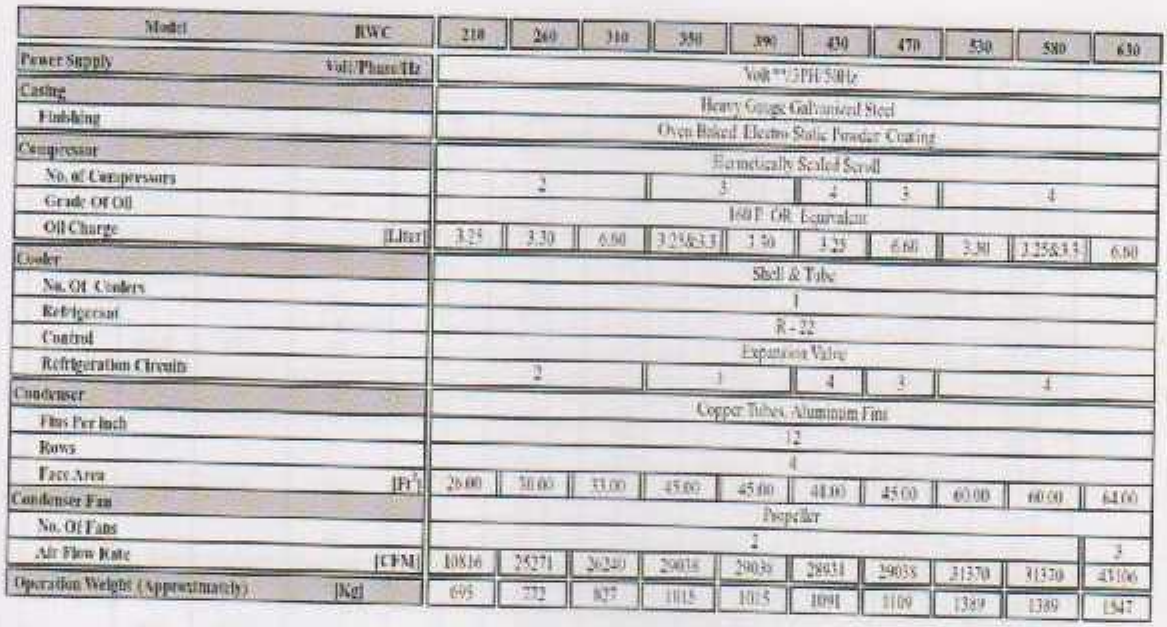
No.	Module	1 inch Thick Insulation Width	Depth (mm[Inch])	Height	Static Pressure Drop inch of water
1	Mixing Box Module+1 inch Flat Filter	1370[53.9]	750[29.5]	1370[53.9]	0.08
2	95% Bag Filter Module+Media	1370[53.9]	750[29.5]	1370[53.9]	0.68
3	Cooling / Heating Module	1370[53.9]	500[19.7]	1370[53.9]	----
4	4 Rows Cooling / Heating Coil	----	----	----	0.233
5	Forward Curved Fan Module	1370[53.9]	1450[57.1]	1370[53.9]	0.08
6	Petra 8 Fan	----	----	----	----
External Static Pressure					0.5

Pressure Drop Through Coils

3/8 coil pipe

8 Fins Per Inch	Rows Pressure Drop (Inch Of Water)													
	1		2		3		4		5		6		8	
Face Velocity (FPM)	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
350	0.024	0.028	0.048	0.057	0.072	0.085	0.096	0.116	0.116	0.149	0.136	0.162	0.182	0.217
400	0.029	0.036	0.060	0.071	0.089	0.108	0.121	0.144	0.146	0.188	0.172	0.205	0.230	0.274
450	0.036	0.043	0.073	0.087	0.110	0.131	0.147	0.176	0.179	0.231	0.211	0.252	0.282	0.336
500	0.044	0.052	0.087	0.104	0.130	0.156	0.175	0.210	0.215	0.277	0.254	0.303	0.338	0.403
550	0.051	0.061	0.102	0.122	0.154	0.184	0.206	0.246	0.255	0.328	0.300	0.358	0.399	0.475
600	0.059	0.071	0.118	0.142	0.178	0.212	0.238	0.285	0.297	0.382	0.348	0.418	0.464	0.553

Table A-26 Chiller RWC Model 530 from Petra company.



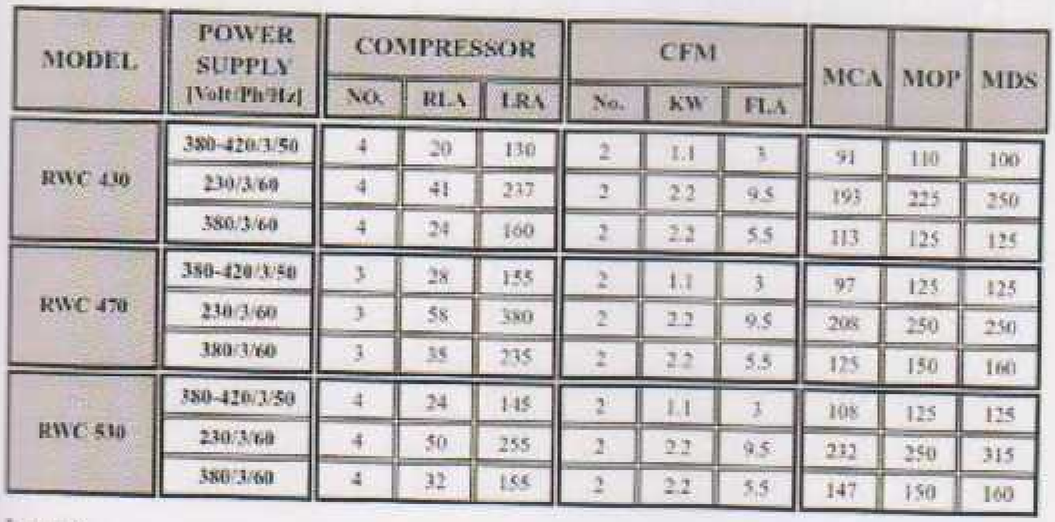
Model	RWC	210	260	310	350	390	430	470	530	580	630
Power Supply	Volt/Phase/Hz	Volt**/3PH/50Hz									
Casing		Heavy Gauge Galvanized Steel									
Finishing		Oven Baked Electro Static Powder Coating									
Compressor		Hermetically Sealed Scroll									
No. of Compressors		2			3		4	3	4		
Grade Of Oil		160F OR Equivalent									
Oil Charge	[Liter]	3.25	3.30	6.50	3.25&3.3	3.50	3.25	6.60	3.30	3.25&3.3	6.50
Cooler		Shell & Tube									
No. Of Coolers		1									
Refrigerant		R-22									
Control		Expansion Valve									
Refrigeration Circuits		2			3		4	3	4		
Condenser		Copper Tubes, Aluminum Fins									
Fins Per Inch		12									
Rows		4									
Face Area	[Ft^2]	26.00	30.00	33.00	45.00	45.00	48.00	45.00	60.00	60.00	64.00
Condenser Fan		Propeller									
No. Of Fans		2									3
Air Flow Rate	[CFM]	10816	25271	26240	29038	29036	28931	29038	31370	31370	43106
Operation Weight (Approximately)	[Kg]	695	772	827	1015	1015	1091	1109	1389	1389	1547

Note:

* Data Above Are Based On Water IN/OUT : 55/45 °F /°F

** For Power Supply Voltage Refer To Electrical Data Tables

Electrical Data Table.



MODEL	POWER SUPPLY [Volt/Ph/Hz]	COMPRESSOR			CFM			MCA	MOP	MDS
		NO.	RLA	LRA	No.	KW	FLA			
RWC 430	380-420/3/50	4	20	130	2	1.1	3	91	110	100
	230/3/60	4	41	237	2	2.2	9.5	193	225	250
	380/3/60	4	24	160	2	2.2	5.5	113	125	125
RWC 470	380-420/3/50	3	28	155	2	1.1	3	97	125	125
	230/3/60	3	58	380	2	2.2	9.5	208	250	250
	380/3/60	3	35	235	2	2.2	5.5	125	150	160
RWC 530	380-420/3/50	4	24	145	2	1.1	3	108	125	125
	230/3/60	4	50	255	2	2.2	9.5	232	250	315
	380/3/60	4	32	155	2	2.2	5.5	147	150	160

Legend:

KW: Nominal Output Power (in Kilo Watt)

RLA: Rated Load Ampere.

FLA: Full Load Ampere.

MOP: Maximum Overcurrent Protection.

MDS: Non-Fused Main Disconnect Switch.

LRA: Locked Rotor Ampere.

MCA: Minimum Circuit Ampacity.

CFM: Condenser Fan Motor.

Table A-27 Heat pump performance data cooling part load WRA-420.

Source			Load				Capacity Btu/h	Heat of Rejection Btu/h	Watts	Source LWT
EWT	GPM	WPD	EWT	GPM	LWT	WPD				
40	75.0	9.6	50	75	40.0	16.7	371,290	410,056	13,061	51.5
				90	41.6	23.2	376,802	415,498	13,106	51.7
			55	75	44.3	16.7	399,720	438,132	13,293	52.3
				90	45.9	23.2	405,919	444,252	13,344	52.5
			60	75	48.5	16.7	429,362	467,432	13,541	53.2
				90	50.3	23.2	436,301	474,297	13,600	53.3
	90.0	13,3	50	75	40.0	16.7	387,750	433,753	13,768	49.6
				90	41.6	23.2	393,548	439,552	13,813	49.8
			55	75	44.7	16.7	417,539	463,575	14,004	50.3
				90	45.9	23.2	424,085	470,107	14,056	50.4
			60	75	48.4	16.7	448,656	494,714	14,257	51.0
				90	50.2	23.2	455,968	502,042	14,317	51.1
50	75.0	9.6	50	75	40.7	16.7	380,340	450,043	15,183	60.9
				90	42.2	23.2	385,822	455,762	15,230	61.1
			55	75	45.0	16.7	409,340	480,302	15,433	61.6
				90	46.6	23.2	415,502	486,735	15,487	61.8
			60	75	49.3	16.7	439,573	511,873	15,700	62.4
				90	50.9	23.2	446,469	519,078	15,762	62.6
	90.0	13.3	50	75	40.7	16.7	377,271	434,244	15,423	59.1
				90	42.1	23.2	382,749	439,804	15,459	59.2
			55	75	45.0	16.7	406,150	463,562	15,668	59.7
				90	46.5	23.2	412,314	469,822	15,720	59.9
			60	75	49.2	16.7	436,274	494,168	15,929	60.4
				90	50.9	23.2	443,177	501,186	15,990	60.5
70	75.0	5.6	50	75	41.5	16.7	335,475	383,304	18,694	80.4
				90	42.8	23.2	340,029	387,721	18,740	80.5
			55	75	45.9	16.7	361,037	408,104	18,954	81.1
				90	47.3	23.2	366,152	413,068	19,007	81.2
			60	75	50.2	16.7	387,672	433,960	19,229	81.8
				90	51.7	23.2	393,394	439,517	19,289	81.9
	90.0	13.3	50	75	41.5	16.7	355,032	430,739	19,255	78.7
				90	42.8	23.2	359,890	435,745	19,300	78.8
			55	75	45.8	16.7	382,183	458,725	19,509	79.2
				90	47.3	23.2	387,645	464,355	19,561	79.4
			60	75	50.2	16.7	410,492	487,919	19,779	79.8
				90	51.7	23.2	416,606	494,228	19,838	80.0

Table A-28 Heat pump performance data heating part load WRA-420 and correction factor.

Source		Load				Capacity Btu/h	Heat of Absorbtion Btu/h	Watts	Source LWT
EWT	GPM	EWT	GPM	LWT	WPD				
70	**75.0**	**90**	75	103.0	16.7	500,597	393,069	27,176	59.6
			90	100.9	23.2	501,420	395,062	26,852	59.6
		100	75	112.8	16.7	493,212	374,220	30,342	60.1
			90	110.7	23.2	493,988	376,295	29,984	60.1
		110	75	122.6	16.7	486,284	354,408	33,895	60.6
			90	120.5	23.2	486,989	356,550	33,499	60.6
	90.0	**90**	75	103.1	16.7	498,374	411,879	27,324	61.2
			90	101.0	23.2	499,242	414,011	26,995	61.2
		100	75	112.9	16.7	490,678	391,948	30,505	61.7
			90	110.8	23.2	491,495	394,163	30,141	61.6
		110	75	122.8	16.7	483,460	371,042	34,076	62.1
			90	120.6	23.2	484,232	373,335	33,679	62.1
85	**75.0**	**90**	75	105.5	16.7	581,123	475,857	26,819	72.1
			90	103.0	23.2	582,563	478,645	26,449	72.1
		100	75	115.3	16.7	570,523	454,074	29,888	72.7
			90	112.7	23.2	571,848	456,916	29,472	72.6
		110	75	125.0	16.7	560,738	431,539	33,380	73.3
			90	122.5	23.2	561,924	434,419	32,916	73.3
	90.0	**90**	75	105.7	16.7	593,522	504,747	27,308	74.1
			90	103.2	23.2	595,076	507,780	26,927	74.0
		100	75	115.4	16.7	582,234	481,390	30,424	74.6
			90	112.9	23.2	583,663	484,473	29,996	74.6
		110	75	125.2	16.7	571,808	457,274	33,974	75.1
			90	122.7	23.2	573,087	460,389	33,497	75.1

Notes:

1. **Heating Data in BOLD** = Freeze protection of the source loop is required.
2. All data is based on 100% water as the heat transfer fluid.
3. Apply capacity correction factors based on the percent anti-freeze mixture.
4. Do not select units above 120°F leaving water temperature for the load in the heating mode or below 40°F for the load in the cooling mode.
5. Capacity - Btu/h produced by the load loop.
6. Load - water loop serving the air handler or terminal device.
7. Source - heat rejection water loop; geothermal or boiler/tower loop.

