USMANU DANFODIYO UNIVERSITY, SOKOTO

(POST GRADUATE SCHOOL)

DESIGN, CONSTRUCTION AND PERFORMANCE EVALUATION OF EARTH TO AIR HEAT EXCHANGER FOR ROOM COOLING/HEATING APPLICATIONS

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BY

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DEDICATION

This work is dedicated to my parents, my wife and my children.

CERTIFICATION

This dissertation by ABDULLAHI Yahuza (Adm NO. 112103051412) has met the requirements for the award of the Degree of Master of science (Physics) of the Usmanu Danfodiyo University, Sokoto and is approved for its contribution to knowledge.

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LIST OF ABBREVIATIONS

ASHRAE:	American Society of Heating, Refrigeration, and air-Conditioning
AHU:	Air Handling Unit
CO_2:	Carbon Dioxide
EAHX:	Earth air heat exchanger
EREC:	European Renewable Energy council
HVAC:	Heating, Ventilation, and air Conditioning
HCFC:	Hydro-chlorofluorocarbon
IAQ:	Indoor Air Quality
IEA:	International Energy Agency
IIR:	International Institute of Refrigeration
KWH:	Kilo-watt –hour
PH:	Passive House
O_3:	Ozone
PVC:	Polyvinyl Chloride
CFC:	Chlorofluorocarbon

CFD	Computational Fluid Dynamics
IIR	International Institute of Refrigeration
IEEE	Institute of Electrical and Electronic Engineering
ASAE	American Society of Association Executives
IIUM	International Islamic University Malaysia
COP	Coefficient of Performance for Cooling/Heating
IIT	Indian Institute of Technology
GHG	Green House Gas
FFT	Fast Fourier Transform

NOMENCLATURE

Cp: Specific heat capacity of air (J/kg.k)

Ma: Mass flow rate of air in pipes (kg/s)

K: Thermal conductivity of soil (W/mk)

R: Radius of the pipe (m)

L: length of the pipe (m)

D: Diameter of the pipe (m)

Ti: Air temperature at the inlet of earth air heat Exchanger (^{0}C)

T_o : Air temperature at the outlet of the earth air heat Exchanger (^{0}C)

T_a: Ambient Temperature (^{0}C)

T_s: Soil Temperature (^{0}C)

N: Number of pipes in Parallel in the heat Exchanger

V: Volumetric flow rate of air m^3/s

V_a: Velocity of air (m/s)

W_{in}: Rate of energy input into the heat exchanger (energy used by blower)

T: Thickness of the pipe

q: The rate of heat Transfer

A: Cross Sectional area of the pipe

dT: The Change in Temperature

dX: Thickness of the pipe

$\frac{dT}{dX}$ **:** Temperature Gradient

Subscript

In: indoor

Out: outdoor

a: air

s: soil

ABSTRACT

Tropical climate is characterised by high ambient temperatures and solar radiation, a combination of these factors causes thermal discomfort in buildings. The common approach to maintaining comfortable thermal environment in buildings in such climates is using mechanical air-conditioning systems. High energy demand is needed to operate and maintain these systems continuously over long periods of time. Earth air heat exchanger (EAHX) is a subterranean ventilation system that explores soil temperature below the surface to pre-cool or pre-heat ventilation air. Performance of the earth air heat exchanger varies with climatic and soil condition of the area. In this research, an Earth air heat exchanger (EAHX) was designed, constructed and installed at Sokoto Energy Research Centre. Its actual field performance was evaluated. The average coefficient of performance (COP) in the hot season was 3.45 and for cold (hamattan) was 3.2.The earth air heat exchanger was able to cool the hot ambient air by 4.5^0C during hot seasons and raised the temperature by 3.4^0C during cold seasons.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Nigeria is the most populous country in Africa. Its population currently stands at 170million people and is expected to grow to 230 million by 2030. The steady economic and population growth is putting significant strain on the country's electric supply and distribution infrastructure, which is currently meeting less than 50% of demand: more than 64% of Nigeria electricity is generating from fossil fuel and about 34 % from hydro plants (World Bank 2001).

Energy consumption of the building sector is high. Although figures differ from country to country, buildings are responsible for about 30 to 40% of the total energy demand. However, energy needs for cooling increases in a dramatic way. The increase of family income and information technology has led to an increasing demand for cooling in the residential and commercial building sectors. Cooling is a significant use of energy in buildings, and its importance as a contributor to greenhouse emissions is enhance by the fact that these systems are usually electrically driven. High cooling requirements can result in high electrical demands, with consequent problems for utility companies (Heap, 2001).

Air conditioning is the most widely used cooling system for indoor air in Nigeria. The main component used in an air conditioner is compressor mainly driven by electricity. Electricity generation processes are fossil based and responsible for nitrogen dioxide, carbon, sulphur and other green house gas (GHG) emission.

Refrigerants that are used in air conditioning have also negative impact on the environment. Freon like chlorofluorocarbon (CFC) and hydro-chlorofluorocarbon (HCFC) refrigerants are harmful to ozone layer and are out of used nowadays. CFC, HCFC and HFC (which used as replacement of CFC and HCFC) are all greenhouse gas.

Global warming is the impact of GHG gases responsible for average temperature rise worldwide. The increase in temperature in the 20th century is likely to have been the largest in any century during the past 1000 years. 1990s were the warmest decade and 1998 was the warmest year. Global average land and sea surface temperature in May 2003 were the second highest since records began in 1880 – WMO (World Meteorological Organization) in a press release 2th July 2003. All these happened due to consumption of fossil energy.

According to central Bank of Nigeria (2010), residential consumption accounted for 56.3 percent of total electricity consumption, while commercial and street – lighting and industrial consumption accounted for 25.7 and 18.0 percent of the total respectively. The rule of thumb for any developed industrial nation is that at least 1gigawatt (i.e. 1,000 megawatts) of electricity generation and consumption is required for every 1 million head of population. Nigeria's per capita electricity consumption is amongst the lowest in the world and far lower than many other African countries.

Nigeria's per capita electricity consumption is just 7% of Brazil's and just 3% of South Africa's as at August 2010, the peak generation supplied by Nigeria's PHCN was just 3,804 MW for a population of 170 million people (Road map for power sector reform in Nigeria 2010).

However, Nigeria need to start considering alternative low energy (passive) cooling strategies and technologies that have potential to reduce energy consumption and cost associated with the use of air conditioning. Passive system have potential to reduce operational energy consumption for cooling buildings in the tropical climate help reduce rising energy demands and the associated greenhouse gas emission that is detrimental to the planet (Ahmed and Gidado 2008). In hot climates, such as Nigeria, using earth-to-air heat exchanger (EAHX) for low energy cooling/heating can reduce energy consumption whilst a healthy and comfortable environment for people.

Building cooling demand in Nigeria increased living standards in the developing world using non-climatically responsive architectural standards have made air conditioning quite popular. Importantly, this has increased energy consumption in the building sector. Actually there are more than 240 million air conditioning units and 110 heat pumps installed worldwide according to the International Institute of Refrigeration (IIR) (IIR, 2002). IIR's study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide (IIR, 2002).

In hot climate, such as Nigeria, commercial and residential buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load to 5kWh/m^2/year, (Santamouris and Daskaki, 1998),while buildings of low quality environmental design may present loads up to 450kWh/m^2/year (Santamouris *et al*., 1997). Under the same climate conditions and when internal gains are not important, such as in residential buildings, the use of air conditioning may be completely avoided when efficient solar and heat protection as well as heat modulation techniques are used.

Landscaping is a natural and beautiful way to keep home comfortable and reduce energy consumption by up to 25%. Apart from adding aesthetic value and environmental quality to home, trees, shrub or vine can help deliver effective shade and act as windbreak. A well designed home can reject overhead heat to reduce the energy spent for cooling.

Low quality windows can cause air conditioner to work two or three times harder. In warm climates, it is advisable to use windows with special coating that will help to reduce heat gain. Replacing single paned windows with double paned windows can help to reduce heat gain and reduce the energy spent on cooling (Uyigue, 2008 and Ahmed, 2009).

Naturally ventilated buildings are likely to overheat more frequently in extreme conditions and air conditioning system may fail more regularly. It is probable that full air conditioning will be demanded in more buildings to control summer temperatures and humidity, leading to an increase in energy usage. It is imperative that designs for future buildings and major refurbishments account for a changing climate to ensure that buildings can provide comfortable and healthy internal environments over their lifetime, whilst minimising energy use and greenhouse gas emission. To diminish the threat of global warming and energy depletion, research into building energy efficient over the last decade has been undertaken to improve building service systems and specific construction components in order to create technologies and solutions (Heiselberg, 2004).

The use of air conditioning is the course of different problems. A part from serious increase of the absolute energy consumption of buildings, other important impacts include:

1. The increase of peak electricity load;
2. Environmental problems associated with the ozone depletion and global warming;
3. Indoor air quality problems.

High peak electricity loads oblige utilities to build additional power plant in order to satisfy the demand, but as those plants are used for short periods, the average cost of electricity increases considerably.

One of the major scientific and technical requirements of our days is to address successful solution to reduce energy and environmental effects of air conditioning. Passive cooling techniques when applied to buildings have been proven to be very effective and contribute greatly in decreasing the cooling load of buildings, provide excellent thermal comfort and indoor air quality, together with low energy consumption.

Earth as a heat source and heat sink is a well-studied topic using the earth as a component of the energy system, or “earth-tempering” can be accomplish through three primary methods; direct, indirect and isolated. In the direct system, the building envelop is in contact with the earth, and conduct through the building element (primarily walls and floor) regulate the interior temperature. In the, indirect system, the building interior is conditioned by air brought through the earth, such as in earth-air heat exchangers (EAHX). The isolated system uses earth temperature to increase the efficiency of heat pump by moderating temperatures at the condensing coil. A geothermal heat pump is an example of an isolated system. This dissertation will focus on indirect systems.

1.2 Statement of the Problem

Tropical climate is characterised by high ambient temperature and solar radiation, a combination of these and other factors causes thermal discomfort in buildings. The common approach to maintaining comfortable thermal environment in buildings in tropical climates is using mechanical air-conditioning systems. In buildings where mechanical cooling is not affordable, buildings are occupied in harsh conditions which affect performance especially in offices and other work environments .High energy demand is needed to operate and maintain mechanical systems continuously over long period of time during a day with rapid increase in population and economic growth of countries in tropical regions such as Nigeria. Passive and low energy strategies must be used as suitable alternatives. Passive system have the potential to reduce operational energy consumption for cooling buildings in the tropical climate, help reduce rising energy demands and the associated greenhouse gas emission that is detrimental to the planets.

