EFFECT OF PIPE MATERIALS ON THERMAL REDUCTION IN EARTH AIR HEAT EXCHANGER (EAHE)

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ABSTRACT

Global warming and the excessive emission of CO_2 contributed to the increase of temperature in the earth's atmosphere. The increase of the earth's temperature thus leads to the reduction in the thermal comfort. Air conditioner are often used to induced cooling to building interior, however the concern over CO_2 emission and carbon footprint lead to the invention of a more environmental friendly cooling system such as Earth Air Heat Exchanger (EAHE). EAHE is a system that provides cooling by driving hot air from the environment through pipe buried and dissipates heat through soil underground. The efficiency of the system is highly influenced by several factors including pipe materials, length, and type of soils and depth of pipe buried. In this study, a simple small scale EAHE system was designed and constructed to evaluate the thermal reduction efficiency of different pipe materials. Two different types of pipe materials of similar design were tested namely, polyvinyl chloride (PVC) pipe and Galvanized iron (GI) pipe. The tests results indicated that material having greater thermal conductivity provide better thermal reduction efficiency. The maximum reduction in temperature of 7°C was observed using GI pipe whereas, a maximum of 4°C was observed for the PVC pipe. The use of material having higher density, higher specific heat capacity and higher thermal conductivity provides better thermal reduction efficiency for an EAHE system.

ABSTRAK

Pemanasan global dan pelepasan CO_2 yang berlebihan menyumbang kepada peningkatan suhu di dalam atmosfera bumi. Peningkatan suhu bumi itu membawa kepada pengurangan dalam keselesaan terma. Penghawa dingin sering digunakan untuk mendorong penyejukan dalaman bangunan, namun kebimbangan pelepasan CO_2 dan karbon jejak membawa kepada ciptaan mesra sistem penyejukan lebih alam sekitar seperti Penukar Bumi Udara Haba (EAHE). EAHE adalah satu sistem yang menyediakan penyejukan dengan memandu udara panas dari persekitaran melalui paip yang dikebumikan dan haba dihilangkan melalui tanah bawah tanah. Kecekapan sistem ini sangat dipengaruhi oleh beberapa faktor termasuk bahan-bahan paip, panjang, dan jenis tanah dan kedalaman paip dikebumikan. Dalam kajian ini, skala kecil sistem EAHE mudah telah direka bentuk dan dibina untuk menilai kecekapan pengurangan haba bagi bahan-bahan paip yang berbeza. Dua jenis bahan paip reka bentuk yang serupa telah diuji iaitu, polyvinyl chloride (PVC) paip besi bergalvani (GI). Keputusan ujian menunjukkan bahawa bahan yang mempunyai keberaliran haba yang lebih besar menyediakan kecekapan pengurangan haba yang lebih baik. Penurunan maksimum suhu sebanayk 7 °C diperhatikan menggunakan paip GI manakala, maksimum 4 °C telah diperhatikan untuk paip PVC. Penggunaan bahan yang mempunyai ketumpatan yang lebih tinggi, muatan haba tentu yang lebih tinggi dan kekonduksian haba yang lebih tinggi menyediakan kecekapan pengurangan haba yang lebih baik untuk sistem EAHE.

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LIST OF ABBREVIATIONS/SYMBOLS/UNITS

EAHE	Earth Air Heat Exchanger
G.I.	Galvanized Iron
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
PVC	Polyvinyl Chloride
UMP	University Malaysia Pahang
USA	United State of America
XRD	X-ray Diffraction
CO_2	Carbon Dioxide
°C	Degree Celsius
%	Percent
J/kg.K	Joule per kilogram Kelvin
kg/m^3	kilogram per meter cube
kW	kilo Watt
mm	milimeter
m	meter
W/m.°C	Watt per meter degree Celsius
W/m.K	Watt per meter Kelvin

CHAPTER 1

INTRODUCTION

1.1 Study background

Global warming and climate change refer to an increase in average global temperatures (Anup, 2012). Natural events and human activities are believed to be contributing to an increase in average global temperatures. This is caused primarily due to the increased in "greenhouse" gases such as Carbon Dioxide (CO_2). The greenhouse effect is a process by which absorption and emission of infrared radiation by atmosphere gases warm a planet's lower atmosphere and surface. The Intergovernmental Panel on Climate Change (IPCC) have observed the increase in global temperatures since the mid-20th century has caused the melting of glaciers in the northern hemisphere and added to the rising sea levels, confirmed by 30 scientific societies. Eco-entrepreneur Matthias Gelber, currently based in Malaysia said global warming is the increasing rise of temperature triggered by the increasing $C0_2$ concentration and related emissions in the atmosphere. These will affect the thermal comfort of occupants in a building.