EWT = Entering water temperature, °F
GPM =Gallons per minute flow
WPD = Water pressure drop, ft. of water
Btu/h = Btu per hour of heat transfer
LWT = Leaving water temperature, °F

Cooling EER	C_{fc}	Heating COP	C_{fh}
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-29 Long-Term change in ground filed 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
500/1500	4.6	7.1	29.9
	6.1	3.7	22.0
	7.6	1.9	19.4
0/2000	4.6	Not advisable	
	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-30 High density polyethylene pressure drops."1 1/4 in "

Flow			Velocity		Pressure Drop			
(m^3/s)	(liters/s)	(US gpm)	(m/s)	(ft/s)	(Pa/100m)	($mmH_2O/100m$)	(psi/100ft)	($ftH_2O/100ft$)
1.3E-4	0.13	2.1	0.135	0.44	1041	106	0.046	0.106
1.4E-4	0.14	2.2	0.145	0.46	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	7396	754	0.33	0.75
5.0E-4	0.5	7.9	0.52	1.7	10786	1100	0.48	1.1
6.0E-4	0.6	9.5	0.62	2.0	14976	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	24661	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	1.45	4.8	69454	7082	3.1	7.1
0.0015	1.5	24	1.56	5.1	76263	7777	3.4	7.8
0.0016	1.6	25	1.66	5.5	86771	8848	3.8	8.9
0.0017	1.7	27	1.77	5.8	97956	9989	4.3	10.0
0.0018	1.8	29	1.87	6.1	109819	11198	4.9	11.2
0.0019	1.9	30	1.97	6.5	116799	11910	5.2	11.9
0.0020	2.0	32	2.1	6.8	129417	13197	5.7	13.2

Figure A-31 F0 vs. G for a cylindrical heat source.

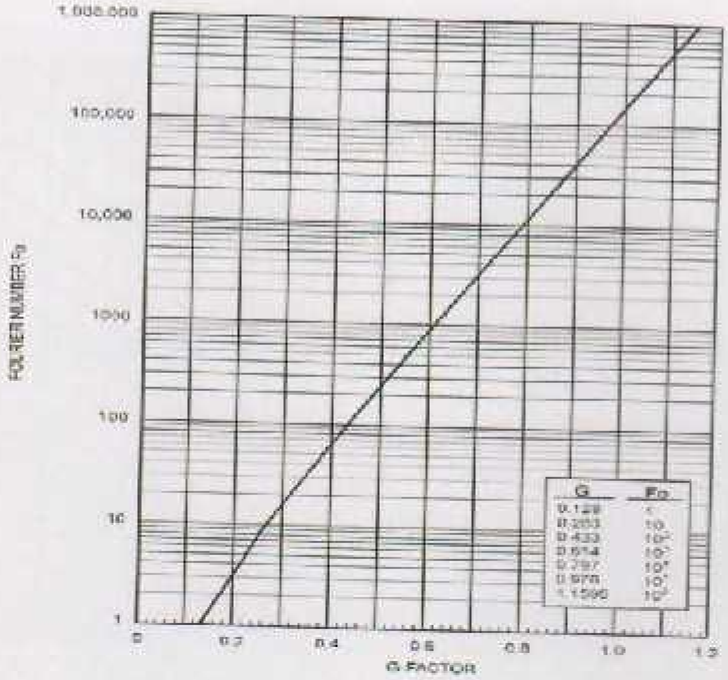


Figure A-32 Performance curves for TPE Series 1000 Grundfoss pump.

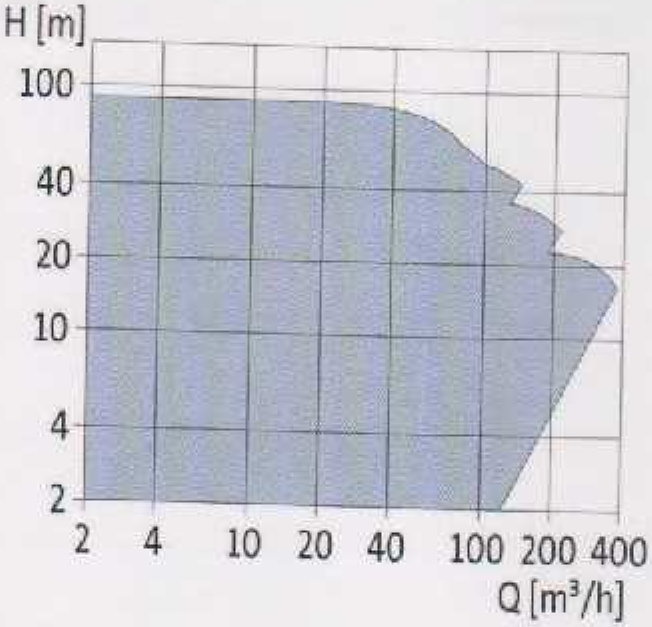
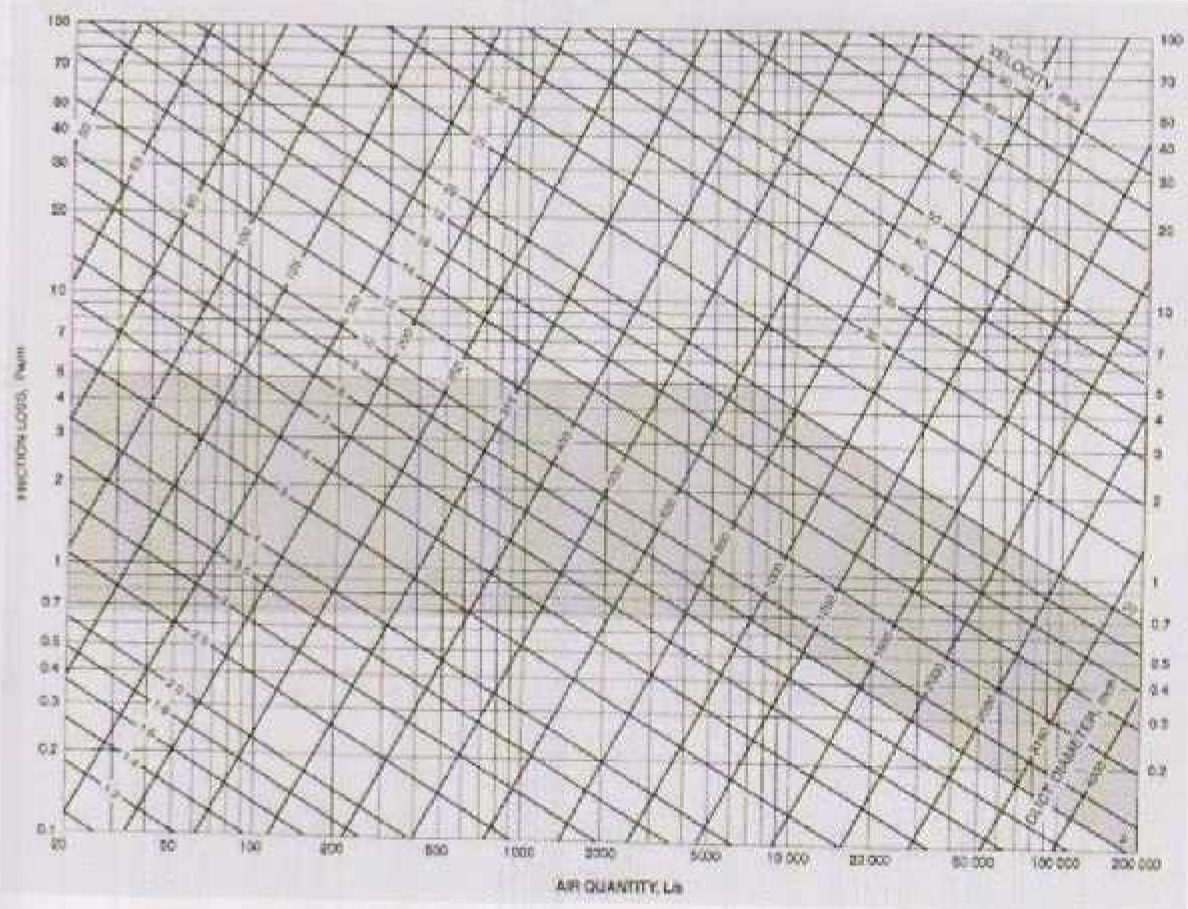
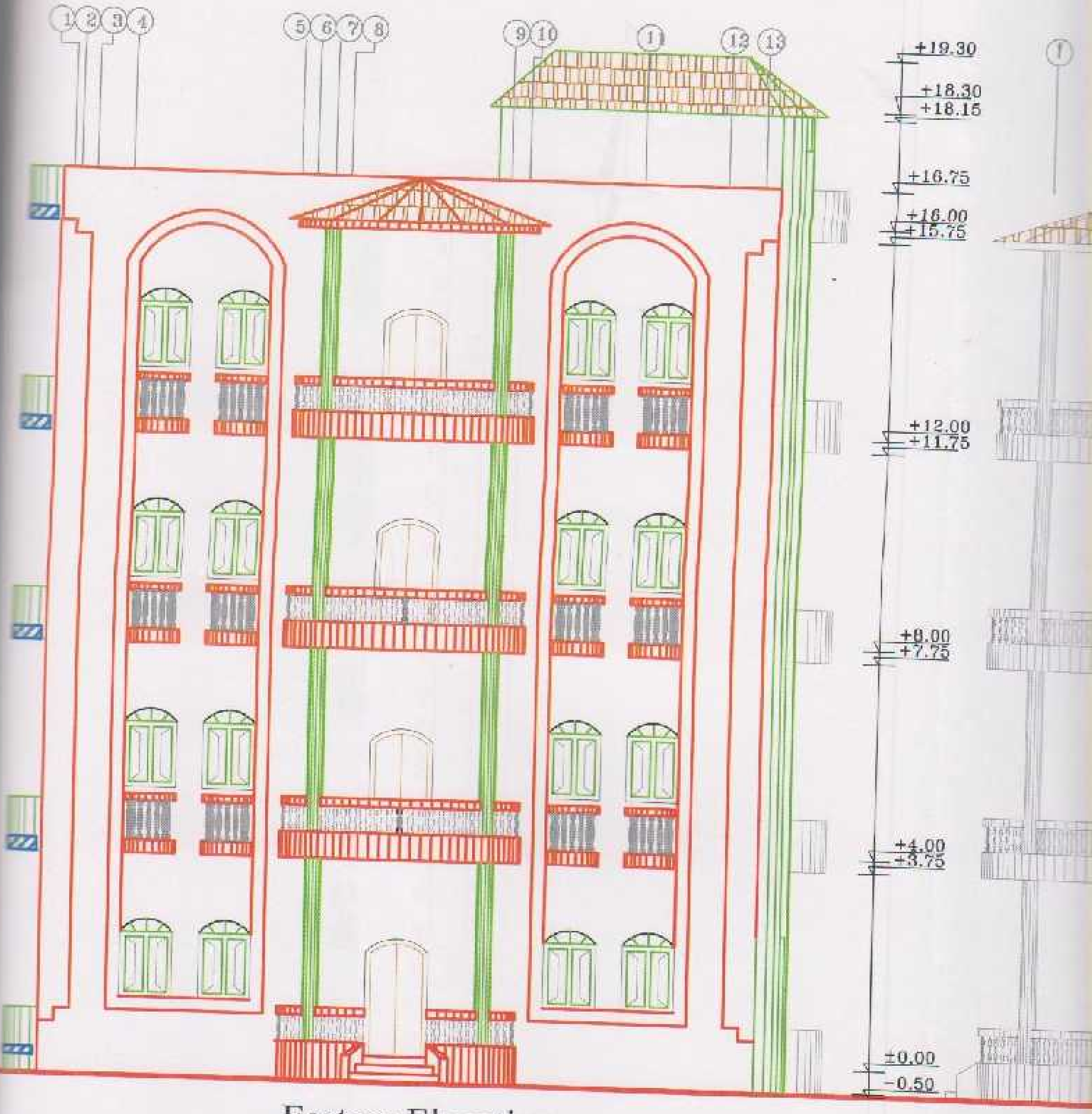


Figure A-33 Pressure drop (ΔP/EL), for air in galvanized steel ducts, based on round duct diameter.