1.3 Aim and Objectives

The aim of this research work is to design, construct and carry out performance evaluation of Earth to Air heat Exchanger system for cooling and heating and evaluate its actual field performance.

Specific objectives of this work are:

i. To design, construct an earth to air heat exchanger

ii. To install the earth to air heat exchanger and

iii. Test and evaluate its actual field performance

1.4 Significance of the Study

Being result of a naturally phenomena deep on the ground as a heat source and heat sink is available easily in most places in the world. Such a use is sustainable and equivalent to having a renewable energy source. Earth to air heat exchanger based systems cause no toxic emission and therefore, are not detrimental to environment. Earth to air heat exchanger based systems for cooling and heating do not need water a feature available in hot and arid areas. It is this feature that motivated our work on earth to air heat exchanger (EAHX) development. EAHXs have long life and require only low maintenance. However, initial installation costs are likely to be higher than the comparable conventional (refrigerant based) systems. Conventional system can be customised easily for varied application and industry is well developed. This is not yet the case for ground coupled systems.

1.5 Scope and Limitation

This research focus on the design, construction and performance evaluation of earth to air heat exchanger for room cooling/heating applications in office building at Sokoto Energy Research Centre of Usmanu Danfodiyo University Sokoto. However, the emphasis would be on effects of the design parameters such as: pipe length selection, pipe material selection, pipe diameter selection, air flow rate selection and coefficient of performance of an earth to air heat exchanger applications.

However, this work is limited to the performance evaluation of the earth to air heat exchanger (EAHX) installed at one of the offices in Sokoto Energy Research Centre.

CHAPTER TWO

2.1 THEORITICAL FUNDAMENTALS

The thermal performance of the EAHX system can be estimated in terms of the coefficient of performance COP.

Coefficient of performance (COP) is one of the measures of heat exchanger efficiency. It is defined as a ratio of the cooling/heating capacity of earth to air heat exchanger to the heat/cool rejected to soil, Q_s and the power consumption of the blower/fan, that is,

$$\text{COP} = \frac{Q_s}{P_f} \quad \text{.......} 2.1$$

Where;

Qs = Total cooling/Heating of Earth to air heat exchanger (W)

Pf = Power Consumption of the blower/fan (W)

According to (ASHRAE, 1985) the thermal performance of the earth to air heat exchanger can be evaluated as

$$COP = \frac{Q_{out}}{W_{in}} \quad \text{.......} 2.2$$

Where:

Q_{out} = Total Cooling/Heating (W)

W_{in} = Energy use by blower (W)

$$Qout = MaCp(Ti - To) \quad \text{......2.3}$$

Where;

$Ma =$ Mass flow rate of air through the pipe (kg/s)

$Cp =$ Specific heat capacity of air (J/kg.k)

T_i = inlet temperature of air (^{0}C)

T_o = outlet temperature of air (^{0}C)

When a temperature gradient exists in a body, there is an energy transfer from the high temperature region to the low temperature region. The energy is transferred by conduction and that the heat transfer rate per unit area is proportional to the normal temperature gradient

$$q = KA\frac{dT}{dx} \quad \text{......2.4}$$

Where:

q = The rate of heat transfer (W)

k = Thermal conductivity of the material (W/mK)

A = Cross section of the pipe/heat transfer area (m^2)

dT = The change in temperature (K)

dx = Thickness of the pipe

$\frac{dT}{dx}$ = Temperature gradient

The heat transfer area in the earth air heat exchanger is a function of both length and diameter of pipe and is given by:

$$A = \pi DL \quad \text{.......... } 2.5$$

Where

A = heat transfer surface of the tube (m^2)

D = tube diameter (m)

L = tube length (m)

Performance of the Earth Air Heat Exchanger/ heat exchanger effectiveness can also be calculated as:

$$\eta = \frac{Ti - To}{Ti - Ts} \quad \text{.......... } 2.6$$

Where

T_I = inlet air temperature

T_O = outlet air temperature

T_S = soil temperature

η = heat exchanger effectiveness/performance

The convection coefficient inside the tube is defined by;

$$h = \frac{Nu\lambda}{D} \text{.......... } 2.7$$

Where;

h = the convection coefficient of the air (W)

Nu = the Nusselt- number for flow inside a tube

λ = thermal conductivity (W/mk)

D = pipe diameter (m)

2.2 Review of Past Work

The idea of using earth as a heat sink or source was known in ancient times. Leyla (2011) in about 3000 B.C, Iranian architects used wind towers and underground air tunnels for passive cooling. Paepe and Jannsens (2003) Earth to air heat exchanger is a passive climate control technique that has application in residential as well as agricultural building utilizes the underground soil temperature that stays fairly constant at a depth of about 1.5m to 3.5m.

Fabrizio *et al*., (2011) in agricultural facilities (animal buildings) and horticultural facilities(green houses) Earth air heat exchangers have been used over the past several decades and have been used in conjunction with solar chimneys in hot and arid areas for thousands of years, probably beginning in the Persian empire Earth air heat exchangers are one of the fastest growing applications of renewable energy in the world, with annual increase in the number of installation with 10% in about 30 countries over the last 10 years. With the exception of Sweden and Switzerland, the market penetration is still modest throughout Europe but is likely to grow with further improvements in the technology and the increasing need for energy savings. From the middle of the 20^{th} century, a number of investigators have studied the cooling potential of buried pipes.

Earth to air heat exchanger (EAHX) is a device that enables transfer of heat from ambient air to deeper layers of soil and vice versa. Since the early exploration of its use in cooling commercial livestock buildings (Scott *et al.,* 1965) there has been considerable increase in its application. Earth is used to condition the air in livestock buildings

(Spengler and Stombaugh, 1983). It is use in North America and Europe to cool and heat greenhouses (Santamouris *et al*., 1995).

There have also been works aimed at gaining better understanding of its working for cooling and heating mode (Baxter 1992,).

There has also been some work in India. Sawhney et al., (1998) installed an earth to air heat exchanger system (EAHX) based system to part of a guesthouse. Sharan *et al*., (2001) installed a EAHX based cooling system for tiger dwelling at Ahmedabad zoological garden. Earth air heat exchanger (EAHX) is also known as earth air pipe system (Huijun *et al*.,2007), Earth tube system (Rakash *et al*.,2003) and underground air pipe air conditioning system (Sawhney *et al*.,1999).

This earth pipe cooling technology has been explored by many researchers and used by building designers as cooling means for various building types in temperate countries as well as hot and arid countries, where the results have been significant and positive. Min. (2004) analyzed application of EAHE in Montreal, Canadian climate. Lee and Strand, (2008) conducted parametric study of EAHE in USA at four different locations (Spokane, WA: Mild and dry; Peoria, IL: mild and wet; phoenix, AZ: hot and dry; key West, FL: hot and wet). Fabrizio *et al*., (2011) evaluated the energy performances achievable using EAHE in different Italian climates (i.e. Naples, Rome, & Milan). Vikas *et al*., (2010) analyzed the performance of the system in dry climate of the western India. Darkwa (2011) evaluated the EAHE system as an energy saving technology for a typical hot and humid location in Ningbo, China.

Many studies (Paepe *et al.*, 2003, Ghosal *et al*., 2006,) used simplified way of modelling the air temperature at the outlet of the Earth to Air Heat Exchanger. Those models often confined to a linear configuration with a single tube, take soil temperature as a parameter without considering how it may be influenced by the exchanger and the ground. Thus the soil temperature is similar to a simplified sine function depending solely on depth and time.

Lee and Strand (2012) parametric analysis was carried out to investigate the effect of pipe radius, pipe length, air flow rate and pipe depth on the overall performance of the earth tube under various conditions. As the pipe length and depth increases, the inlet air temperature decreases. Air flow rate and pipe radius increases, the earth tube inlet air temperature also increases. In addition, pipe length and pipe depth tube turned out to affect the overall cooling rate of the earth tube, while pipe radius and airflow rate mainly affect earth tube inlet temperature.

Hullmuller doctoral thesis is now one of the main references for earth air heat exchangers, (Hullmuller, 2002). The work was on the theoretical analytical modelling of the depth and also many in-situ measurements; the author establishes basic rules for the design of these exchangers. The dynamics of heat exchange and the influence of different physical characteristics of the social are studied in an ideal case (single tube in the ground). After an adimensionalization of the problem, the study describes the complete analytical solutions to simulate the heat exchange occurring between a tube and the surrounding soil.

Thiers, and Peuportier (2008) .Considered a model constructed as the superposition of three independent phenomenon, conduction in the soil temperature signal from the surface (the effect of weather conditions, including wind), conduction of heat flow from a building `near the ground portion considered (influence of the building on the ground temperature) and, finally, conduction flow from the soil (geothermal heat flow).

Bansal *et a*l., (2010) investigated the performance analysis of Earth to Air Heat Exchanger (EAHX) for summer cooling in Jaipur, India using 23.42 meter long and 2 to 5 m/s flow rate for steel and PVC pipes achieve cooling in the range of 8.0^0C to 12.7^0C, they showed performance of system is not significantly affected by the materials buried pipe instead it is greatly affected velocity of air fluid. They observed COP variation 1.9 to 2.9 for increasing 2 to m/s.

Chel and Tiwari (2010) analyzed space heating and cooling with an Earth to air heat exchanger integrated stand alone photovoltaic system in New Delhi, India. It was found that the energy payback is less than 2 years on investment in earth to air heat exchanger system and total average coefficient of performance in the experimental period was 10.09.

In South America, Larsen *et al*., (2003) presented results about a buried pipe located in La pampa (argentina) that indicated a poor performance of the system, but as suggested by the authors, it can originate from the location of the pipe which was buried at only 0.4m depth.

Hollmuller *and Lachal* (2005) in their study of passive cooling for building located in saopaulo and Florianopolis concluded that buried pipes system alone is not efficient and has to be used in combination with nocturnal ventilation to improve its potential.

Misra *et al*., (2013) conducted an exhaustive parametric analysis on the performance of earth air heat exchanger (EAHX) also analyzed how in continuous operation performance degrades and devised a term “derating factor” to relate this degradation. Their results show a variation of 0% to 64% in derating factor which is caused by choosing different parameters like air velocity, pipes dimensions, depth, and soils thermal conductivity.

Tudor *et al*., (2013) studied influence of certain design parameters on the performance of a registry type system considering the weather of south Eastern Europe. Length, diameter of pipe and depth of burial were the parameters under consideration. Results have shown that increasing the depth lead to 24.31% rise in heat gain and 47.57% more heat loss is observed.