The first major issue about climate is the comfort level (Salleh, 2004). Thermal comfort conditions in residential buildings vary according to the designs, modifications of the house and adaptation of the occupants. While air conditioning is the most popular form of adaptation, natural ventilation is still relied upon for some parts. According to Nasibeh *et al.* (2012), the house was thermally comfortable for almost fifteen hours during day and night. Comfort conditions mostly occurred during night hours while around noon hours could be considered as critical times. To improve the thermal conditions, ceiling fans were used to increase indoor air velocity. However, it was observed that this measure did not improve the thermal comfort condition when the air temperature had reached its maximum level. On the other hand, adaptation of air conditioning could improve the thermal comfort condition of the house.

Due to climatic differences, various methods have been devised to deal with hot, cold and humid environmental conditions (Sulaiman and Mohd, 2008). In the last decade, there has been growing public awareness on thermal comfort in Malaysia. In a country with a hot and humid climate, a large number of the buildings are served by air-conditioning and other mechanical ventilation systems that are designed to maintain a thermally comfortable indoor environment. Nicol (2007) stated that a proper and precise delineation of the interior climate is essential in determining the efficacy of a building because it will not only ensure the comfort of its occupants but will also impact upon energy consumption and its sustainability. The significant rising of energy cost is affecting everyone, it have put massive pressure on energy consumption.

In an attempt to reduce the electricity consumption while maintaining a satisfactory comfort level, new technologies are current being developed. In recent years, the use of Earth Air Heat Exchanger (EAHE) have been shown to provide cooling as well as reducing electricity consumption and emission of greenhouse gasses. EAHE uses single or series of pipes buried underground and circulate hot air from the surrounding. The hot air is then cooled down by dissipating heat to the surrounding soil. Although soil plays a significant role in the efficiency of the system, the pipe material used also were found to be affecting the heat dissipation efficiency of an EAHE systems.

In this study, a small scale EAHE system was designed and tested. Two different type of pipe material was used to determine the heat reduction efficiency of different pipe material in EAHE system.

1.2 Problem statement

Global warming had caused surrounding temperature to increase. Due to temperature increase, a large number of the buildings are served by air-conditioning to maintain a thermally comfortable indoor environment. In an attempt to reduce the electricity consumption while maintaining a satisfactory comfort level, new technologies are current being developed which is EAHE system. Thus, identifying the best pipe having excellent thermal dissipation behavior might help in improving the design and performance in EAHE system.

1.3 Research objectives

The objectives of this study are:

1. To compare the effects of pipe materials on the thermal reduction efficiency in Earth Air Heat Exchange (EAHE).

2. To measure the thermal reduction efficiency in Earth Air Heat Exchange (EAHE) using different pipe materials.

1.4 Scope of study

A simple pilot scale EAHE system was designed and constructed in University Malaysia Pahang. The experiment is set with small scale system that considered very limited site which is 2.5 m (L) x 0.15 m (B) x 1 m (D). Two different types of pipe material which are PVC pipe and galvanized iron pipe were chosen as a variable factor. For constant factor, a similar diameter and pipe length (i.e. 20 mm and2.5m) were used. The pipes are first buried 0.5 m below the ground surface and connected to an air pump to circulate air.

1.5 Thesis layout

This thesis consists of five consecutive chapters.

Second chapter is literature review. This chapter presented on global warming, cooling thermal comfort, energy consumption and earth air heat exchanger (EAHE).

Third chapter is methodology. This chapter explained on site preparation, soil properties, mineralogy properties and design of earth air heat exchanger (EAHE).

Forth chapter is result and discussion. In this chapter, result and discussion of soil properties is presented first, followed by the result of main test which is thermal reduction of PVC pipe and galvanized iron pipe.

Fifth chapter is conclusion. The final conclusions based on the finding obtained from the study are presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter consists of three consecutive sections. The first section briefly explained on effect of global warming on building temperature. The second section presented on energy consumption due to usage of air conditioning system. The third section explained on EAHE system in a building and parameters affecting thermal reduction.