Eastern Elevation

Division

ame: IBRAHIM&HANI&MOHAMMAD

SCALE: 1/100

pervisor Eng.Mohammad Awad

Sign

Figure A-34

F1

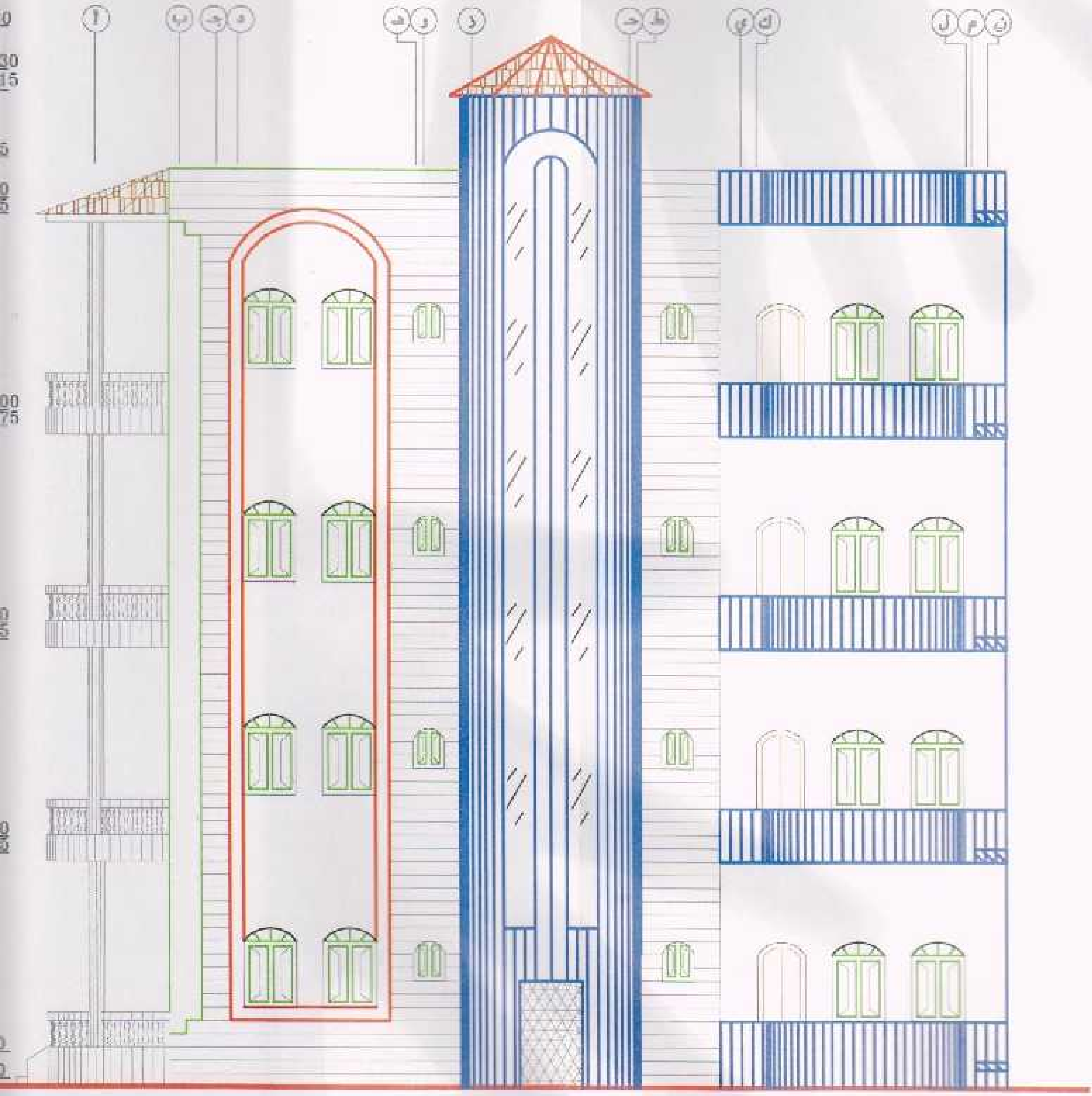
21.5.2013

Dra

Graduation Project

HEBRON

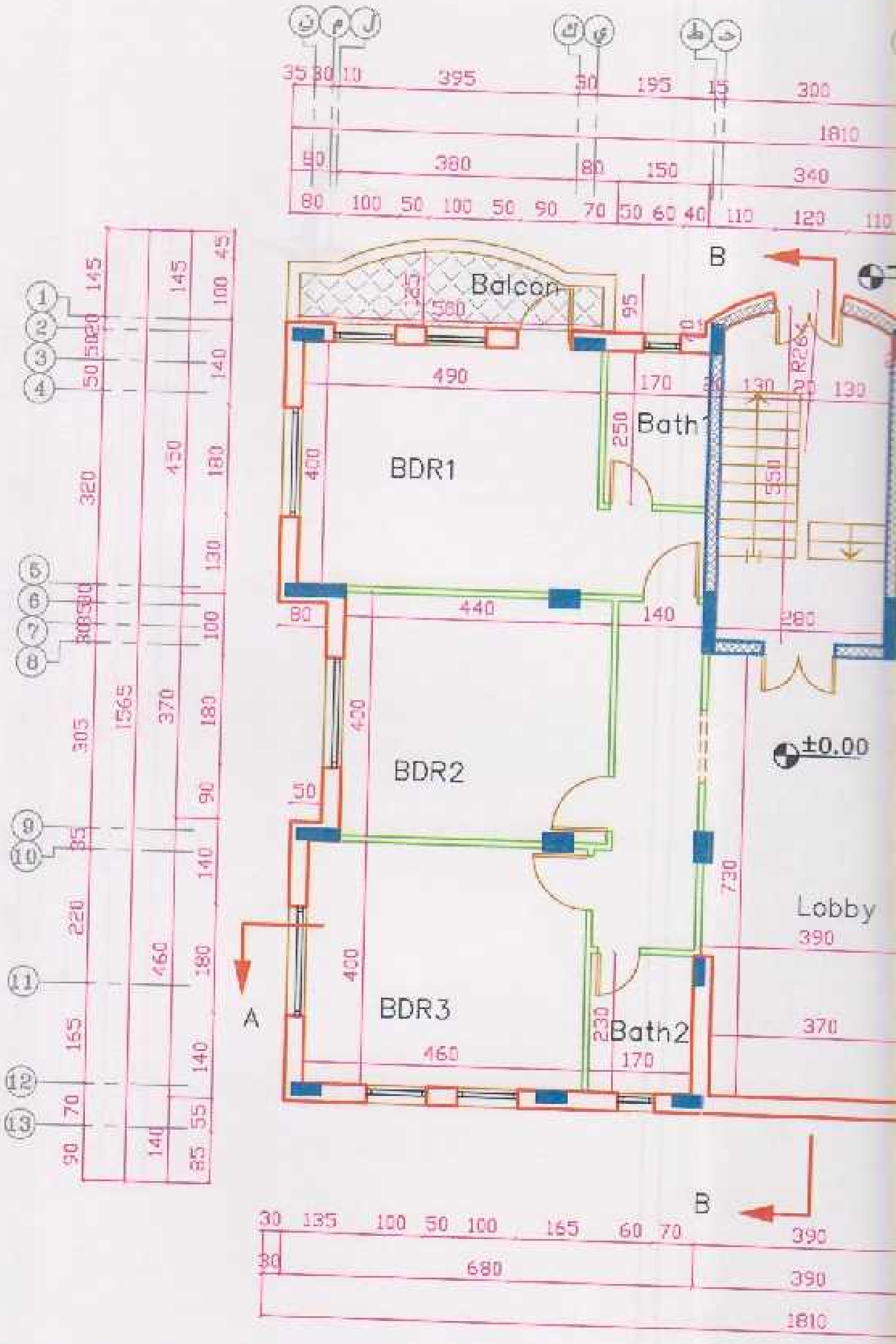
Pale



Northern Elevation

Drawing Name: Elevations

Palestine Polytechnic University "PPU"