Paepe and Jannsens (2003), used a one dimensional analytical method to examine the influence of the design parameters of the heat exchanger on the thermo-hydraulic performance and devise an easy graphical design method which determines the characteristic dimensions of the earth-air heat exchanger in such a way that optimal thermal effectiveness is reached with acceptable pressure loss. The choice of the characteristic dimensions becomes thus independent of the soil and climatological conditions. This allows designer to choose the earth-to-air heat exchanger configuration with the best performance.

Kumar *et al*., (2003) experimentally tested earth tunnel located in Mathura (India). The result of the experiment was used to validate a transient implicit numerical model based on finite difference scheme and fast Fourier transform (FFT) algorism implemented in mat lab. The authors predicted the tunnel extracted temperature for various value of air parameter as humidity, flow rate and ambient temperature. It was indicated that average heating potential of 80m EAHX system is equal to296 kwh and cooling potential higher and equal to 456 kWh per day.

Ghosal *et a*l., (2004) studied the cooling and heating potential of recirculation type EAHX that operated with energy saving building located in Indian Institute of Technology (IIT) Delhi, India. As it turned out, internal air temperature in green house, couple with this system, significantly raised over 6^0C in winter and decreased by 3 to 4^0C during summer compared to the same building without ground air heat exchanger. It should be noted that the effectiveness of the developed system was higher in winter than in summer.

Sharan and Jadhav (2000) concluded experiment on single pass earth tube heat exchanger; they conducted experiment in Ahmadabad Gujarat India these found. If A single pass earth-tube heat exchanger (EAHX) was installed and EAHX is made of 50m long ms pipe of 10 cm nominal diameter and 3mm wall thickness. EAHX is buried 3m deep below face. Ambient air is pumped during it by a 400 watt blower. Air rate in the tube is 11m/s. Air temperature is measured at the inlet of the pipe and at the outlet by Thermistor placed within the pipe. Cooling tests were passed out three successive days in every month. On every day system was operated for 7 hours throughout the day and shut down for night.

Givoni (2007) has shown that the potential of the EAHX system in hot climates may however be improved using various soil cooling strategies to lower the natural subsurface soil temperature such as shading, surface irrigation, surface treatment using plants and pebbles.

Al – Ajmi *et al.*, (2006) investigated the cooling potential of earth to air heat exchangers for domestic building in a desert climate. A theoretical model of an earth to air heat exchanger was developed for finding outlet air temperature and the cooling potential of these devices in hot, arid climate of Kuwait. Model is validated to other published models and shows the good agreement. Simulation results shown that the earth to air tunnel heat exchanger provide a reduction of 1700W in peak cooling load, with an indoor temperature reduction of 2.8^0C during the summer peak hours. EAHX was shown to have potential for reducing the cooing energy demand in the typical house by 30% over peak summer season.

An experiment on EAHX cooling technology was carried out in Milan (Solaini et al., 1998). The air temperature during summer ranges between 15^0C to37^0C and the result of EAHX cooling ranges between 22^0C to 30^0C, which gives 7^0C air temperature reduction.

Ghosal and Tiwari (2006) investigated the modelling and parametric studies for thermal performance of an Earth to Air Heat Exchanger integrated with a greenhouse. The thermal model has been developed to investigate potential of using stored thermal energy of ground for greenhouse heating and the cooling with the help of an earth to air heat exchanger system integrated with greenhouse in premises of Indian institute of technology (IIT), Delhi, India. The temperature was risen up to 7^0C to 8^0C and 5^0C to 6^0C reduction of temperatures for greenhouse air for winter and for summer period respectively, due to incorporation of EAHX as compared to temperatures without the EAHX.

Thanu *et al*., (2001) analyzed thermal performance of a Ground Heat Exchanger (GHE) connected to a farmhouse. The farmhouse had six main areas: three bedrooms, a living room, a dining room and a kitchen. The single pass mode of GHE was implemented consisting of two rectangular tunnels measuring 60cm x 80cm with a length of 76.5m. The tunnels were buried at a depth of 4m. Thermal performance of the Ground Heat Exchanger was analyzed in three seasons: summer, monsoon and winter. The best achievement of temperature reduction was recorded in summer at 14.8^0C and the worst was in winter with 2^0C of temperature increment.

Bansal *et al*., (2012) developed a new concept of 'Derating factor' for assessment of thermal performance of EAHX under transient operating conditions. The authors concluded that under transient conditions, thermal performance of EAHX declines due to continuous use of EAHX for long durations.

Lee and Strand 2008) developed a Ground Heat Exchanger module for implementation in energy plus software. A parametric study was carried out to investigate the effect of pipe radius, pipe length, airflow rate, and pipe depth on the overall performance of the Ground Heat Exchanger. Cooling and heating potential were investigated and the performance was found to depend on climate conditions and locations the highest reduction in cooling load requirement was 8.8kwh with 52% of efficiency saving.

Ascione *et al.*, (2011) analyzed the energy performance of an Air – conditioned building combined with Ground Heat Exchanger in the Italian climate. They used dynamic building energy performance simulation codes for analyzing the system performance during both winter and summer. The authors reported that the highest primary energy saving for a 50m length of Ground Heat Exchanger tube was about 14.2kWh. The implementation of a Ground Heat Exchanger for building was feasible and economically acceptable with a simple payback of five to nine years.

Santamouris *et al.*, (1994) described the design, construction and operation of a prototype $1000m^2$ passive solar agricultural greenhouses by using several methods to increase heat gain such as water, latent heat material, and rock bed and buried pipes. The researchers also discovered that the cooling potential of the ground heat exchanger was very important. In the following year, they concluded a study on the performance of an earth to air heat exchanger in cooling agricultural greenhouses and conserving energy. A parametric analysis was performed of a typical glass greenhouse to illustrate the effect of pipe length, pipe diameter, and depth and air velocity on the performance of the system with the transient system simulation program (TRNYS 1990). The simulation results were compared with their previous measured data and were found to be in very agreement (1995).

Wu *et al*., (2008) evaluated cooling capacity produced by a ground Heat Exchanger implemented in southern China. A daily cooling capacity up to 74.6kWh was obtained from a system with 60m of pipe buried at a depth of 3.75m.

Ascione *et al*., (2011) conducted a study of underground temperature as part of research on implementing a Ground Heat Exchanger in an air conditioned building during winter and summer. They found that configurations for the Ground Heat Exchanger at a depth of 3m for summer and winter showed a good compromise between energy performance and cost of excavation.

Al – Ajmi *et al*., (2006) conducted a measurement and simulation study of soil temperature for hot and arid climate. The temperature was attenuated from 13.3^0C at the ground surface to 3.9^0C at a depth of 4m.

Yoon *et al*., (2009) discussed a design procedure for multiple pipes in a close arrangement taking into account thermal interference between the pipes and proposed an estimation method for multiple pipes systems. In this study, multiple pipes were laid in a close arrangement and monitored for two years in a four story building in Japan. They present a correction factor for the decrease in heat transfer rate due to inference between pipes.

Peretti *et al*., (2013) discussed the effect of soil cover, climate and soil composition on the performance of the EAHX and concluded that the bare surface improves the performance of EAHX for heating whereas the wet surface is better for cooling purpose. It has also been concluded that higher water content and closely packed soil near the pipes of EAHX improves the performance of the EAHX.

Derbal *et al.*, (2008) investigated the soil temperature variation for different depths and types of soil using neural network prediction. Four types of soil and four different depths were considered. The result showed that different diffusivity produces different temperature variation at the same depth.

Sharan *et al*., (2002) measured and simulated the soil temperature regime up to 3m depth with 1m intervals. The temperature amplitude was attenuated with depth: 2.8^0C at 3m compared with 4.6^0C at 1m. The findings were applied to ground heat exchangers for buildings and greenhouses cooling/heating.

Yusof *et al*., (2014) analyzed ground temperature based on mathematical model which summarized that the constant temperature occurred at depth of 6 m with 27^{0}C of temperature. Significant cooling for ground heat exchanger purpose can be produced from the depth of 2.4m and deeper.

Bisoniya *et al*., (2013) gave an extensive literature review covering design, characteristics of EAHX, modelling adopted by several researchers when the earth air heat exchanger was integrated by solar chimney which utilizes both the geothermal energy as well as solar energy, the energy savings were greater compared to uncoupled system.

Khalajzadeh *et al*., (2012) evaluated thermal performance of ground heat exchanger and evaporative cooler hybrid system in summer conditions of Tehran, Iran. They found that the hybrid system is capable to replace the conventional air conditioner effectively and its cooling effectiveness is more than unity.

Vaz *et al*., (2011) conducted experimental and numerical analysis of an EAHX which was used to reduce consumption of conventional energy for heating and cooling of built environments through the use of thermal energy contained in the soil.

In operation, the control strategy plays a decisive role for the actual usable energy supply by the EAHX. A temperature control is important to prevent unwanted heating in dry season and cooling in Harmattan season. An open control runs robustly but usually its programming should be adjusted after the first year of operation, when the temperature behaviour is known (Pfafferott, 2003). In order to maximize the control of such a system it is necessary to provide an automatic control algorithm. This algorithm must compare the indoor temperature with the temperature at the air outlet and, when the former is lower them the latter, the fan must be stopped. Obviously, if the system is to be linked with conventional air conditioning, the automatic control has to be more sophisticated.

The possibility of the forming of water by condensation inside the tubes has been well studied (Abrams, 1986). Condensation will occur if the temperature of the inside tube walls is lower than the dew point temperature of the air, which depends on the air temperature and on the humidity of the air. Condensation has been observed in some system (Goswani et al, (1990), but only with very low airflow and high ambient dew point temperature. Reports of water flowing continuously from systems in operation are probably attributable to groundwater leakage into the tube (Labs, 1989).

Even if some moisture can be removed from the ambient air, it is even more difficult to dehumidify to normal interior comfort conditions. In cooling warm, humid air, an EAHX system will always increase the relative humidity of the air. As air is cooled, its capacity to hold water is reduced. When cooled without moisture removal, air initially at 30^0C and 60%RH will reach 70 %RH at 28^0C, 83%RH at 25^0C and 98%RH at 21^0C (Abrams,1986). Note that comfort for the human body is determined by relative humidity, not absolute moisture content. The discharge of humid air, even though it is cooler, into the interior of a building can cause discomfort, as well as mildew. Since the system may not be able to remove moisture from the air, it may have to be used in combination with a regular air conditioner or a desiccant.

Water in the tube or corresponding structures can be a source for the growth of mould or mildew. This cause a reduction in the indoor air quality, as spores can be responsible for respiratory problems or allergic reactions in humans. Mould and mildew grow on most surfaces if the relative humidity at the surface is above a critical value and the surface temperature is above 40^0C (EREC, 2002). The international energy agency 14 (IEA, 1999) established a surface humidity criterion for design purposes: the monthly average relative humidity at the surface should remain below 80%. So, if the monthly average humidity is above 80%, risk for moulds growing is imminent.