2.2 Global warming

Global warming happens when the earth heats up (the temperature rises). It happens when the “greenhouse effect” (referring to certain gases in Earth's atmosphere) trap heat. These gases let in light but keep heat from escaping, like the glass walls of a greenhouse. The process will involve the sunlight shines onto the Earth's surface, there it will be absorbed and then radiates back into the atmosphere as heat. In the atmosphere, “greenhouse” gases trap some of this heat and the rest escapes into space. The more greenhouse gases are in the atmosphere, the more heat gets trapped. It is expected that the global temperatures will rise up to 1.5 and 4.5°C over the next century (Nelson and Serafin, 1996).

Global warming has already been experienced by the community in Malaysia. Wai *et al.* (2005) have detected a significant increase of the mean annual temperature, ranging from 0.99-3.44°C per 100 years and they also have detected that global warming trend in Malaysia has increased in the past 30 years. International Panel on Climate Change (IPCC) has supported the research done by Wai *et al.* (2005) when they found that the average temperature in Malaysia is predicted to increase between 0.6-4.5°C in 2060. Moreover, Deni *et al.* (2008) noted that the frequency of long dry period tended to be higher with a significant increase in the mean and the variability of the length of the dry spells whereas all of the indices of wet spells in these areas show a decreasing trend.

A previous study analyzed the distribution of temperature, sea level pressure, evaporation, and insolation in East Malaysia (Camerlengo *et al*, 1999). Given the fact that Malaysia gained its independence in not more than 60 years, the collected temperature data set of East Malaysia is quite recent. Thus, in that particular study, only thirty years of data has been available. Nevertheless, the results of (Camerlengo *et al*, 1999) show a perfect agreement with the temperature forecast for the next 100 years according with the IPCC latest report (Houghton *et al*, 2001). This is due to the fact that the global warming rate has greatly increased in the last 30 years (Houghton *et al*, 2001).

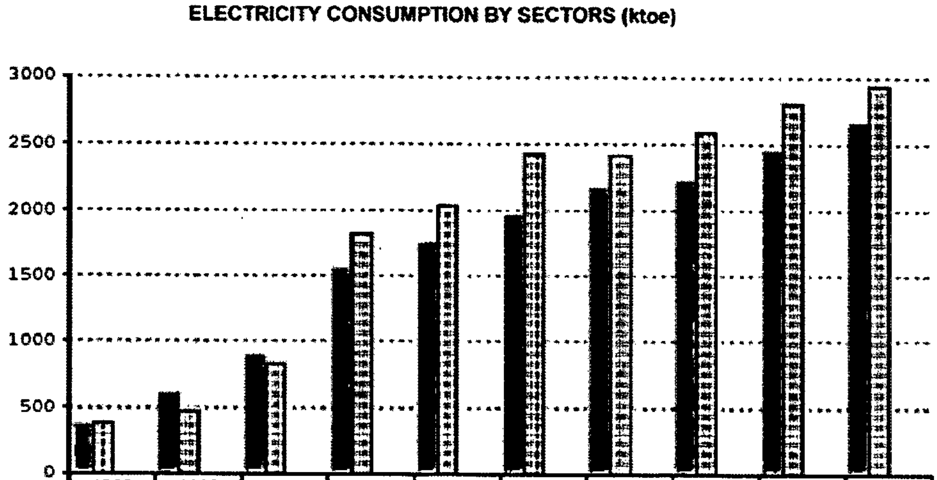
The Intergovernmental Panel on Climate Change (IPCC) (Pachauri and Reisinger, 2007) estimated that the Earth's surface temperature has increased by 0.6°C and that human activities, such as burning fossil fuels for energy, have played a major role in climate change. Unfortunately, the world's insatiable thirst for energy will only increase as poorer countries become more industrialised. Future energy demand will be particularly strong in the home heating and cooling sector in the developing world. As people gain affluence, one of the first luxuries they seek are heating and cooling systems for their homes and offices. For example, in the United States (USA), 87% of homes have air conditioning, while in India, only 2% of homes have air conditioning

(Sivak, 2009). By 2030, India will catch up with the USA in the number of air conditioning units used within the country (Issac and van Vuuen, 2009). Once a home has air conditioning, the system can account for more than half of the home's energy consumption (Environmental Protection Agency, 2009). A study conducted by Michael Sivak (2009) estimates that 24 of the top 50 metropolitan cities are in the developing world and are in warm climates. One city alone, Mumbai, has a cooling need equal to one quarter of the USA. It is predicted that by the end of the 21st century, the energy used for indoor cooling will be 40 times greater than it is today. This will cause the total CO2 emissions to rise from 0.8 Gt C in 2000 to 2.2 Gt C in 2100 (Issac and van Vuuen, 2009).