Division

Name: IBRAHIM&HANI&MOHAMMAD

SCALE: 1/100

Supervisor Eng.Mohammad Awad

Sign

Figure A-35

F2

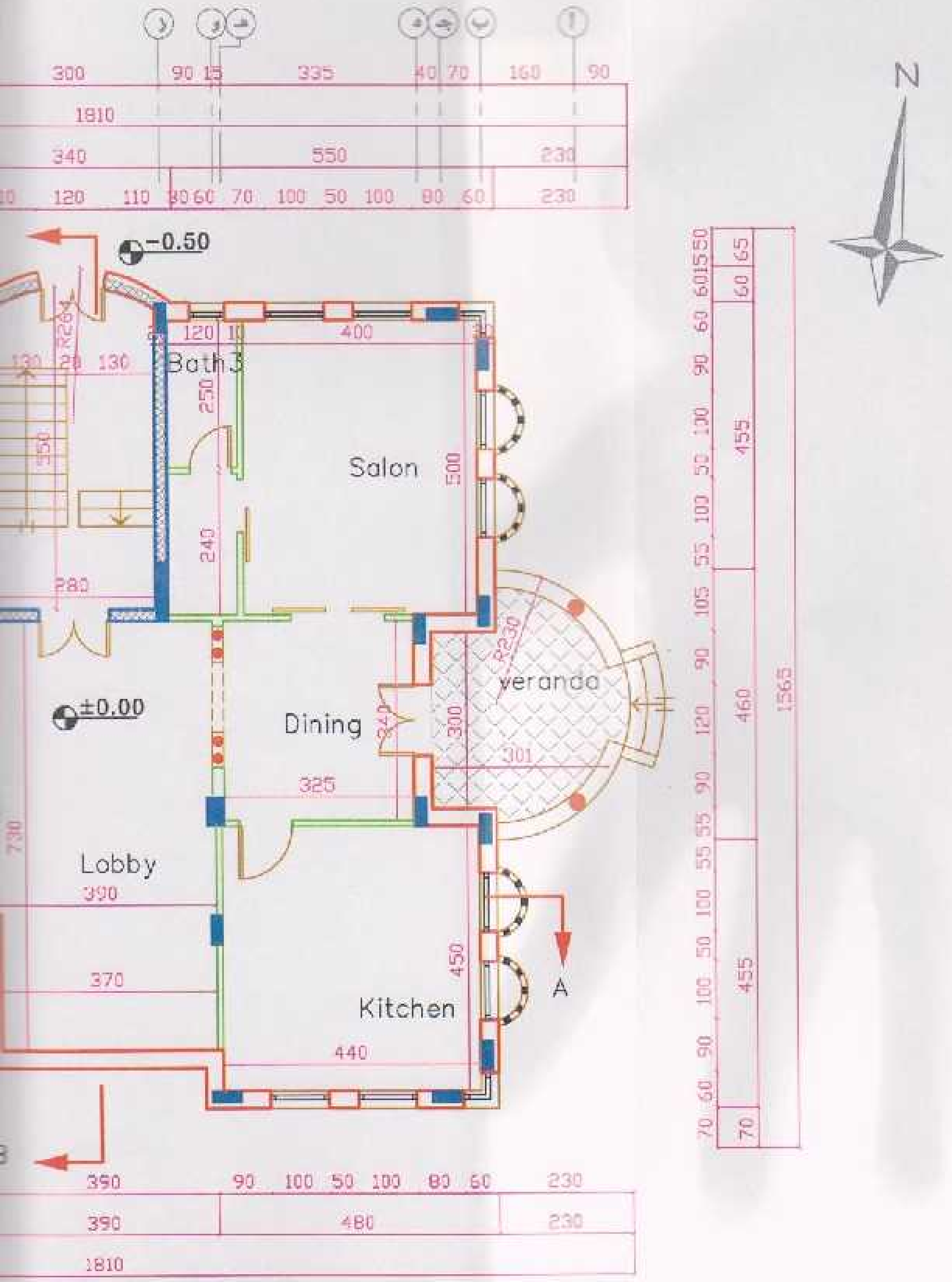
21.5.2013

Graduation Project

HEBRON

Dra

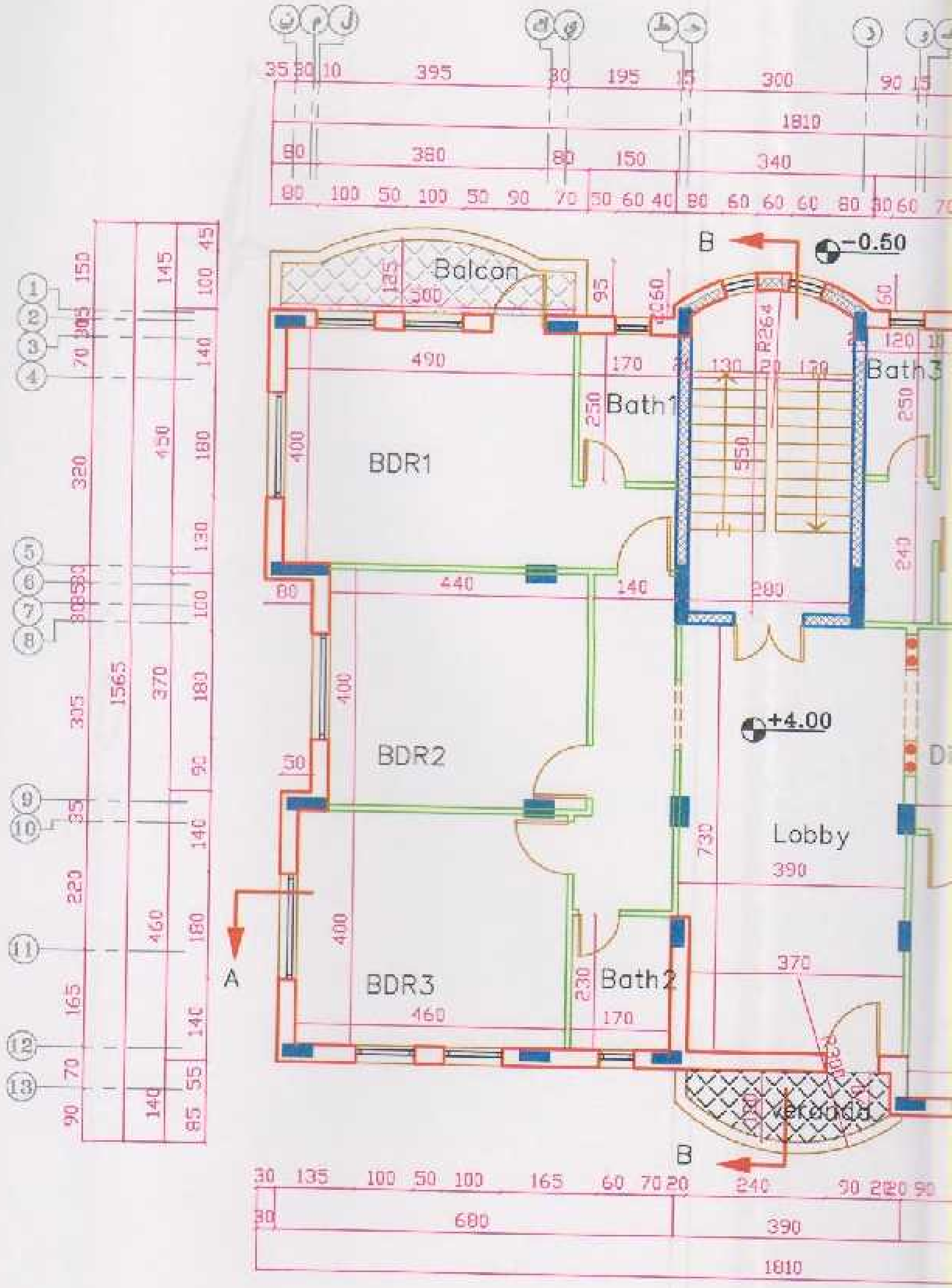
Pales



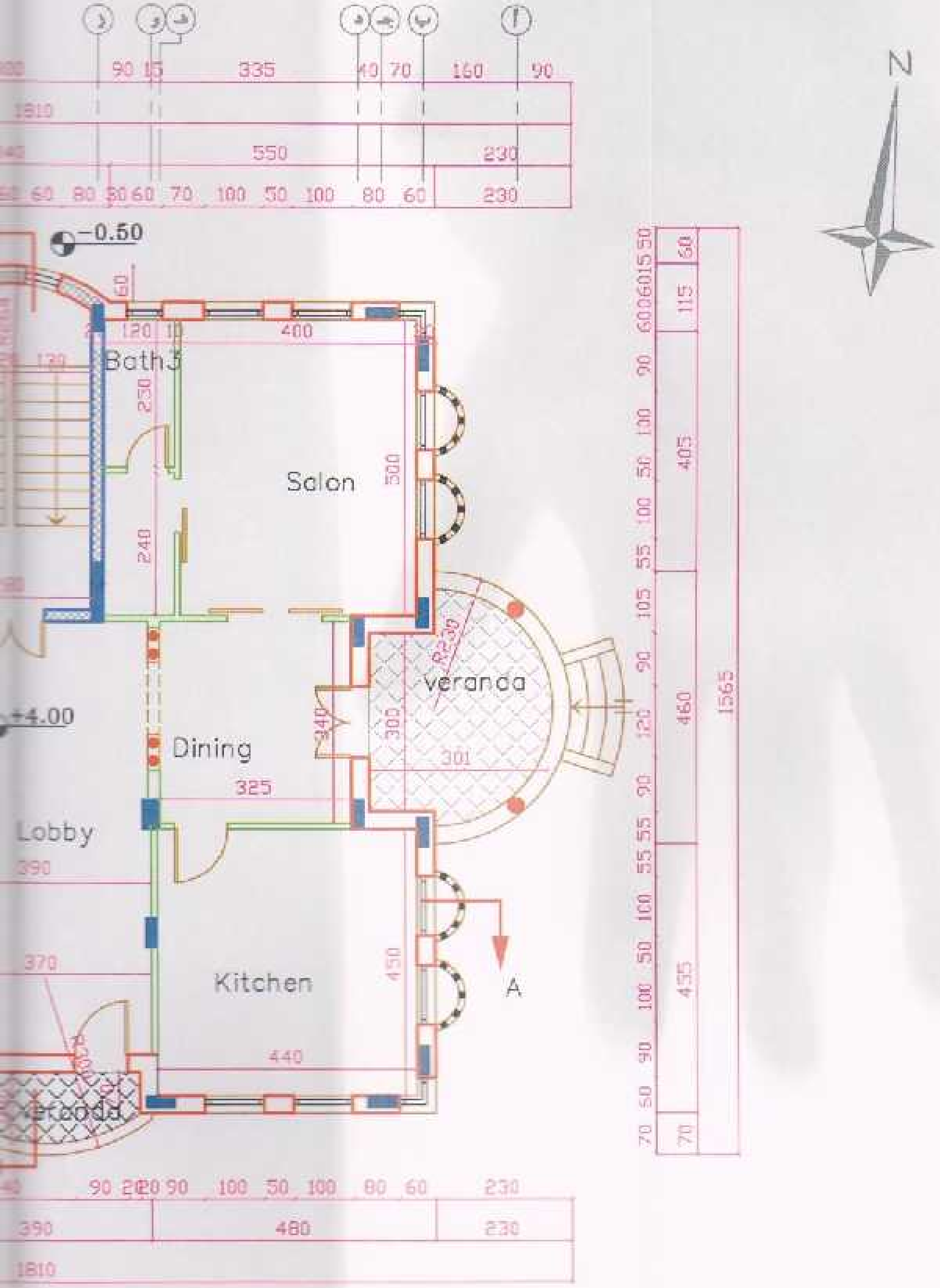
3

Drawing Name: Ground Floor Plane

Palestine Polytechnic University "PPU"

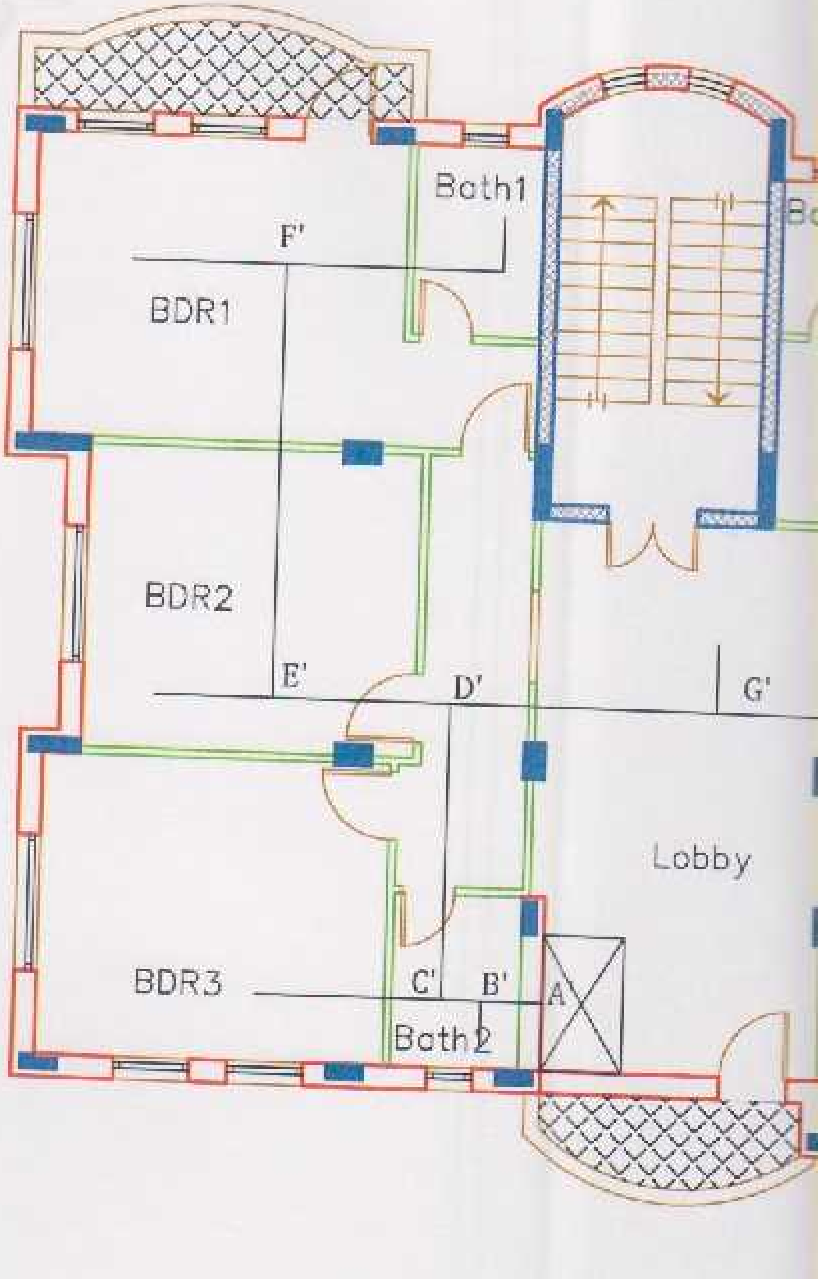


Division		F3	21.5.2013	Dr Re
Name:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100		
upervisor	Eng.Mohammad Awad			
Figure A-36		Sign	Graduation Project	HEBRON	Palest