Good construction and drainage could eliminate condensation and groundwater. To avoid water standing in the tubes, the tubes are tilted 1^0 (Santamouris et al, 1996).

2.4 Earth air heat exchanger Technology

Earth to air heat exchanger (EAHX) is a device that permits transfer of heat from ambient air to deeper layers of soil and vice versa. Earth air heat exchanger is basically a series of plastic, metallic or concrete pipes buried underground at a specified depth and fresh atmospheric air passes from one end to another. It is the property of earth that temperature of ground at a depth of 1.5m to 3.5m remains fairly constant throughout the year. This constant temperature (earth's undisturbed temperature) remains lower than ambient temperature in summer and vice versa in winter. The fresh ambient air drawn through pipes of EAHX gets cooled in summer and vice versa in winter and if at sufficiently low/high temperature can be supplied directly for cooling /heating of space. Otherwise, the output of EAHX is connected to the conventional AC. In both the cases EAHX system can be used to save significant amount of electrical energy.

In hot region, where cooling is of interest, the temperature of the soil in summer is usually too high for serving as a cooling source. However, it is possible by very simple means to lower the soil temperature well below the natural temperature characteristics of a given location. In order to cool the soil it is necessary to eliminate or minimize the heating of the soil by the sun, by shading, while enabling cooling by evaporation from the earth surface (Givoni, 2008).

The consumption of energy in buildings for cooling and heating purpose has increased considerably. The passive heating as well as cooling technique in which either heat is removed or given to buildings from a natural heat sink like earth has become popular today. In the operation of an earth to air heat exchanger, freely available energy, stored inside the earth has been used for heating and cooling purposes. Thus, less amount of conventional energy is required, which leads to a decrease in the mitigation of CO_2 in the environment (Ahmad, 2010).

Earth to air heat exchangers may be used to save energy in those buildings which are equipped with an active ventilation system (Badescu, 2007). This is particularly easy in case of passive houses (PH) where the active ventilation system makes part of the standard.

Passive houses (PH) are buildings in which a high level of comfort is achieved in winter and in summer without a separate heating system or air conditioning system-the house ‘heat’ and ‘cool’ itself purely ‘passively (Adamson,1987).

Earth air heat exchanger system (EAHXS) performance strongly depends on the air inlet temperature (ambient air temperature) and the pipe wall temperature which in turn depends on the ground temperature variation. The influences of the inlet temperature and the pipe wall temperature on the EAHX’s performance have been reported since the 1980s (Sodha *et al*., 1985). They applied a mathematical model and an experimental study on the EAHX and the result showed good agreement between the mathematical and experimental study. Most existing EAHXs are installed in mechanically ventilated buildings in which fans provide the required driving force for the air flow.

Various technical terms are used to refer to earth air heat exchanger:

i. Earth- air heat exchanger (EAHX)
ii. Earth tubes
iii. Earth channels
iv. Underground air pipe
v. Subsoil heat exchanger
vi. Earth-air tunnel system
vii. Ground tube heat exchanger or ground heat exchanger (GHE)
viii. Buried pipes
ix. Hypocaust (Hollmuller and Lachal 2001)
x. Ground couple heat system

These terms all refers to the same kind of device: in which pipes or series of pipes are buried underground, and through which ventilation air is circulated. Throughout this research work, the term ‘Earth-to- air heat exchanger’ (EAHX) was used for consistency of understanding. Although ‘earth tubes’ also enjoys wide used. The systems can either be ‘closed-loop’ (i.e recirculation the air from the building through the earth tubes), or ‘open-loop’ (i.e drawing outside air through the pipes to ventilate the house). The system we have used in our set- up is an open loop system.

2.5 Types of earth to air heat Exchanger (EAHX)

There are mainly two types of heat exchangers. One is open systems and second is closed systems

1. Open system:

   In open systems, ambient air passes through tubes buried in the ground for preheating or pre-cooling and then the air is heated or cooled by a conventional air conditioning unit before entering the building as shown in figure 2.1. It has some advantages over others which are; simple design; lower drilling requirements than closed-loop designs; subject to better thermodynamic performance, typically lowest cost.

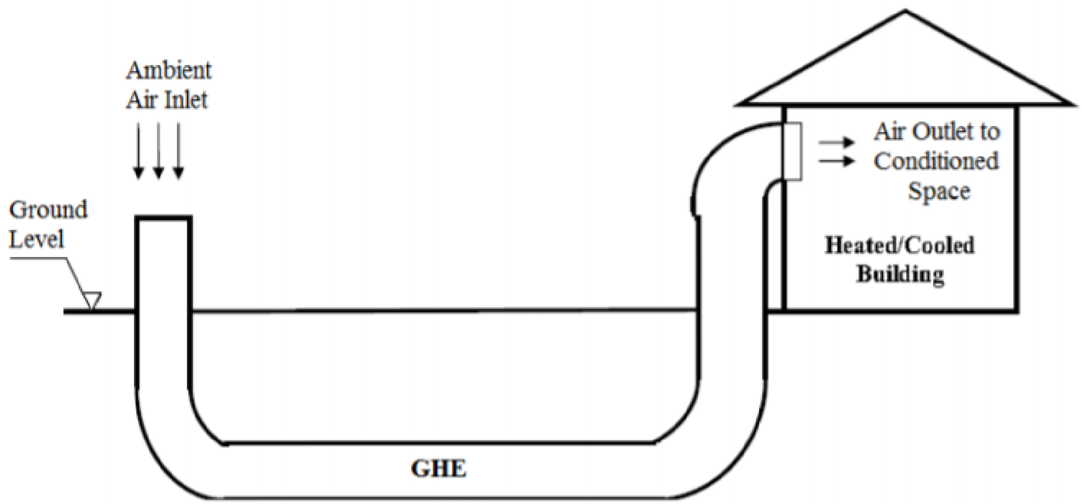

Figure 2.1: Schematic of open loop EAHX

2. Closed systems:

In closed systems the heat exchangers are located underground, either in horizontal, vertical or oblique position, and a heat carrier medium is circulated within the heat exchanger, transferring the heat from the to a heat pump or vice versa. This type of system is schematically shown in figure 2.2.

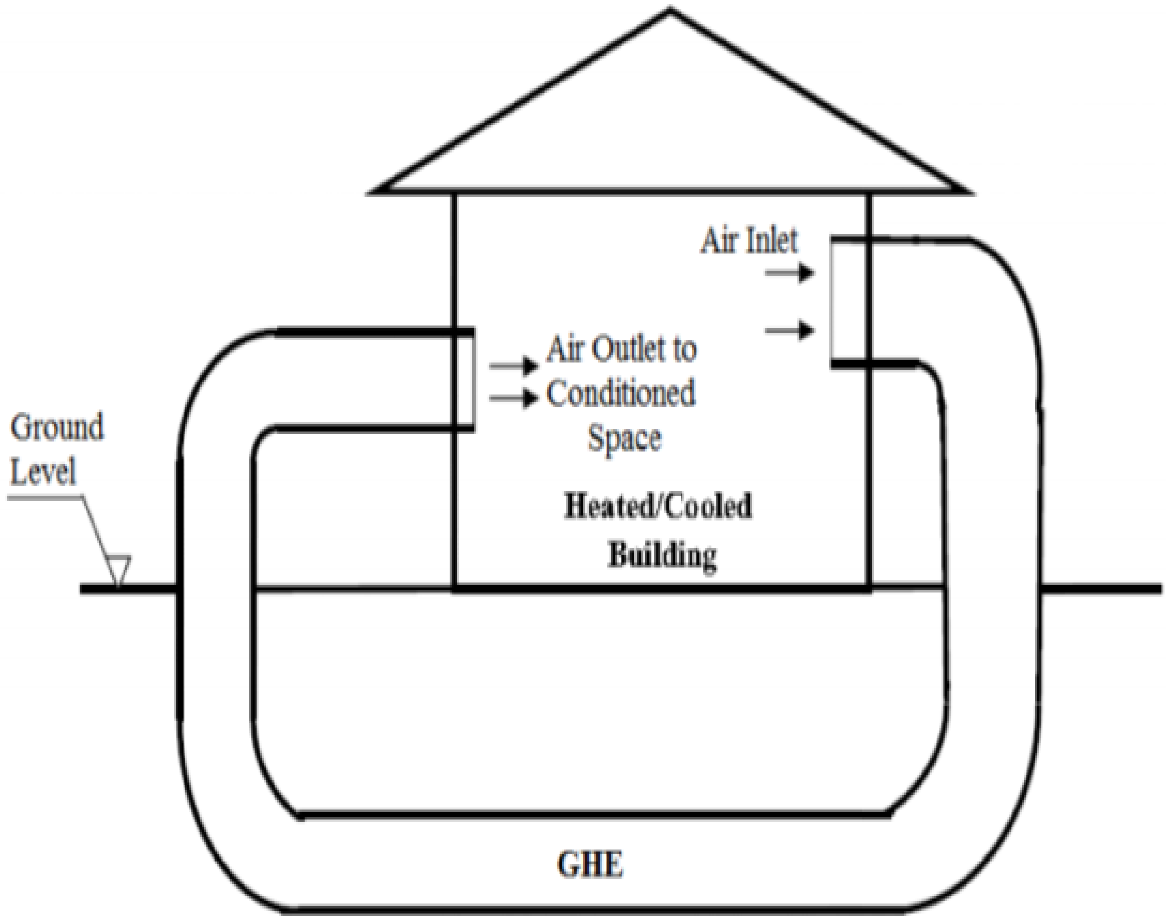

Figure 2.2: Schematic of closed loop EAHX

Advantages and Disadvantages of earth to air heat Exchanger

Advantages:

1. The earth to air heat exchangers are very simple to use and easy to maintain
2. In the long run, the low maintenance cost and the electricity cost saving make up for the initial investment.
3. Earth to air heat exchangers uses only the energy stored in the earth and has no harmful impact on the environment.

Disadvantages:

1. High initial investment cost.
2. Use of earth to heat is recommended in new house which has excellent insulation and air tightness.
3. Space requirement is the major hindrance to the adoption of the earth to air heat exchangers.
4. The design and installation of an effective earth to air heat exchanger depends on the local geology and the heating or cooling requirements of the building and to get the benefit of a well designed system, one needs to consult a expert installer which increases the cost of the system.