Nowadays, air conditioning is widely used not only for industrial productions but also for the comfort of occupants. It can be achieved efficiently by vapour compression machines, but due to the depletion of the ozone layer and global warming by chlorofluorocarbons (CFCs) and the need to reduce high grade energy consumption; numerous alternative techniques are currently being explored (Bansal *et al.*, 2009). One of the techniques that can be used in reduction of energy consumptions is earth air heat exchanger (EAHE).

2.3 Energy consumption

In 2004, a report by Chan has shown a vast increase in energy consumption in buildings in Malaysia. It demonstrated that the energy consumption in Malaysia in the year 2000 is almost tripled the amount of energy consumption in the year 1990 (Figure 2.1).



	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001
■ Resid. & Comm.	363	604	885	1,549	1,747	1,961	2,165	2.220	2,453	2,660
◻ Industrial	384	475	830	1,826	2,029	2,422	2,411	2,591	2.805	2,930
⁚ Transport	0	0	0	0	1	1	1	4	4	5.17
Total	747	1,079	1,715	3,375	3,777	4,384	4,577	4.815	5.263	5,594

Figure 2.1: Trend of electricity consumption in three different sectors; residential, industrial and transportation from year 1980 to 2001. (Source: Department of Electricity and Gas Supply Malaysia in Chan, 2004).

One of the major factors that are affecting the energy use in buildings in Malaysia is air-conditioning. Being a warm and humid country, cooling of building is in great demand and the majority of building users in Malaysia are depending on air-conditioning to achieve comfort, particularly in non-residential buildings.

In 2003, an energy audit was conducted by Danida and ECO-Enegry Systems on a 987m^2 single storey office building in Malaysia and the report stated that 64% of the energy consumed was for air-conditioning alone (Figure 2.2) (Chan, 2004). Another survey was conducted in a typical Malaysian terraced house of about 180m^2. The breakdown of energy use was found the refrigerator consumed the most and the air conditioning is the next most energy consuming (Figure 2.3).

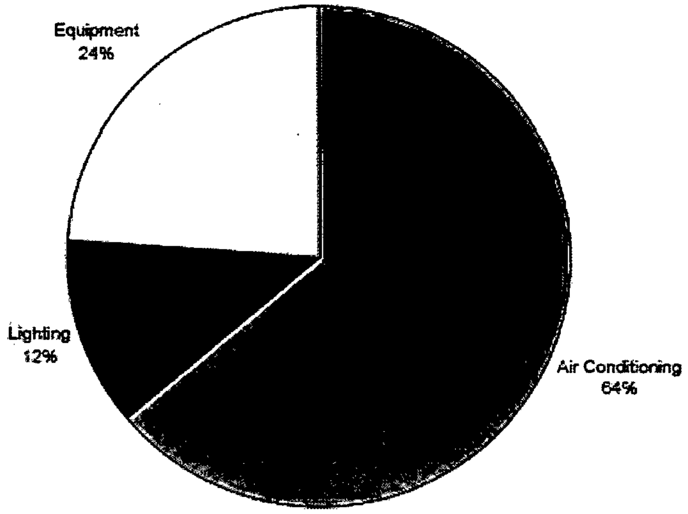


Figure 2.2: Breakdown chart of the energy load in an office building in Malaysia (Source: Chan, 2004).