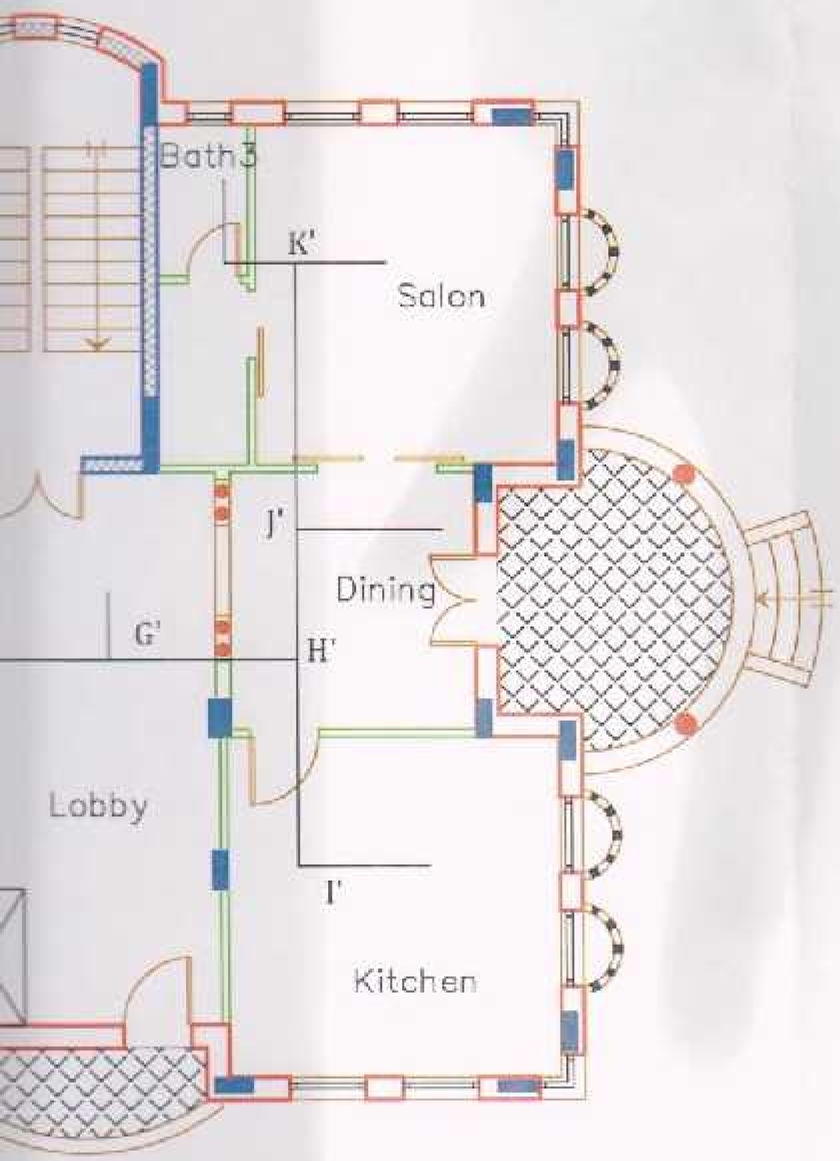
Drawing Name: First Floor Plane Repeated

Palestine Polytechnic University "PPU"



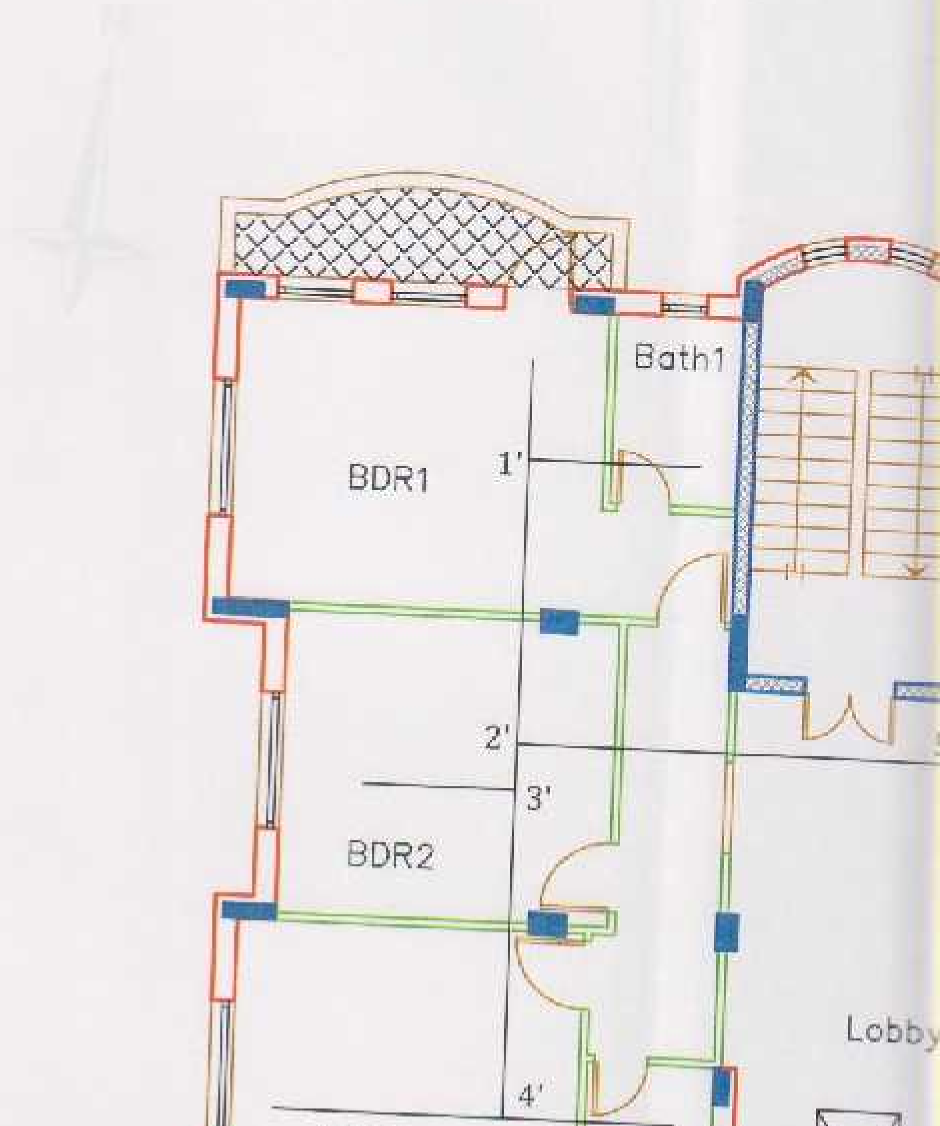
Division

Name:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100	F4	21.5.2013	Draw
pervisor	Eng.Mohammad Awad		Graduation Project	HEBRON	Pales
Figure A-37		Sign			

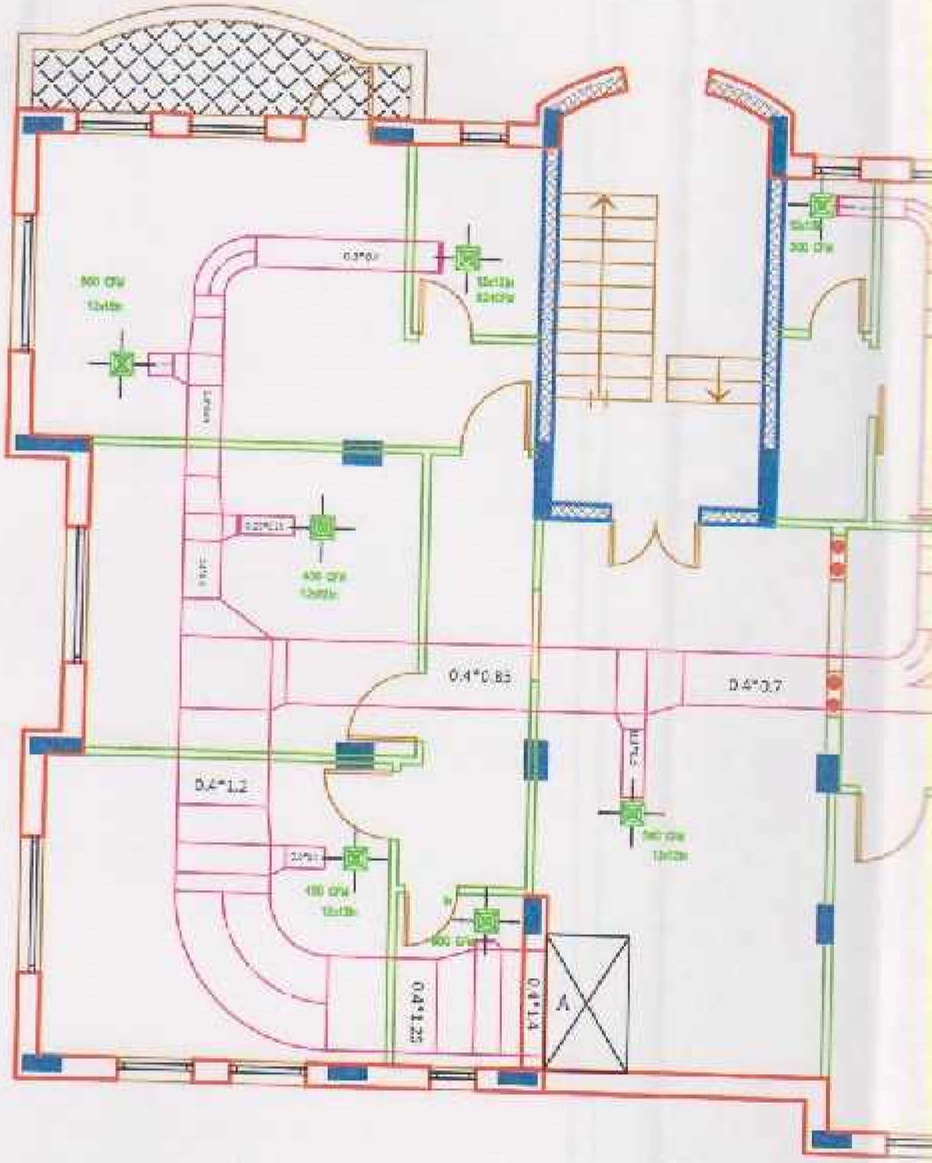


Drawing Name: First Floor Duct Line Repeated

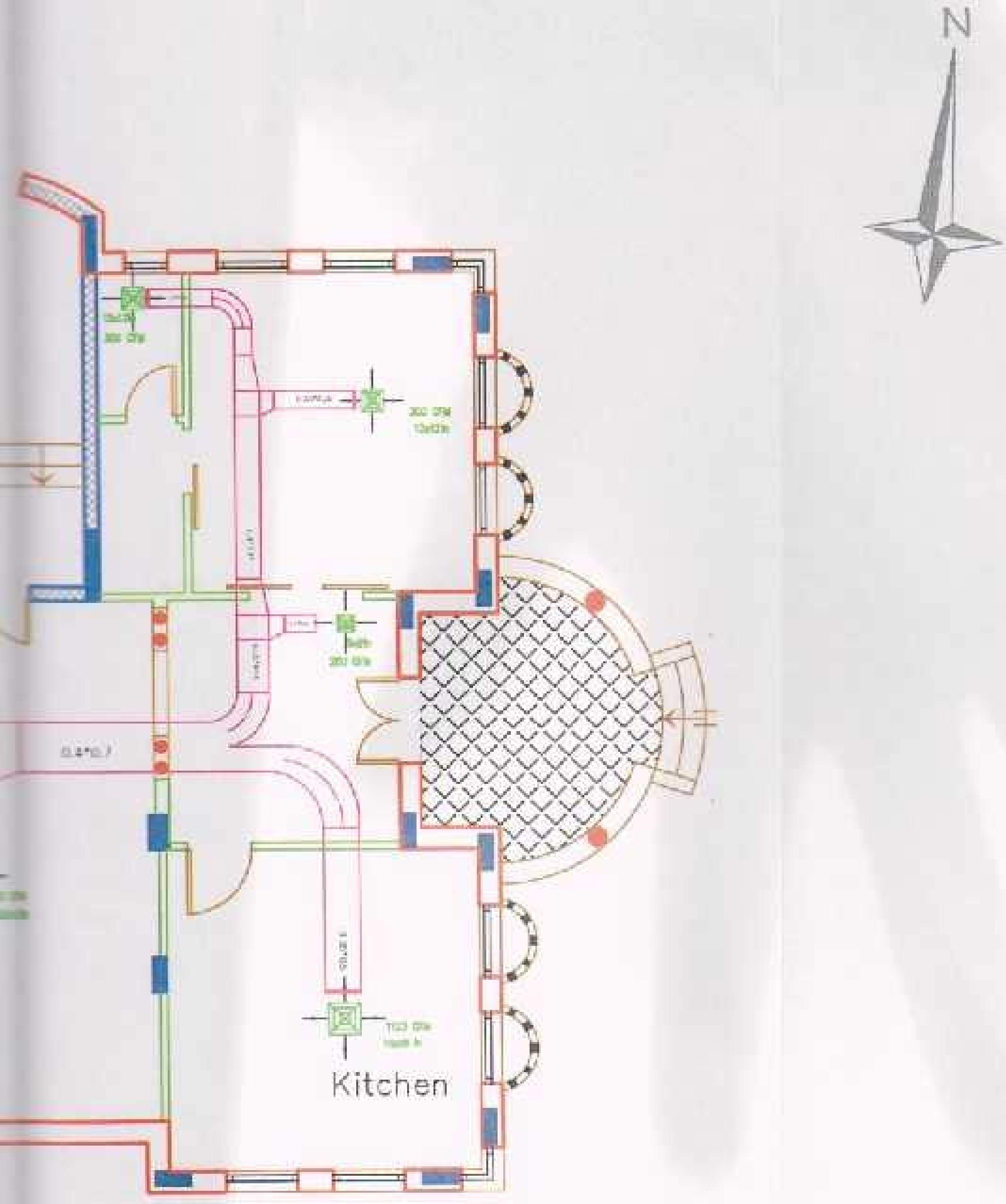
Palestine Polytechnic University "PPU"



Division					
ame:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100	F5	21.5.2013	Dra
pervisor	Eng.Mohammad Awad				
Figure A-38		Sign	Graduation Project	HEBRON	Palesti