2.6 Applications of earth to air heat exchanger

All over the world, the earth to air heat exchanger is implemented in a variety of applications such as building thermal comfort. Examples, commercial buildings, offices, showroom, cinema hall, residential buildings, university campuses, hospitals, animal dwelling (livestock houses) and agricultural green houses (Tahseen *et al*.,2012). These applications are the most effective for passive energy sources from the ground which easily meet the cooling and heating requirement of buildings. The earth to air heat exchanger is also used for district heating in some countries (Dalla and Svendsen, 2011).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The earth-air heat exchanger was designed and constructed using:

i. Galvanised steel pipes
ii. T type thermocouples
iii. 8- channel data logger,
iv. digital vane type anemometer
v. Blower.
vi. Thermometers
vii. Thermistor
viii. Temperature auto scanner

Instruments used during the test measurements are digital vane type anemometer, T type thermocouples, thermistor with temperature auto scanner sensor.

3.1.1 **Anemometer**: Vane type anemometer was used for measuring the velocity of the air. A vane anemometer which uses a small fan is turned by air flowing over the vanes. The speed of the fan was measured by a revolution counter and converted to a wind speed by an electronic chip. Hence, volumetric flow rate may be calculated if the cross-sectional area is known.

It has 13mm LCD display screen and temperature range is from 0^0C to 50^0C. it is extremely light weight instrument weighing 260g and velocity range is from 0.3m/s to 45m/s with an accuracy of ±0.2% to 0.1m/s. plate 3.1 shows the vane type anemometer.

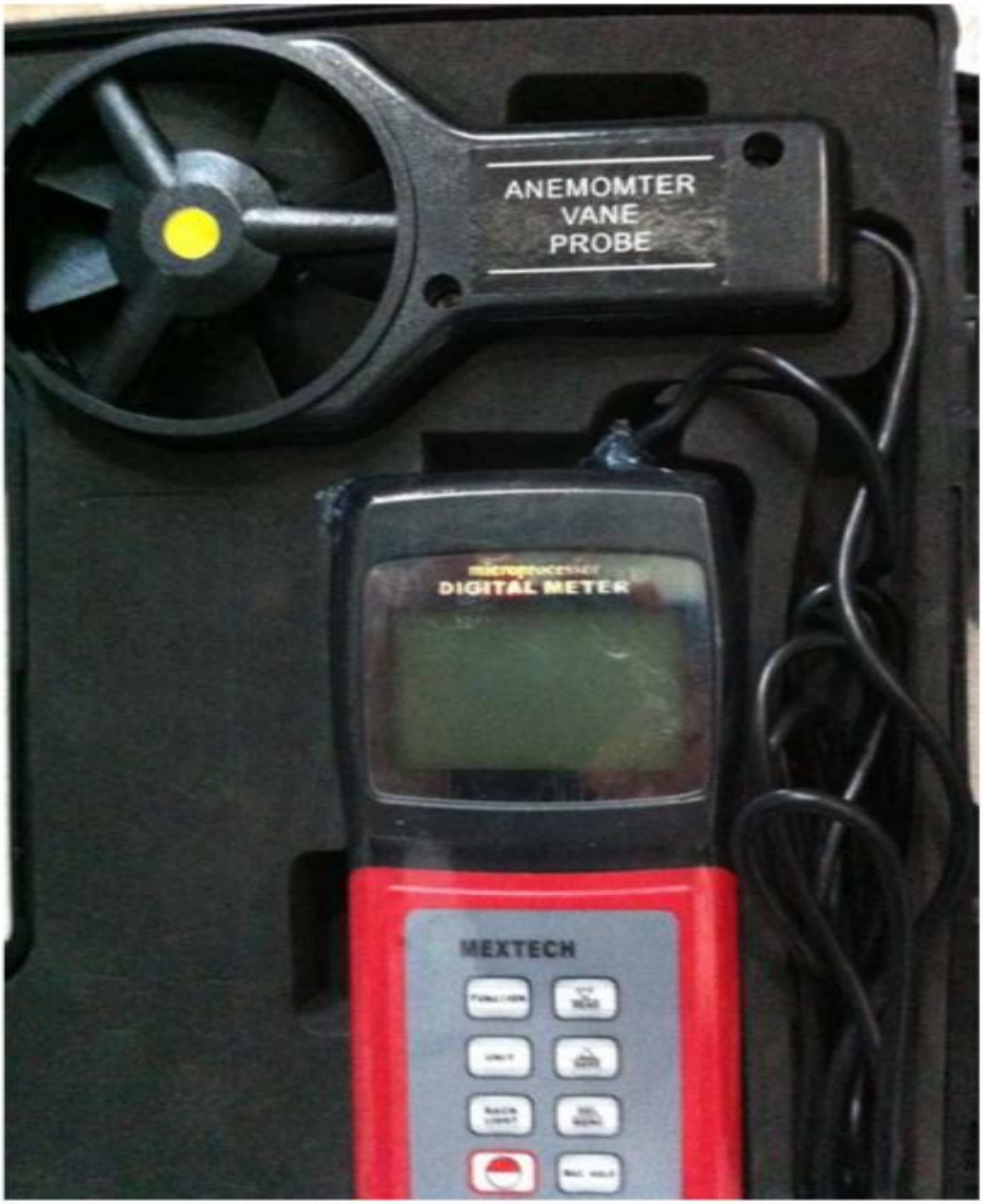

Plate 3.1 Vane type anemometer

3.1.2 **Thermistor**: it was used for measuring the temperature of the air. It has 1.5g mass and operating temperature range – 25 to 100^0 C. A Thermistor is a non – linear resistance made semiconductor material that is extremely sensitive to change in temperature. The Thermistor is used in wide variety of applications it can be used in measurement and control of temperatures, time delay temperature compensation and liquid level indicators. The Thermistor is available in the form of a disk, bolted assembly package. This instrument is shown in plate 3.2.

Plate 3.2: Screw Threaded Thermistor

3.1.3 **Temperature Auto Scanner**: As shown in plate 3.3 it displays the temperature encountered by the Thermistor attached with the instrument.

Figure 3.3: Temperature auto scanner

Display	4 – ½ Digit, segment; 0.56” Height; Red L.E.D
Accuracy	1% of full scale or ± 10% 2^0C
Resolution	0.01^0C up to 200^0C
Sensor break protection	Display starts blinking
Power supply	180 – 230V AC
NO. Input channel	10
Dimensions	96 96 x130mm

3.1.4 **Blower:** the centrifugal blower was used to pass the ambient air into earth- to air heat exchanger.

Plate 3.4: blower

Table 3.2 Specifications Blower

Input voltage	220 – 240V
Wattage	300W
Motor	Blower type motor
RPM	1800

3.2 Method

3.2.1 Design and Construction

The earth to air heat exchanger being design and constructed in this dissertation was an open system. The system consist of galvanised steel pipes of dimensions 200cmx100cmx350cm with 3cm diameter, thickness of 5mm and was buried at depth 1m at yard of Sokoto energy research centre, office building, Usmanu Danfodiyo University, Sokoto. The system made up of inlet, parallel and outlet pipes. The ambient air was suck by blower and was allowed to pass through the inlet pipe, and then passed through the parallel pipes buried underground before entering into room through outlet pipe as cool/

heat air. The velocity of ambient air before entering into inlet pipe was 11m/s and measured by a digital vane type anemometer. The vane size is 66x29.2mm and velocity range 0.3 to 45m/s. The anemometer measures mean air velocity. The ambient air temperature (inlet) and room air temperature (outlet) were measured by thermometer and earth temperature at depth of 1m was measured using the T thermocouples and recorded with an interval of minutes using an 8-channel data logger. In each of the test to carried out, the temperatures of ambient (inlet) and outlet (room) air are recorded. The velocity of the ambient air was maintained in each of the test. The system was tested into two season's mode: the hot season for cooling applications when soil temperature was lower than the ambient air temperature and cold season for heating applications when the soil temperature was higher than the ambient air temperature. In each of the test carried out the result was obtained and recorded. The coefficient of performance of the system was also calculated in each of the test carried out.

3.2.2 Design Parameters

i. Pipe Depth Selection

The ground temperature is defined by the external climate and by the soil composition, its thermal properties and water content. The ground temperature fluctuates in time, but the amplitude of the fluctuation diminishes with increasing depth of the tube, and deeper in the ground the temperature converges to a practically constant value throughout the year. On the basis of temperature distribution, ground has been distinguished into three zones (Popie., *et al* 2001) :

1. Surface zone: This zone is extended up to 1m in which ground is very sensitive to external temperature.

2. Shallow zone: This zone is extended up to 1m to 8m depth and temperature is almost constant and remains close to the average annual air temperature.
3. Deep zone: This zone is extended up to 20m and ground temperature is practically constant.

As the pipe depth increases, the inlet air temperature decreases, indicating that the earth air heat pipe should be placed as deeply as possible, however, the trenching cost and other economic factors should be considered when installing earth air heat pipes. Deeper positioning of the pipes ensures better performance. Typical depths are 1m to 1.5m. The pipes can be positioned under the building or in the ground outside the building foundation (thevenard, 2007).

The depth of the pipes used was 1m. The depth of the pipe required to heat or cool the air generally varies depending upon on the geography of the experimental set – up.

ii. Pipe Length Selection

As the pipe length increases, the inlet air temperature decreases due to the fact that the longer pipe provides a longer path over which heat transfer between the pipe and the surrounding soil can take place given the same overall heat transfer coefficient of earth air heat exchanger. Length can typically range from 10m to 100m longer pipes correspond to more effectiveness systems, but the required fan power and the cost also increase (Thevenard, 2007). For cost considerations, we have taken 200cm for the inlet and 350cm the outlet pipes.

iii. Tube Materials Selection

The main considerations in selection tube material are cost, strength, corrosion, resistances, and durability. Tubes made of concrete, metal, plastic, and other materials have been used. Simulations indicate tube materials have little influence on performance. Increasing the conductivity of the tube to a value corresponding to that of aluminium increased total heat transfer by less than 10% (Abrams, 1986). Bojic *et al*., (1999) studied two earth tubes: one PVC tube, and the other steel tube. They have the same dimension and parallel with each other. Results, showed that steel tube heat contribution account for no more than 54% of heat output from the two tubes PVC or poly propylene tubes perform almost as well as metal tubes (EREC,2002): they are easier to install, and are more corrosion resistant. Based on this steel pipes are selected in the construction of earth ait heat exchanger in this dissertation.

iv. Pipe Diameter Selection

As the pipe diameter increases, the earth air heat exchanger outlet air temperature also increases due to the fact that higher pipe diameter results in a lower convective heat transfer coefficient on the pipe inner surface and a lower overall heat transfer coefficient of earth air heat exchanger pipe system. Smaller diameters are preferred from a thermal point of view, but they also correspond (at equal flow rate) to higher friction losses, so it becomes a balance between increasing heat transfer and lowering fan power (Thevenard, 2007). The pipes we have used has 3cm diameter.