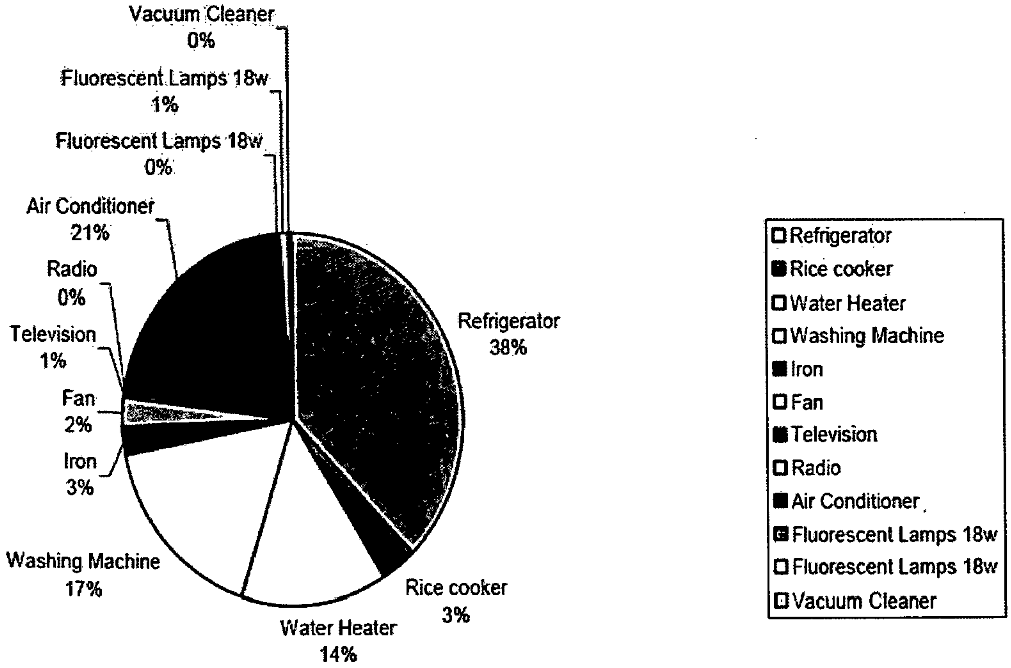


Figure 2.3: Breakdown chart of the energy load in typical terraced house in Malaysia (Source: Chan, 2004)

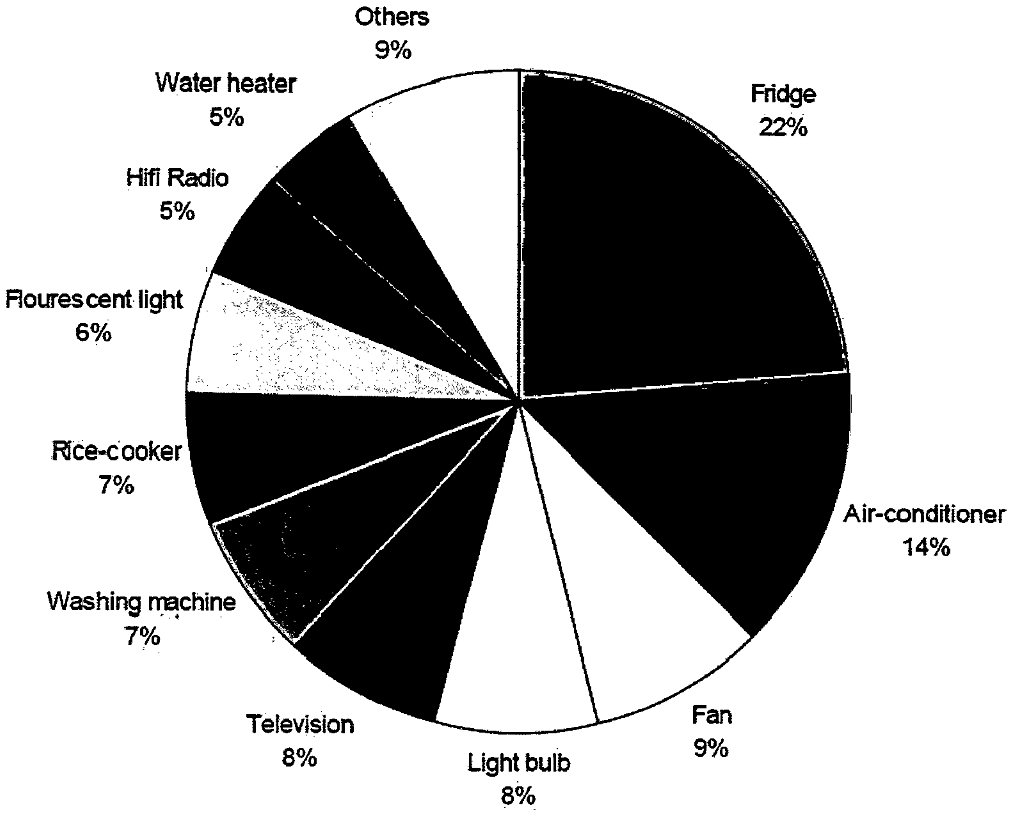


Figure 2.4: Breakdown chart of the energy load in residential sector in Malaysia (Source: Mohd Taha, 2003)

The high percentage of energy consumed by air conditioning in both building types show that there is a potential of significantly reducing energy consumption in the country by using passive cooling system such as earth air heat exchanger (EAHE).