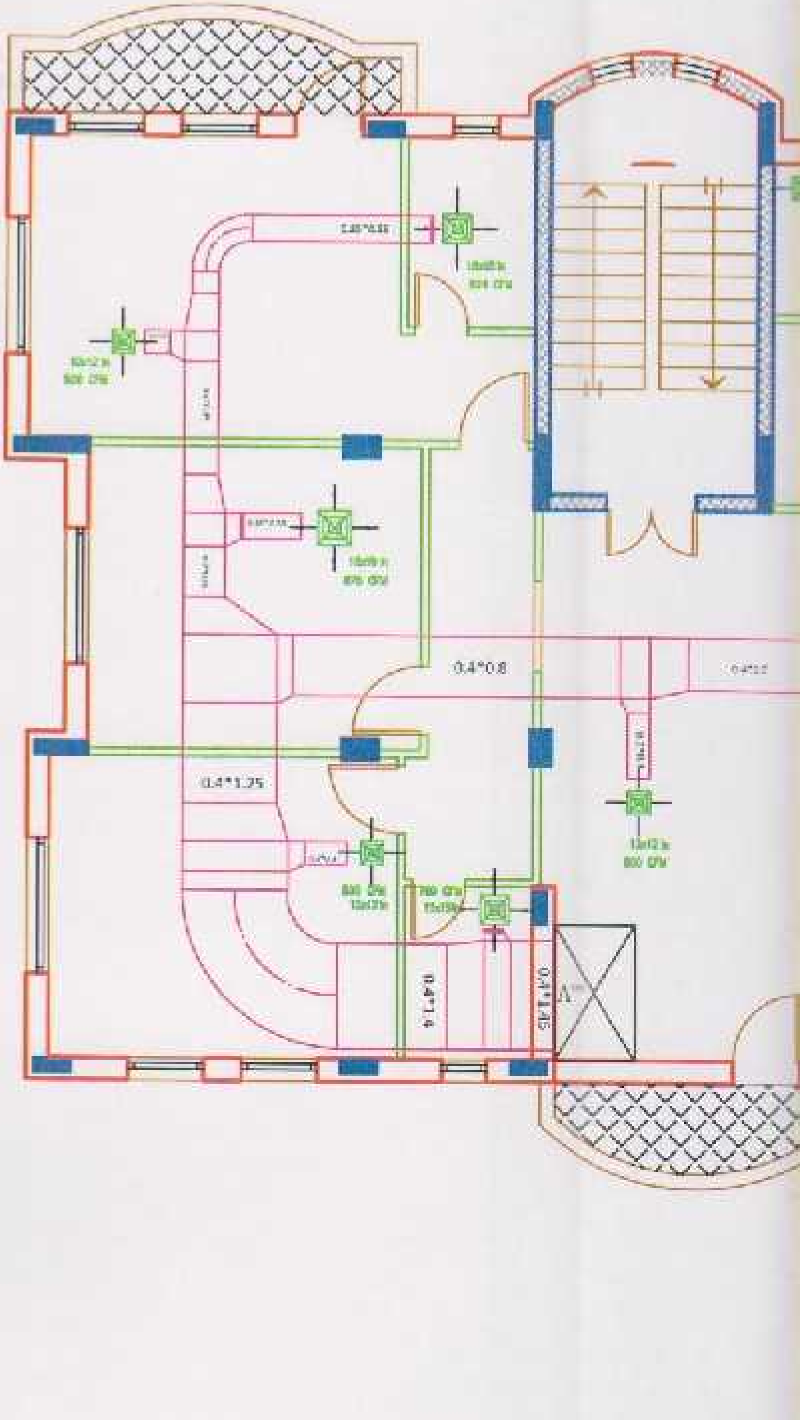


Division					
ame:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100	F6	21.5.2013	Drawi
pervisor	Eng.Mohammad Awad		Graduation Project	HEBRON	Palesti
Figure A-39		Sign			

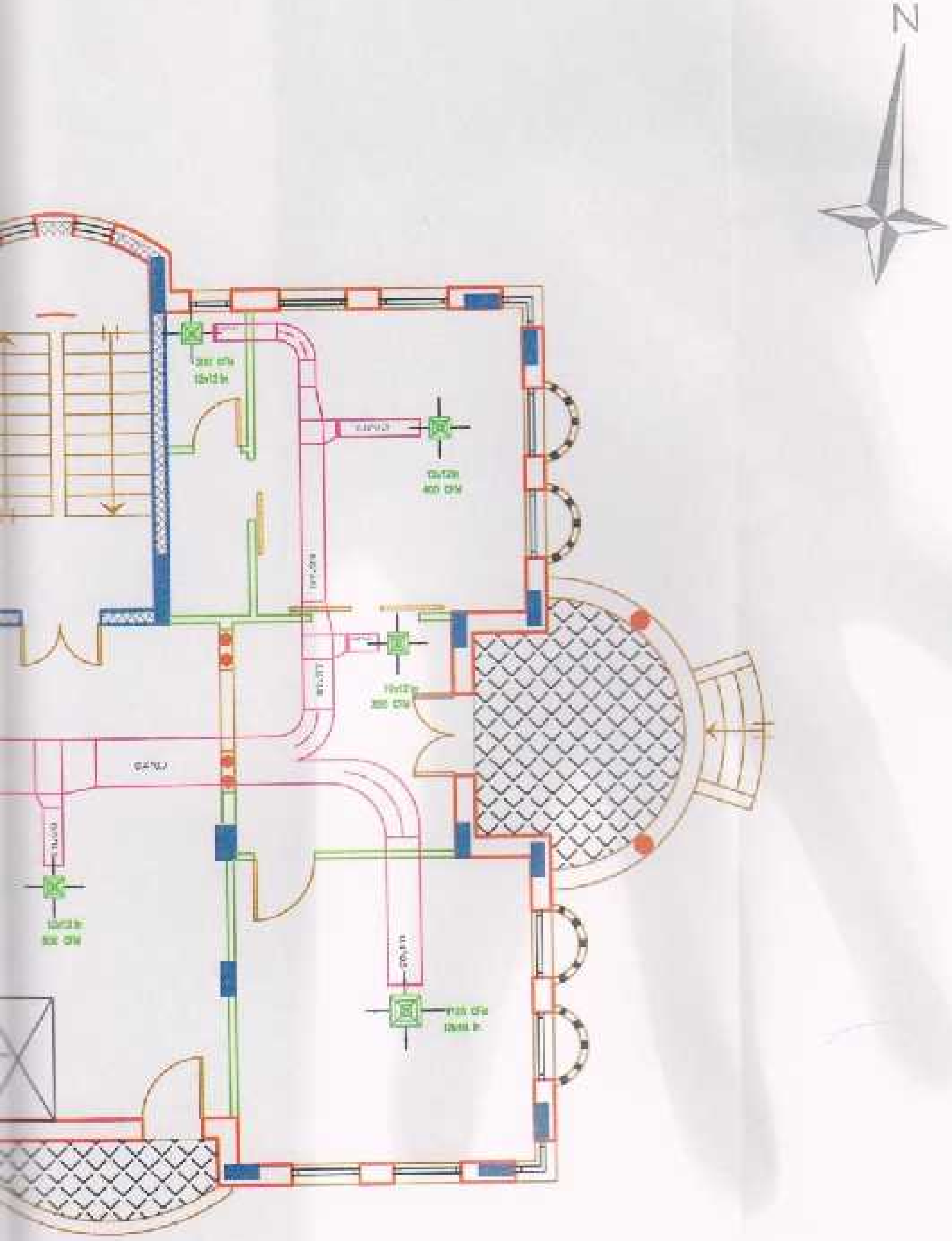


Drawing Name: Ground Floor Duct and supply air

Palestine Polytechnic University "PPU"



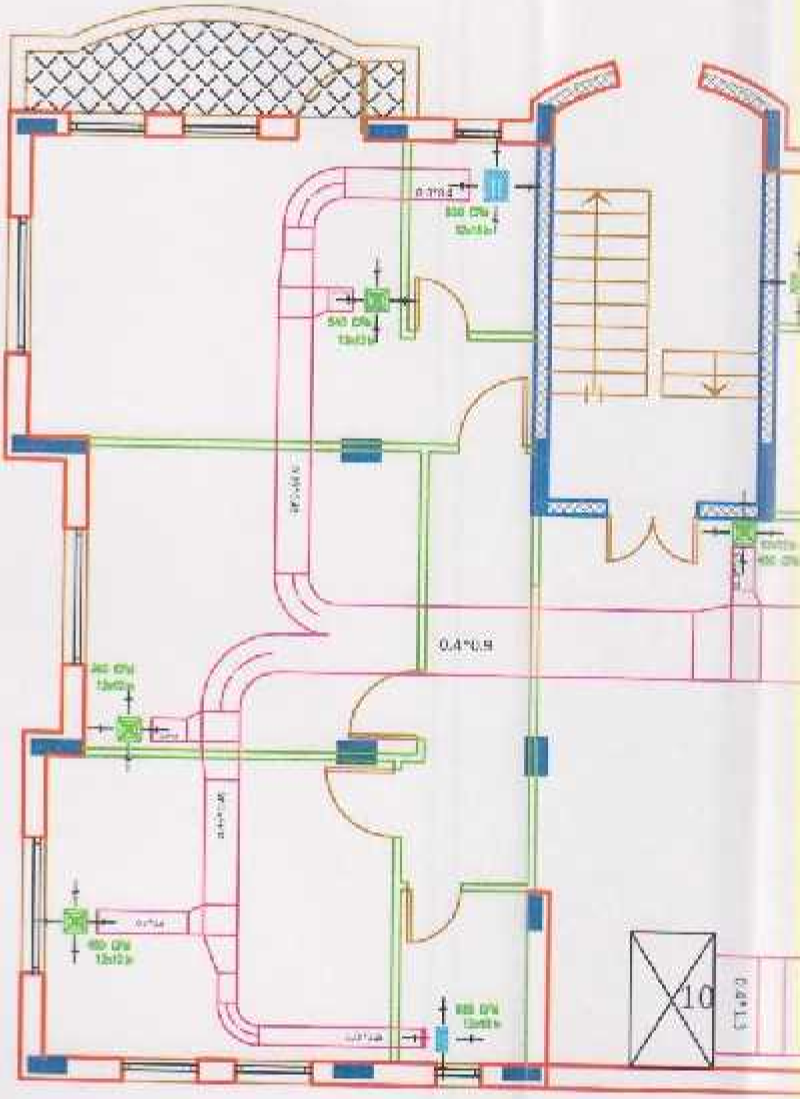
Division			F7	21.5.2013	Dra
Name:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100			
Supervisor	Eng.Mohammad Awad		Graduation Project	HEBRON	Pale
Figure A-40		Sign			



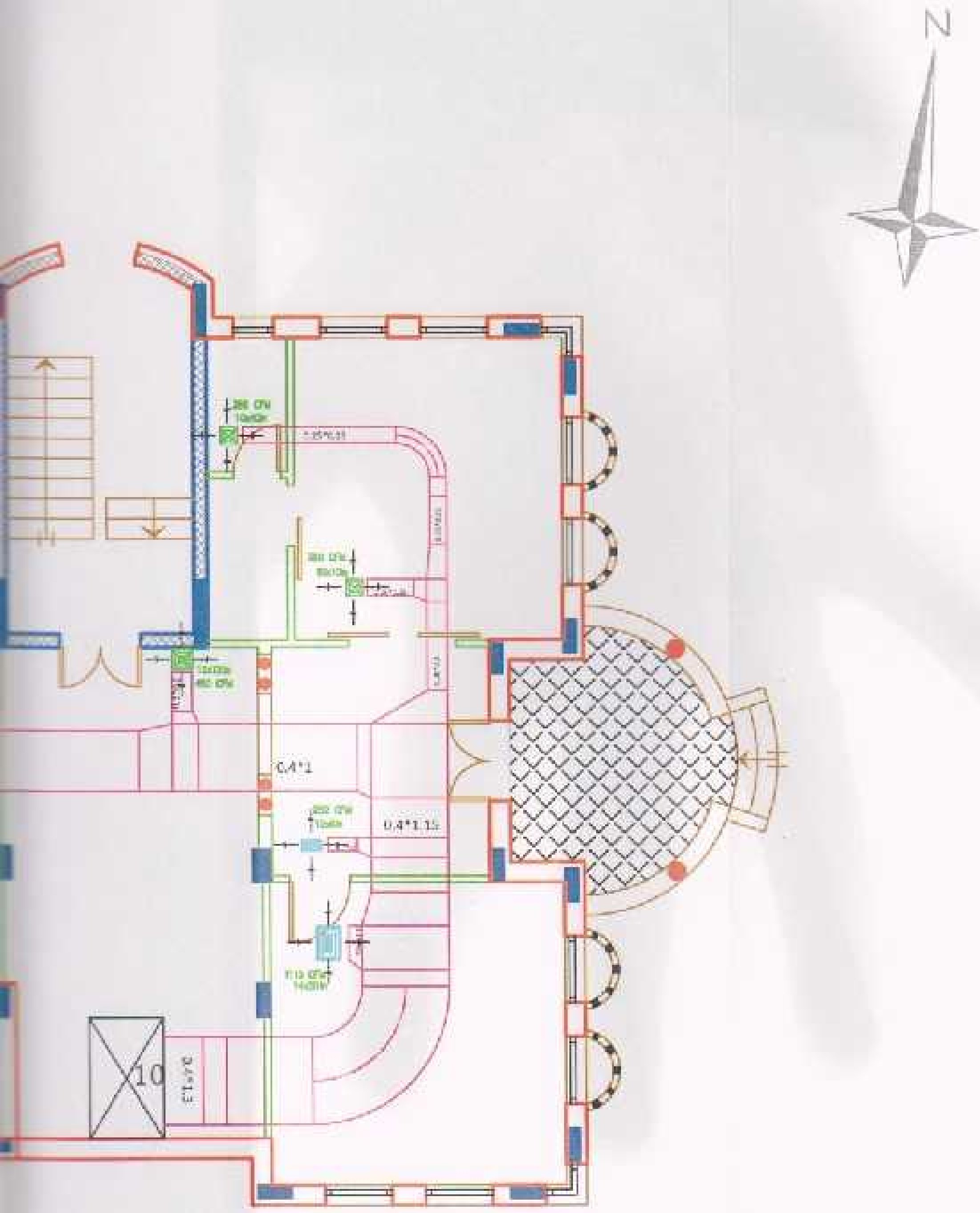
3

Drawing Name: Third Floor Duct and supply air

Palestine Polytechnic University "PPU"