V. Flow Rate Selection

Lower flow rates are beneficial to achieve higher or lower temperatures, and also because they correspond to lower fan power. However, a compromise has to be made between pipe diameter, desired thermal performance, and flow rate. The flow rate we use was 11m/s.

Table 3.3 Parameters Used in the Construction and their Specifications

Parameters	Specifications
Specific heat capacity of air	1007Jkg^{-1}k^{-1}
Thermal conductivity of soil	0.540Wm^{-1}k^{-1}
Mass flow rate of air	0.0975kg/s
Velocity of air	11m/s
Volumetric flow rate of air	0.0863m^3/s
Thickness of pipe	5mm
Length of inlet pipe	200cm
Depth of buried pipes	1m
Diameter of pipe	3cm
Number of pipes buried in parallel connections	22
Energy input into the heat exchanger	300W
Length of outlet pipe	350cm
Space between the pipes buried in parallel connections	5cm

3.2.3 Experimental Set-Up

The experimental set up was an open flow system constructed for experimental investigation on the temperature difference of air flowing through pipes from outside to the inside of the room. The earth to air heat exchanger consist pipe as risers each having 3cm diameters with total length of 38.5m. They were made up of steel pipes and buried at a depth of 1m below the earth surface. Ambient air was sucked through the pipes by means of a centrifugal blower. The blower was used to suck the hot/cold ambient air through the pipe and delivered as cold/hot air to the room. The blower was placed at the inlet to blow the atmospheric air into the pipe for about 15 – 20 minutes to attain the steady state. Velocity of the air at the inlet was measured with the help of anemometer. The thermocouples and thermistor were attached to the temperature auto scanner at the inlet and the outlet to record the temperature change and also at various places below the ground to measure the soil temperature.

Figure 3.1 shows the schematic diagram of the system and the respective dimensions.

Plate 3.1 shows the heat exchanger placed in the excavated earth before being covered with the soil for experimentation. Plate 3.2 shows a pipe conveying air from the heat exchanger to the room.

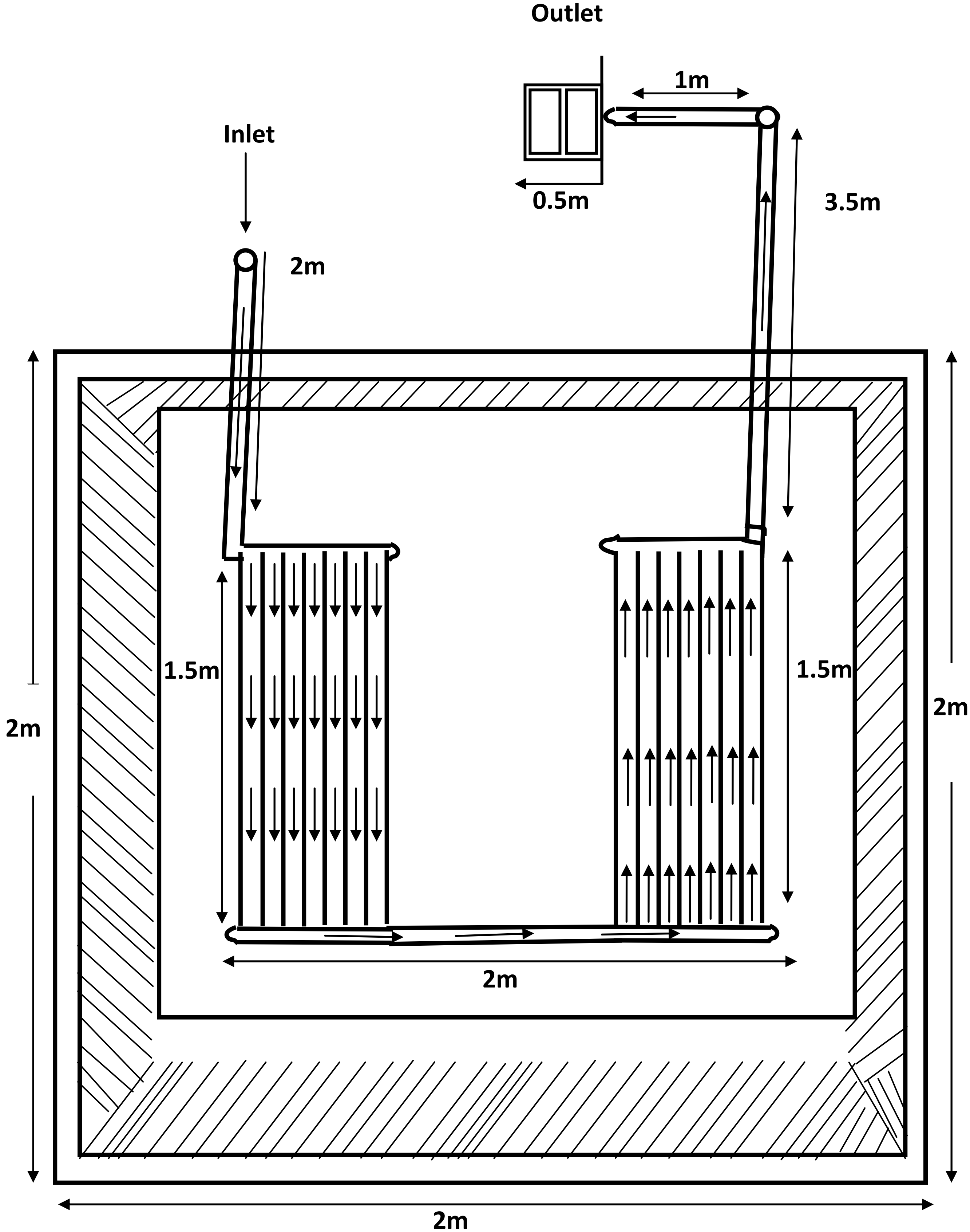

Figure 3.1 Schematic Sketch of EAHX

Plate 3.5 Experimental set up

Plate 3.5 the installation of earth air heat exchanger in the trench before the experimental test

Plate 3.6 the installed earth air heat exchanger buried underground before the experimental test.

3.2.4 Experimental Procedure

For the start of the experiment, the blower was switched on and the air was left to pass through the pipe for some time till the steady state was achieved. The velocity of air at the inlet was read and recorded with the help of the vane type anemometer and the temperature of the inlet (ambient) and outlet air were read and recorded with thermometer. The thermocouple wires are attached with temperature auto scanner which continuously displays the readings of thermocouple for measurement of soil temperature.

The procedure was repeated with different ambient conditions, this was achieved by conducting the experiment 3 days of dry season (29, 30, 31 May-2015) and 3 day of winter season (6, 7, 8 Jan 2016). All the data thus obtained is compiled into a single table as shown in appendix 1 and 2. The graphs are plotted for various sets of observations obtained from the experiment. The total cooling and heating had been calculated for flow velocities 11m/s by the following equations:

For cooling test

$Q_c = MaCp(Ti - To)$ 3.5

For heating test

$Q_h = MaCp(To - Ti)$ 3.6

Due to the convection between the wall and the air, the transferred heat can be also written as:

$Q_h = hA\Delta T$

Where

Q_h = the heating capacity of Earth to air heat exchanger (W)

h = convection coefficient (W)

ΔT = Temperature difference (K)

A = heat transfer area (m^2)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Results for this research work were recorded and tabulated as presented in Appendix I and II. Using Microsoft excel soft ware the results were plotted and presented in Figures 4.1 to 4.6. They consist of the following.

Figure 4.1: Variation of inlet and outlet temperatures with time during the cooling test

Figure 4.2: Comparation of inlet, outlet temperatures and coefficient of performance durng cooling test

Figure 4.3: Variation of coefficient of performance with time during cooling test

Figure 4.4: Variation of inlet, outlet temperatures with time during heating test

Figure 4.5: comparitions of inlet, outlet temperatures and coefficient of performance during heating test

Figure 4.6: Variation of coefficient of performance with time during heating test

4.2 Discussion of Result

4.2.1 Cooling test:

The earth to air heat exchanger system was operated for seven hours a day for three consecutive days. The tube air temperatures at the inlet, outlet and soil temperature at 1m depth were noted at the interval of one hour. System was turned on at 10:00am and shut down at 5pm. Tests were carried out in the three days. The ambient temperature on these three days was very similar. The results of the three days were therefore average as indicated in the appendix. The ambient temperature started with 31.3^0C at 10.00am and rose to a maximum of 40.8^0C at 2pm. The temperature of air at outlet was 26.8^0C; as the system started and rose only slightly to 27.2^{0}C at which it stayed through the 7 hour of test run. The outlet temperature was just above the basic temperature 26.6^{0}C) at 1m depth, suggesting that the tube was exchanging heat quite effectively.

Energy input into the heat exchanger is the energy used by the blower (300W). In the first hour of operation the ambient air temperature rose from 31.3^{0}C to 33.7^{0}C. The mean of this work out 32.5^{0}C.we shall assume this to be, $\mathbf{T_i}$, during this first hour. The coefficient of performance (COP) for cooling test was calculated by the equation:

$$COP = \frac{MCp\ (Ti - To)}{Power\ input} \quad \text{.......} 4.1$$

= 0.0975x1007x (32.5-26.8)/300

=1.9

Hourly, value of the coefficient of performance (COP) was 1.9 at the start, rising to a maximum of 4.5 at 2 pm as shown in appendix 1, when the ambient temperature was at peak. Mean value of COP over the test run 7 hour is 3.45.