2.4 EAHE

Earth Air Heat Exchanger (EAHE) is a device that permits transfer of heat from ambient air to deeper layers of soil and vice-versa. EAHE usually consist of loop(s) of pipe buried in the ground horizontally or vertically. Vertical loops go deeper. Horizontal loops are usually buried at one to four meter depth. Temperature regime at this depth and beyond is stable, with no diurnal fluctuation and with only a small seasonal or annual variation. Ambient air is pumped through buried pipes at moderate velocities. In summer, the temperature is warmer than the usual temperature of soil surrounding the pipe, thus heat is transferred from air to soil resulting in cooling. In winters or at nights the reverse takes place. Thus, EAHE can be used for cooling in summer and heating in winter. EAHE based systems cause no toxic emission and therefore, are not detrimental to environment. EAHE have long life and require only low maintenance. However, initial installation costs are likely to be higher than the comparable conventional system.

Historically, EAHE research and implementation have been confined to Europe and America, although in recent years, researchers in emerging economies have investigated EAHEs. Al-Ajmia, Lovedayb and Hanbyc (2006) conducted a theoretical study on EAHEs for desert environments in Kuwait. Kuwait has a hot and dry desert environment like that of Burkina Faso. In July and August, the average afternoon temperature in Kuwait is 45°C, and in the summer months, the average humidity is between 14% and 42%. Al-Ajmia et al. modelled several EAHEs and concluded that the optimal EAHE configuration used 60 m of pipe with a diameter of 0.25 m, buried 4 m deep, with a 100 kg/hr air flow rate. They conclude that an EAHE at the peak midday temperature in the summer (45°C) can cool a 300 m^3 building by 2.8°C. If the system is combined with traditional air conditioning, it can reduce the monthly energy demand by 420 kW hr and reduce the seasonal cooling demand by 30%.

The study conducted by Ahmed *et al.* (2007) stated, that the Earth-Air Heat Exchanger (EAHE) also known as earth cooling tube is a subterranean cooling system that consists of a length of pipe or network of pipes buried at reasonable depth below the ground surface. When air flows in the earth–air– pipes, heat is transferred from the air to the earth (Bansal *et al.*, 2009). Kumar *et al.*, (2003) stated that the magnitude of the heat exchange between air and pipe is dependent on factors such as, soil temperature, air temperature, pipe dimensions, air flow rate, pipe burial depth and soil and pipe thermal properties (density, heat capacity and thermal conductivity). Besides the thermal properties of the soil, the thermal properties of the tube are also important for the heat transfer from the air inside the heat exchanger to the soil surrounding the exchanger (Brake, 2008).

The other EAHE study conducted in Burkina Faso by Kintonou et al. (2008) examined the relationship between the tube length, tube diameter and the flow rate. The team concluded that a long, thin pipe and slower airflow in the tube allow better heat transfer between the soil and the air. De Paepe and Janssens (2003) reached a similar conclusion in 2003 when they studied EAHXs. However, De Paepe and Janssens also determined that arranging the tubes in a parallel sequence increases thermal performance by decreasing the pressure drop in the tube. Kintonou et al. (2008) concluded that the best EAHE for Burkina Faso would consist of two 17 m long tubes in parallel, buried 2.2 m underground, with a 90 m3/hr ventilator. Overall, the EAHE would cool the air in the tube by 10°C. The simple design of EAHE is shown in figure 2.5.

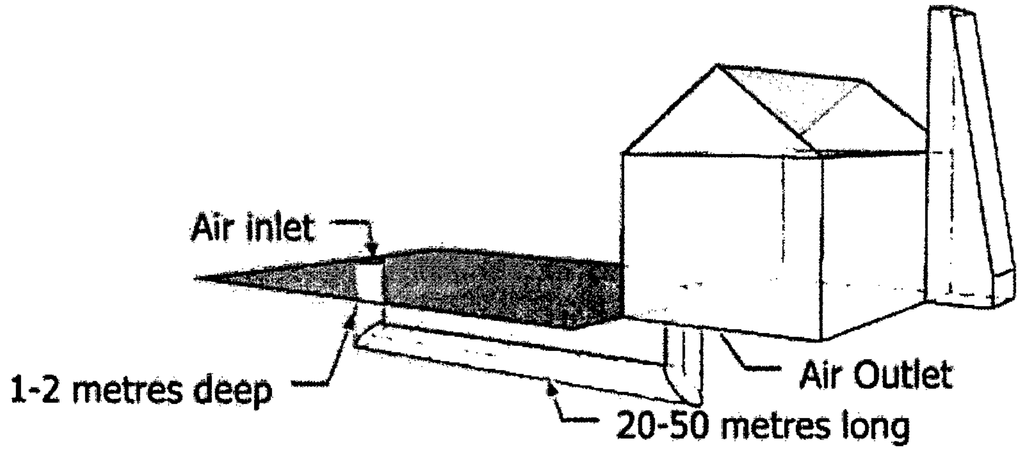


Figure 2.5: Diagram of simple EAHE (Source: Thomas *et al.*, 2012).