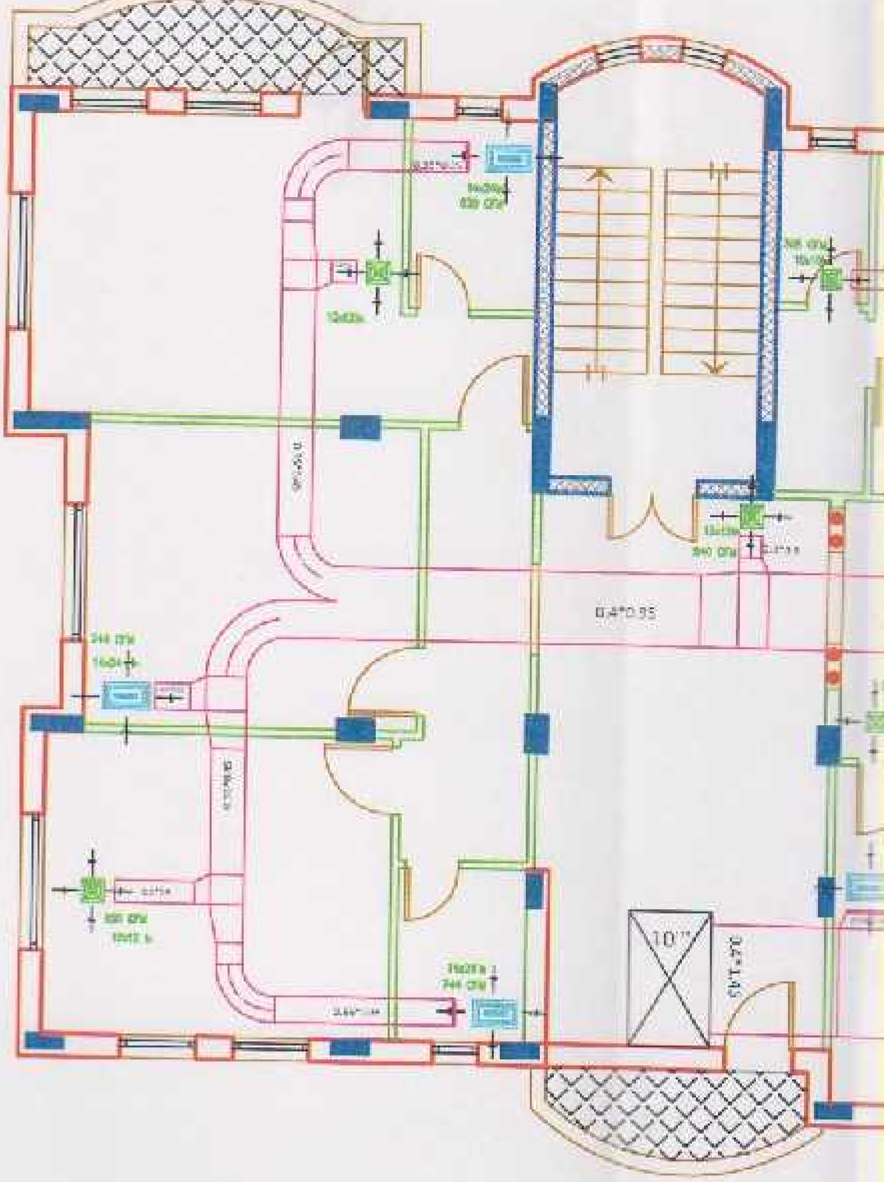


Division			F8	21.5.2013	Drawi
Name:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100			
upervisor	Eng.Mohammad Awad		Graduation Project	HEBRON	Palest
Figure A-41		Sign			



Drawing Name: Ground Floor Return Duct

Palestine Polytechnic University "PPU"