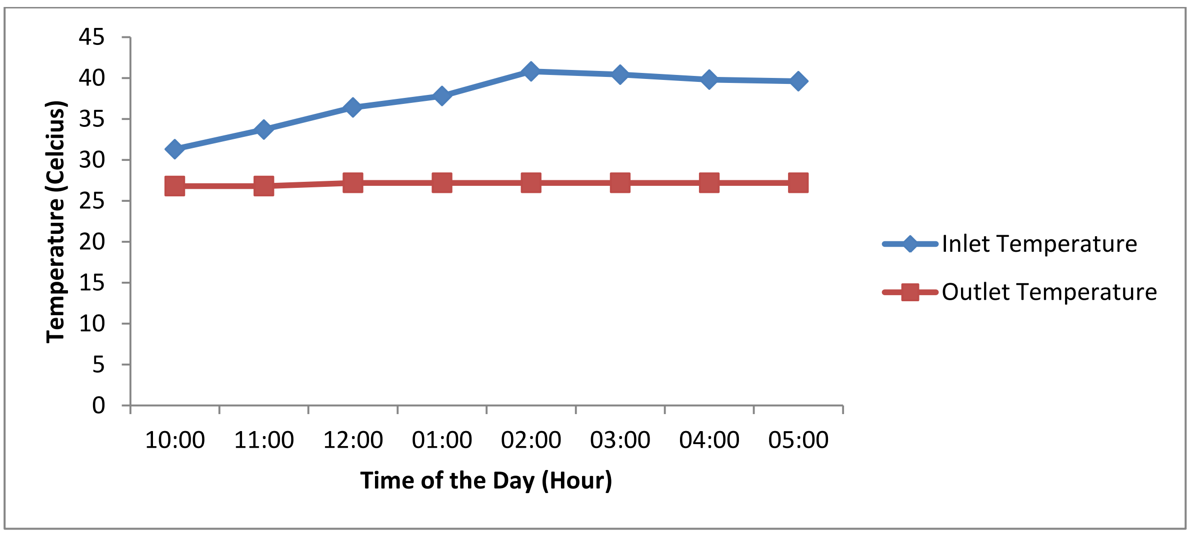

Figure 4.1: Variation of inlet and outlet temperatures with time for the cooling test

Figure 4.1: presents a comparison between the inlet and outlet temperatures during the cooling mode test in the summer day time. What is apparent from the figure 4.1 is that peak cooling exists when temperature is at its highest value. The inlet temperature started at 31.3^{0}C at 10:00 am then increased to a maximum of 40.8^{0}C then declined to become 39.6^{0}C at 5:00pm .The outlet temperature was 26.8^{0}C to 27.2^{0}C with an average temperature of 30.9^{0}C and a peak 27.2^{0}C. The maximum different between the inlet and outlet temperatures was 13.6^{0}C and the minimum was 4.5^{0}C.

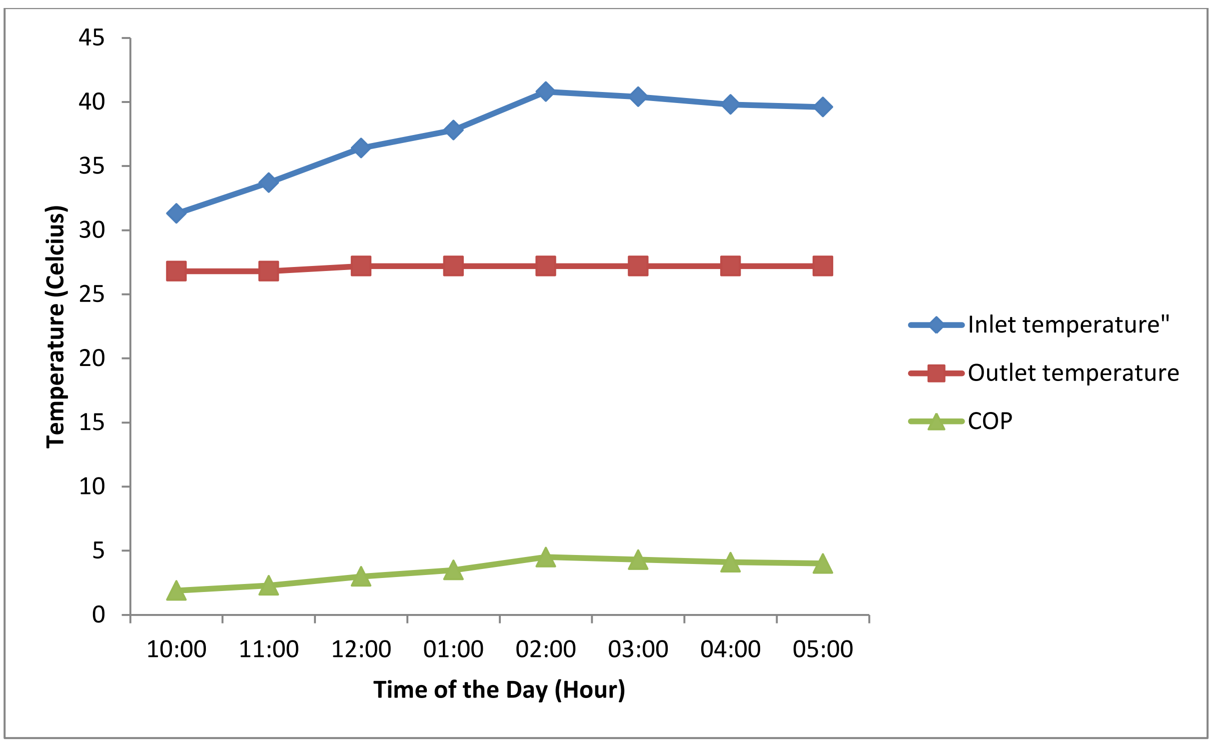

Figure.4.2 Comparison of inlet, outlet temperatures and coefficient of performance for cooling test;

Figure.4.2. shows comparison of inlet, outlet temperatures and coefficient of performance during cooling test; results from figure 4.2 shows a 23^{0}C difference between outlet temperature and coefficient of performance and difference of 8^0C between inlet and outlet temperatures.

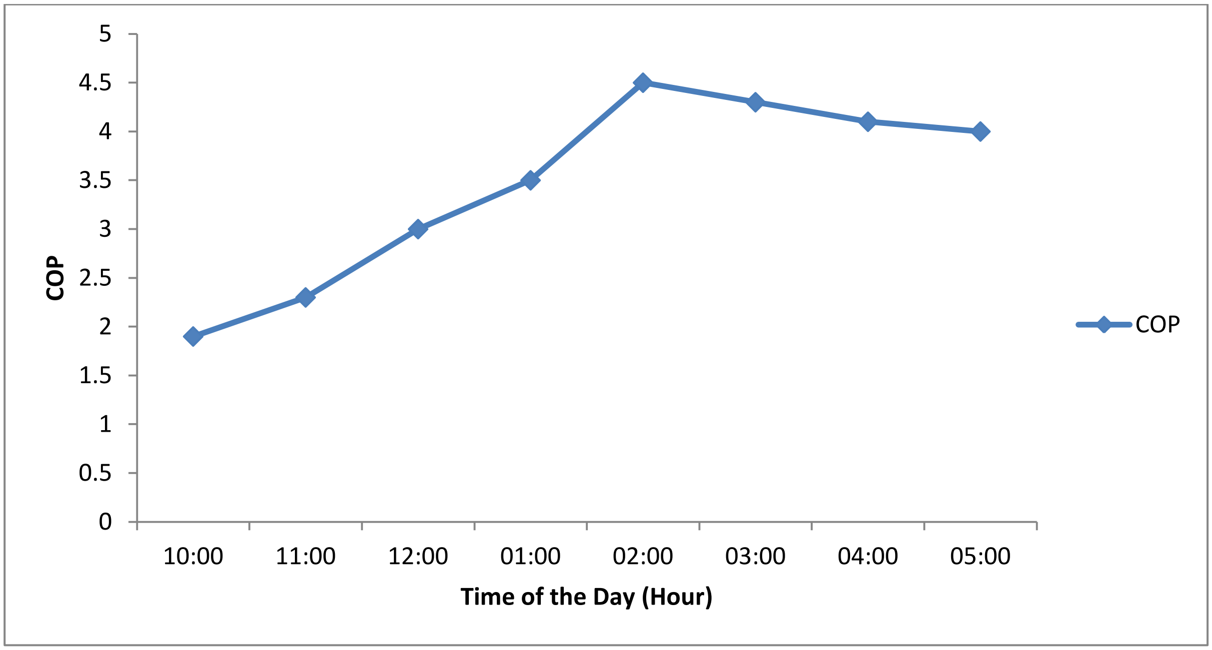

Fig.4.3: variation of coefficient of performance with time for cooling during hot summer days

The final cooling coefficient of performance during high ambient temperatures, where cooling is greatly needed is shown in figure 4.3. During these periods the value of coefficient of performance attained by the system for the cooling tests at high temperature was 4.5

4.2.2 Heating test

Heating tests were carried out. The system was turned on at 10am and operated for 8 hours continuously. Temperature readings were noted at hourly interval. The conditions on the three consecutive days were similar and therefore the results were averaged as presented in table 4.2 in appendix 1. The ambient temperature started at 21^0C increasing the highest value 30.30^0C. Basic soil temperature at 1m depth was constant at 24.2^0C.

Temperature of the air at the outlet varying from 27.53^{0}C to 40.36^{0}C EAHX was able to raise the ambient air temperature at 5pm from 21.00^{0}C to 30.1^{0}C.

The COP of Earth to air heat exchanger for heating test was calculated by the flowing equation;

$$COP = \frac{MC(Tout-Tin)}{power\ input} \quad \ldots\ldots 4.2$$

Hourly, values of the coefficient of performance (COP) started at 2.3 and risen to a 3.4 as shown in appendix 2.

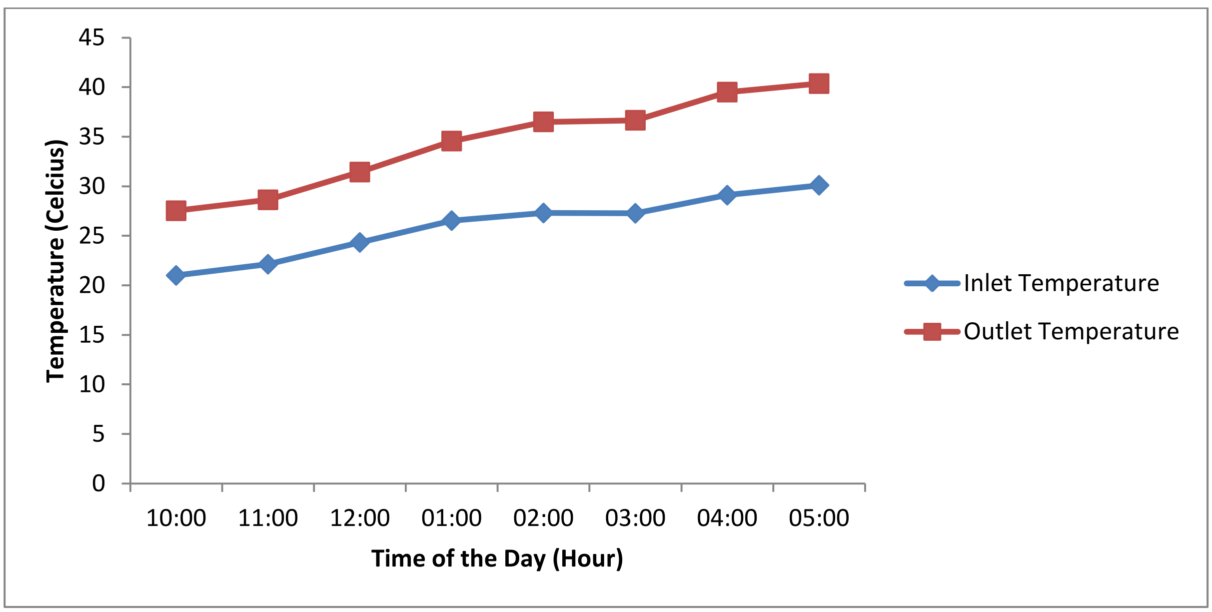

Figure 4.4: Variations of inlet and outlet temperature with time during the heating tests.