2.4.1 Parameter affecting thermal reduction

2.4.1.1 Type of soil

Abdul and Zairul (2012) conducted a study on EAHE using six types of soil. It is fine sandy soil, rough sandy soil, stone yellow soil, organic soil, loam soil and peat soil. From the results of experiment, the lowest thermal resistance of soil is organic soil, following the peat soil, loam soil, stone soil, fine soil and lastly is rough sandy soil. It can be concluded that the thermal resistance is inversely proportional with the thermal conductivity of and soil heat transfer. Increase of thermal resistance, the thermal conductivity and soil heat transfer will decreases accordingly.

Based on a model developed by Bansal *et al.* (1983), annual soil temperatures in New Delhi, India, at 4m depth remain relatively constant for various soil properties and surface conditions. However, significant differences existed among the constant values when different soil properties and surface conditions were selected. The constant temperature at 4m depth can be 17°C for wet shaded surface or as high as 52°C for dry glazed surface under the same climate. In other words, soil properties and surface conditions could have great effects on ETAHE thermal performance.

2.4.1.2 Diameter of pipe

A key factor in overall cooling capacity is the total surface area of EAHE. This can be increased by increasing the diameter or increasing the pipe length. However, increased diameter reduces air speed and heat transfer and greater length increases the pressure drop through the tube and increases fan energy. EREC (2002) noted that the correct design solution is a set of parallel pipes each with the proper diameter for best overall performance. IEA (1999) suggested that pipe with diameters between 150 mm and 450 mm appear to be most appropriate. It is supported by EREC (2002) that smaller tube diameters gives better thermal performance, but also larger pressure drop.

2.4.1.3 Arrangement of pipe

There are two types of EAHE system which are open loop EAHE (see Figure 2.6) and closed loop EAHE (see Figure 2.7). Min (2004) stated that in an open-loop system, outdoors air is drawn into the pipes and delivered to air handing units (AHUs) or directly to the inside of the building. Meanwhile, in a closed-loop system, interior air circulates through the EAHE. Abrams (1986) suggested that using a closed loop results in the best efficiency and reduces problems with humidity condensing inside the pipes.

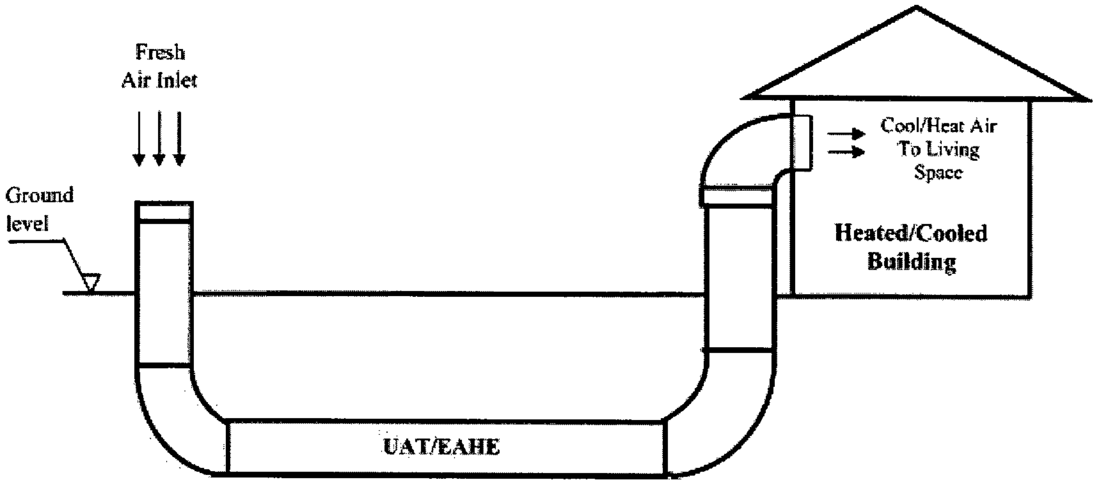


Figure 2.6: Schematic of open-loop EAHE (underground air tunnel).(Adapted from Ozgener, 2011)