Division

Name: IBRAHIM&HANI&MOHAMMAD

SCALE: 1/100

Supervisor Eng.Mohammad Awad

Figure A-42

Sign

F9

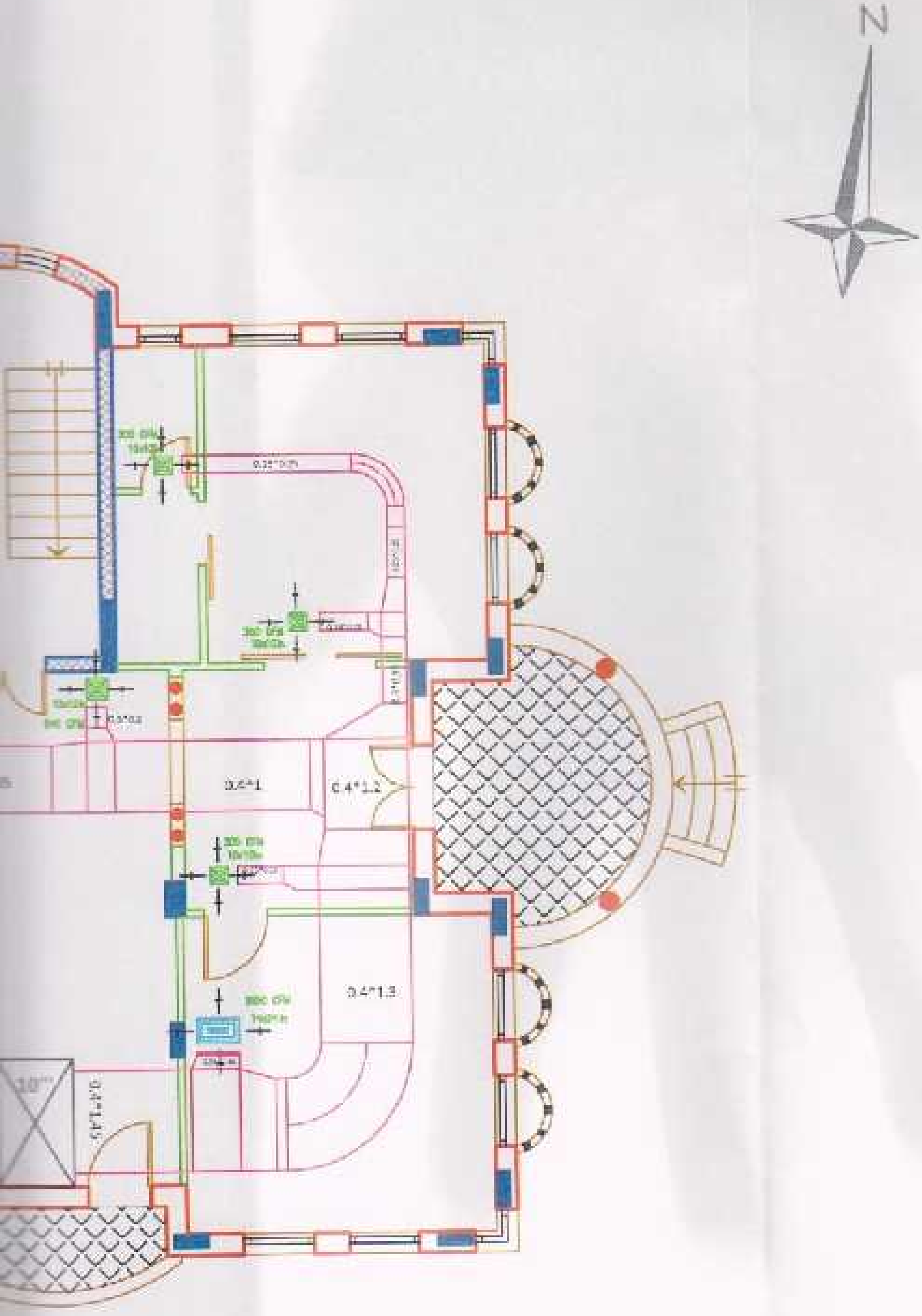
21.5.2013

Draw

Graduation Project

HEBRON

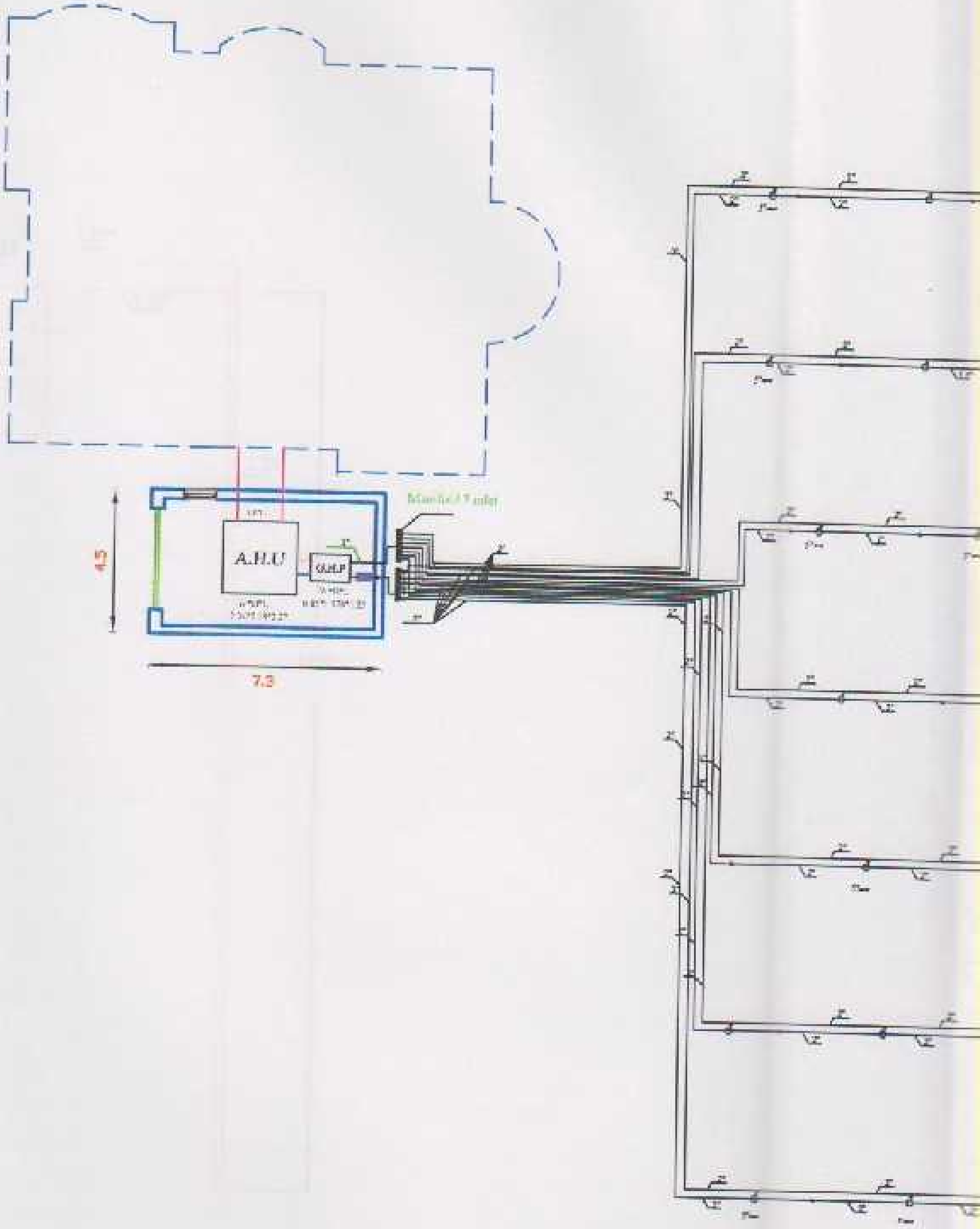
Palest



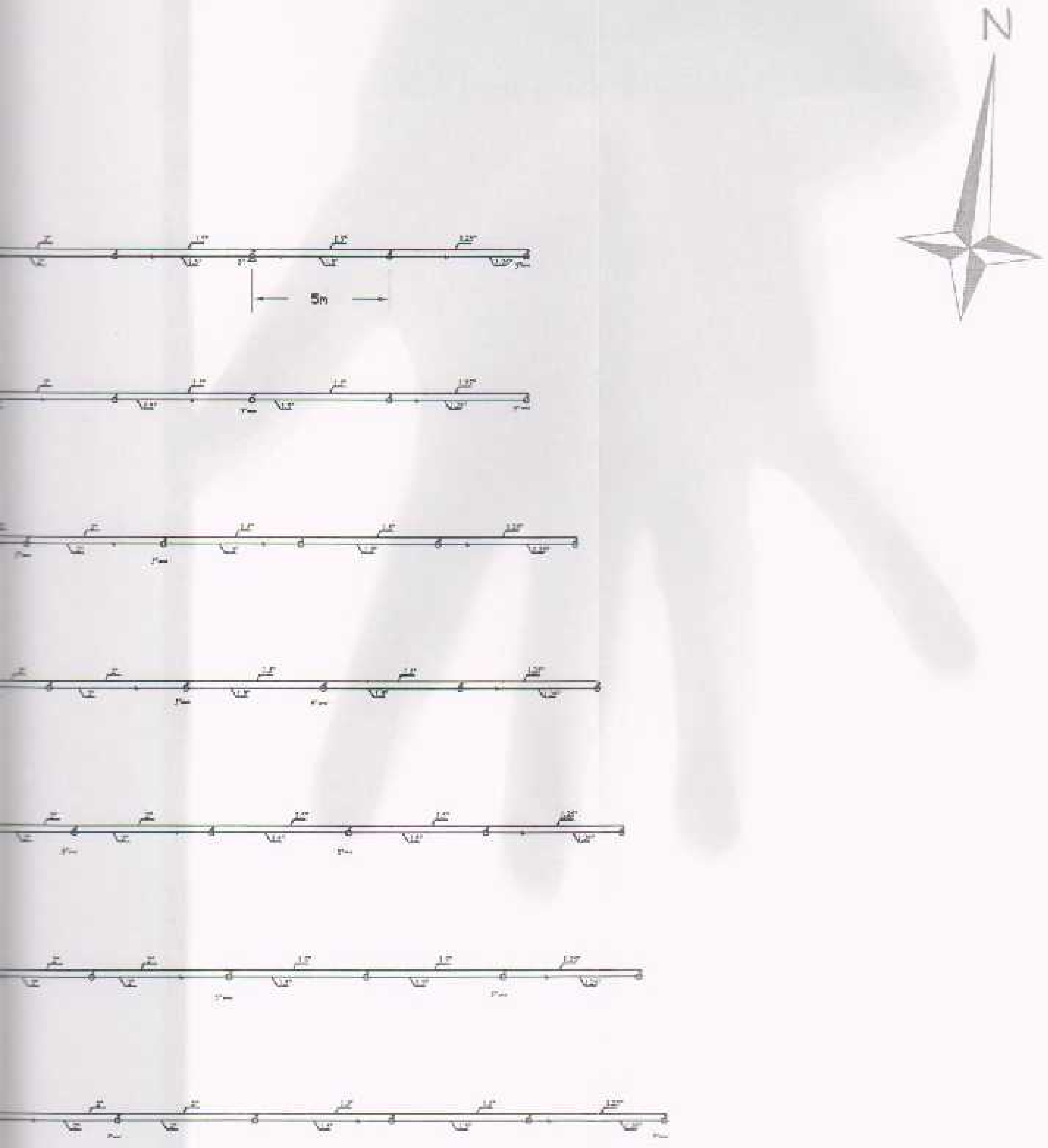
3

Drawing Name: Third Floor Return Duct

Palestine Polytechnic University "PPU"

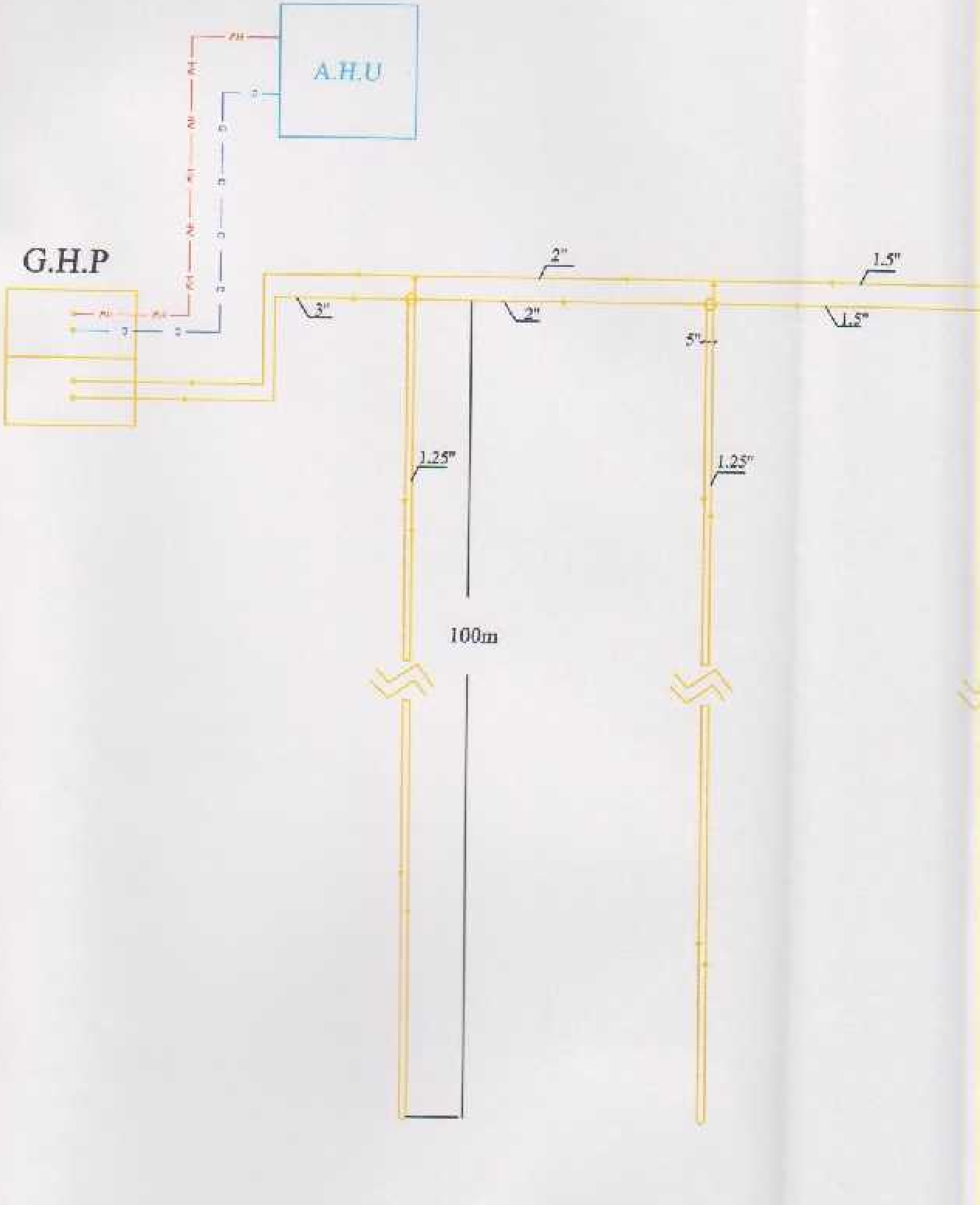


Division			F10	21.5.2013	Draw
Name:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/200			
Supervisor	Eng.Mohammad Awad		Graduation Project	HEBRON	Pales
Figure A-43		Sign			

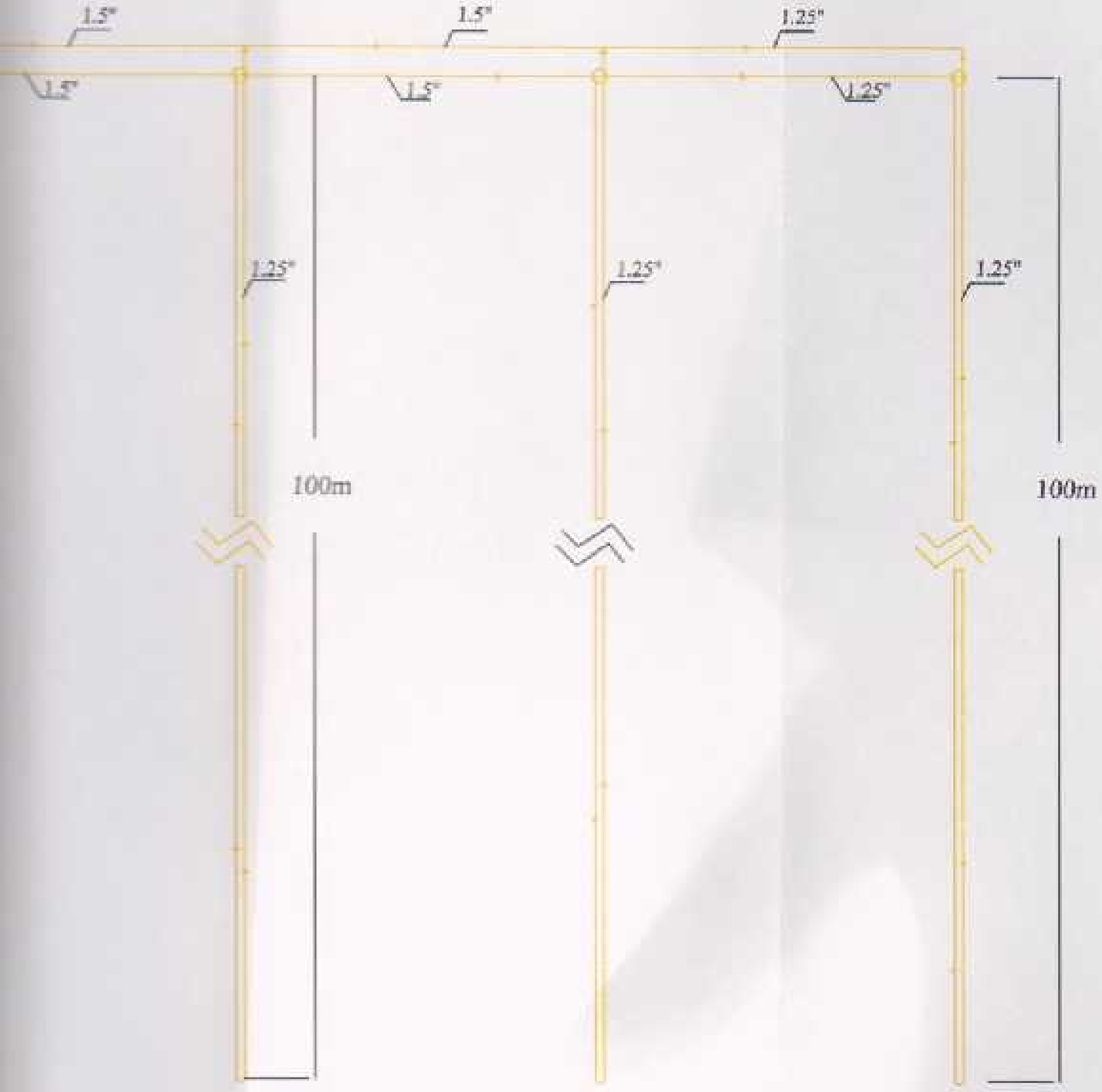


Drawing Name: Ground Floor Plane & GHP Lines

Palestine Polytechnic University "PPU"



Division			F11	21.5.2013	Draw
Name:	IBRAHIM&HANI&MOHAMMAD	SCALE: 1/100			
Supervisor	Eng.Mohammad Awad		Graduation Project	HEBRON	Pales
Figure A-44		Sign			



Drawing Name: GHP Lines Section

Palestine Polytechnic University "PPU"