The result from figure 4.4 presents a comparison between the inlet and outlet temperatures during the winter days time. What is apparent from the figure 4.4 is that the peak heating exists when outlet temperature was at 40.36^{0}C. The inlet temperature started 21.0^{0}C at 10:00am then increased to 31.1^{0}C at 5 00pm. The outlet temperature was

27.53^0C then increased to 40.36^0C at 5.00pm. The different between the inlet and outlet temperatures were 10.26^0C. This means that the earth air heat exchanger was able to raise the inlet (ambient) air temperature.

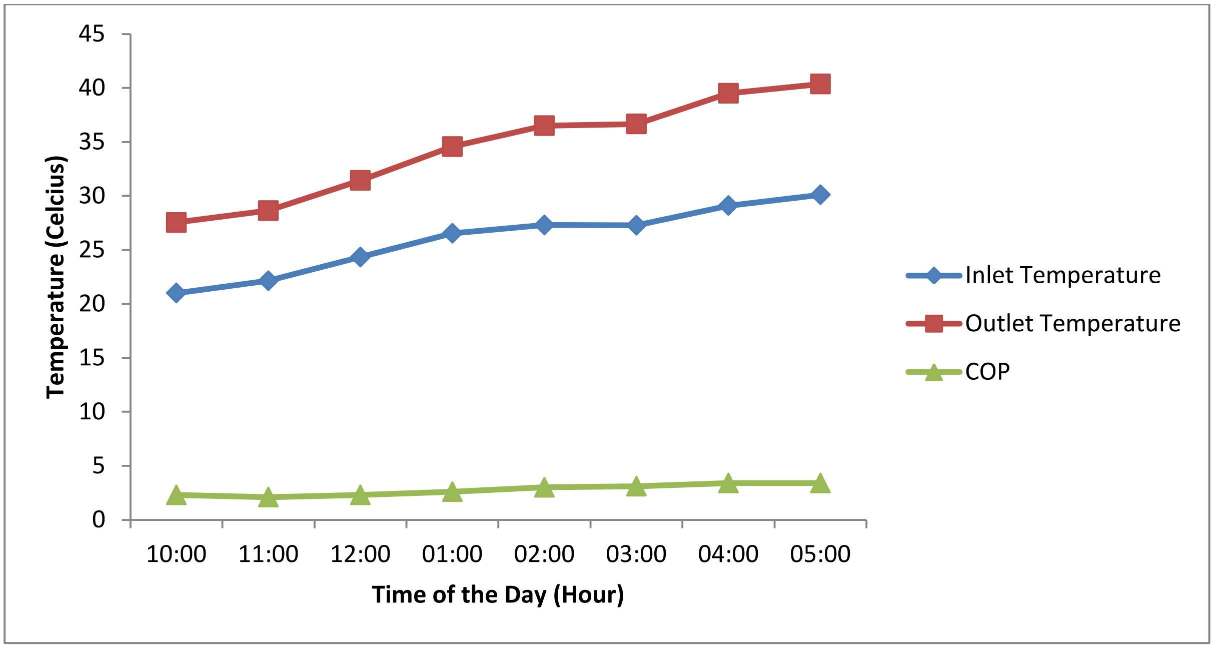

Figure 4.5: Comparison of inlet, outlet temperatures and coefficient of performance with time during heating test;

The results from figure 4.5 shows a 37^0C difference between outlet and coefficient of performance and difference of 10^0C between outlet and inlet temperatures.

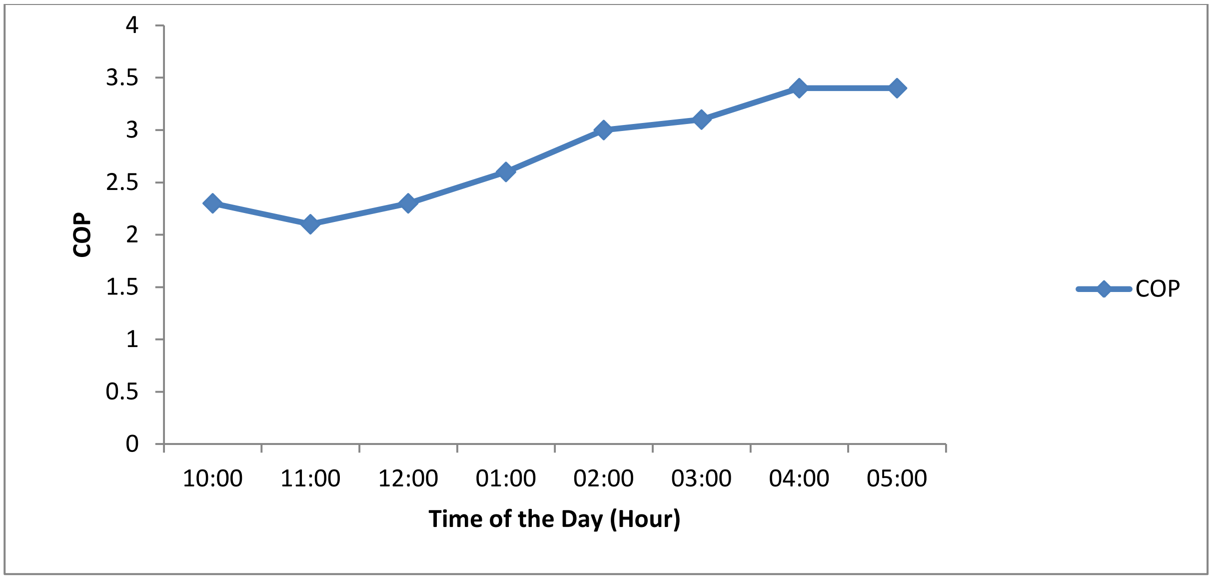

Figure 4.6 Variation of coefficient of performance with time for heating during winter days.

Contrary to the cooling, the heating coefficient of performance gave less result under low ambient temperatures as shown in figure 4.6

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

1. The design of an earth air heat exchanger mainly depends on the cooling/heating load requirement of a building to be conditioned. Earth air heat exchanger is based on the following principles: using the earth as a source or sink; uses soil thermal inertia; depends on the thermal conductivity of soil. It is also environmentally friendly as it uses natural air and has no emission or release of hydro-chlorofluorocarbon (HCFC) and chlorofluorocarbon (CFC) which are detrimental to the environment.
2. Based on the obtained results, it can be stated that the earth air heat exchanger (EAHX) designed, constructed and tested in this work holds considerable promise as means to cool/heat ambient air for variety of applications such as in office buildings. It can also be concluded that though the system alone is not sufficient to cool or heat as conventional air conditioned, but can provide significant portion of heating/cooling load to provide thermal comfort.
3. The earth to air heat exchanger system designed in this project was able to create cooling by temperature drop of 1.9 to 4.5^{0}C in hot season. It was observed that the maximum cooling was obtained when the ambient air temperature was maximum. That is when the ambient air was 40.8^{0}C; the room air temperature was recorded to be 27.2^{0}C.

It was also observed that the coefficient of performance of the earth air heat exchanger system increase with time during cooling test and the system coefficient of performance depends greatly on the increased of ambient air temperature on hot season.

The system was also able to provide heating by 3.4^0C during cold (hamattan) season and the coefficient of performance during that period was significantly increased with time. That is when the outside air was 29.1^0C, the inside was found to be 39.5^0C.

Various factors such as tube length, tube diameter, airflow rate, tube material, tube depth, tube arrangement affect the performance of earth to air heat exchanger which needs to be optimized to maximize the system performance effectiveness.

5.2 RECOMMENDATIONS

i. Though the results of the cooling and heating performance were found to be encouraging it is recommended to have a more control strategy in the operation of the system.

ii. To couple the system with conventional air conditioning system for good thermal comfort of the building's interior, as a supplementary cooling/heating method.

iii. The earth air heat exchanger is not in wide use in tropical regions, as a passive cooling/heating system; hence it is here by recommended for more applications in the field.

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APPENDIX I

Table 4.1 Average inlet temperature, outlet temperature and soil temperature of EAHX (May 2015)

Time/sec	Ti/^{0}C	To/^{0}C	Ts/^{0}C	M(kg/s)	Cp(J/kg/k)	Qout(W)	Qin(W)	COP
10:00	31.3	26.8	26.6	0.0975	1007.00	559.6	300.00	1.9
11:00	33.7	26.8	26.6	0.0975	1007.00	677.5	300.00	2.3
12:00	36.4	27.2	26.6	0.0975	1007.00	903.3	300.00	3.0
1:00	37.8	27.2	26.6	0.0975	1007.00	1040.7	300.00	3.5
2:00	40.8	27.2	26.6	0.0975	1007.00	1335.3	300.00	4.5
3:00	40.4	27.2	26.6	0.0975	1007.00	1296.0	300.00	4.3
4:00	39.8	27.2	26.6	0.0975	1007.00	1237.1	300.00	4.1
5:00	39.6	27.2	26.5	0.0975	1007.00	1217.5	300.00	4.0

APPENDIX II

Table 4.2 Average inlet temperature, outlet temperature and soil temperature of EAHX (Jan-2016)

Time/sec.	Ti/^{0}C	To/^{0}C	Ts/^{0}C	M(kg/s)	Cp(J/kg/k)	Qout(W)	Qin(W)	COP
10.00	21.00	27.53	24.2	0.0975	1007.00	695.1	300.00	2.3
11.00	22.13	28.63	24.2	0.0975	1007.00	638.2	300.00	2.1
12.00	24.33	31.43	24.2	0.0975	1007.00	697.1	300.00	2.3
1.00	26.53	34.56	24.2	0.0975	1007.00	788.4	300.00	2.6
2.00	27.3	36.5	24.2	0.0975	1007.00	903.3	300.00	3.0
3.00	27.27	36.66	24.2	0.0975	1007.00	921.9	300.00	3.1
4.00	29.1	39.5	24.2	0.0975	1007.00	1021.1	300.00	3.4
5.00	30.1	40.36	24.2	0.0975	1007.00	1007.4	300.00	3.4