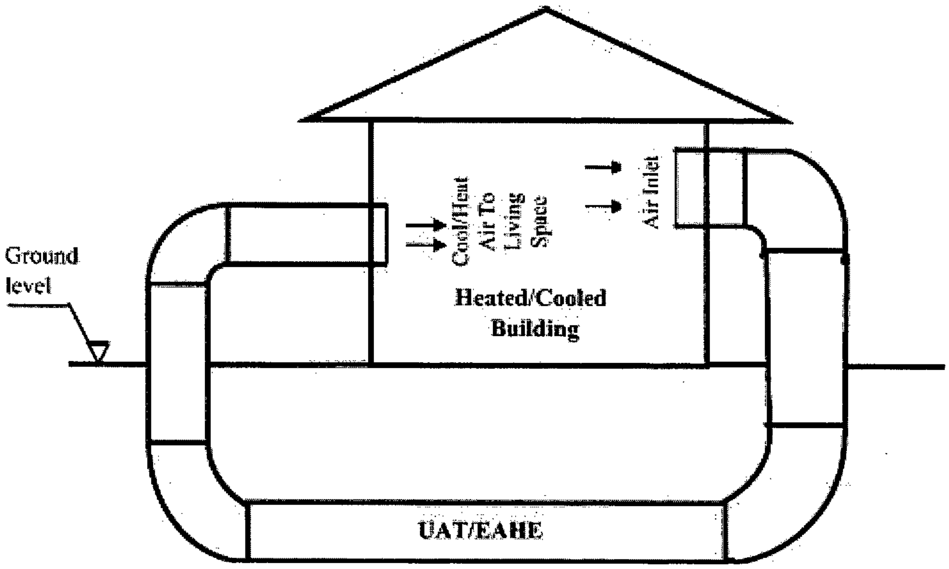


Figure 2.7: Schematic of closed-loop EAHE (underground air tunnel). (Adapted from Ozgener, 2011)

Depending on size of building, one may use more than one tube, buried in the ground parallel to each other to meet the given load requirements. According to De Paepe *et al.* (2003) the distance between pipes should be at least 1 m to prevent interference between the individual tubes. A study conducted by EREC (2002) shows that multiple small pipes optimize performance. This is supported by De Paepe *et al.*

(2003) that more pipes in parallel both lower pressure drop and raise thermal performance. However, IEA (1999) indicated that parallel 300 mm pipes typically offer the highest energy and cost efficiencies.

In India, Shukla, Tiwari and Sodha (2008) tested a closed-loop EAHE for an adobe house in New Delhi. In the summer, the EAHE cooled the room by 3°C, and in the winter, the EAHE heated the room by 6.5°C. Another researcher in India, Girja Sharan (2004), built several EAHEs, including an exchange for a zoo and a greenhouse. Goswami and Ileslamlou (1990) studied the performance analysis of a closed loop climate control system using underground air tunnel system.

2.4.1.4 Depth of pipe

The depth of pipe should be placed as deep as possible. According to Min (2004) the ground temperature fluctuates in time, but the amplitude of the fluctuation diminishes with increasing depth of the pipes. EREC (2002) studied that pipes should be buried at least 1.5 meters below grade, but only rarely is burying them more than 3.5 meters justifiable. In the first study (Ogou et al., 2008), a team tested the underground thermal gradient in Ouagadougou, Burkina Faso and modelled the cooling affects of a 30 m long EAHE buried 2 m underground. Over a two-day period, the team measured the soil temperature at 5 depths (0.4 m, 0.8 m, 1.2 m, 1.6 m and 2.0 m) and found that the soil temperature fluctuated between 30.6°C and 32.5°C at 2.0 m. In comparison, the outdoor temperature varied from 24°C to 40°C. They suggested that the best EAHE design for Burkina Faso would use 30 m of pipe (200 mm in diameter) and a volume flow rate of 245 m^3/hr. They predicted that the EAHE would cool the inside air by 5°C.

2.4.1.5 Material of pipe

The main considerations in selecting pipe material are cost, strength, corrosion resistance and durability (Min, 2004). Pipes made of concrete, metal, plastic and other materials have been used. Simulations indicate pipe material has little influence on performance. According to Abrams (1986), increasing the conductivity of the pipe to a value corresponding to that of aluminium increased total heat transfer by