IMPROVEMENT OF A SIVE EARTH AIR HEAT

NURFARAHIN BINTI SHARKAWI

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Faculty of Civil Engineering and Earth Resources
UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Global warming and the excessive emission of CO_2 due to human activities 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. In order to improve the level of thermal comfort, many air conditioning systems are designed. Earth Air Heat Exchanger (EAHE) is a device used to provide the cool or hot air into the building's interior by taking advantage through the soil thermal conductivity. However, the air quality drawn out from the EAHE system was not assured. The typical EAHE system usually prioritizes the cooling/heating effect of air rather than its quality. Apparently, there was no further studies were done yet to check on the quality of air from EAHE system. The objective of this thesis was to determine the quality of air drawn out from the EAHE system and how the use of filters helps in improving the performance of the air quality. A small scale model of EAHE was constructed which made up of a horizontal 2.5 m Polyvinyl Chloride (PVC) pipe buried 0.5 m underground and attached to an air blower/pump. The air blower was used to drive surrounding air into the buried pipe. A filter attachment consists of a green cotton filter was then attached to the outlet of the system. Additionally, filtration system was later further improved by adding activated carbon powder with the readily available filter to determine the improvement in the air quality of the EAHE system. The results indicated that a simple EAHE system can be constructed to reduce ambient temperature about 0.3°C. The temperature was further reduced to a maximum of 2.9°C with the addition of filter attachment. Furthermore, in the case of air quality dropped, the filter attachment improved the air quality supplied through the EAHE system up to 93% for all parameters considered. The use of EAHE system with activated carbon filtration system may significantly reduce temperature of the building's interior, economical, as well as improving the air quality drawn into the dwelling.

ABSTRAK

Pemanasan global dan pelepasan gas CO_2 yang berlebihan adalah disebabkan oleh aktiviti manusia yang menyumbang kepada peningkatan suhu di atmosfera bumi. Peningkatan suhu bumi mengakibatkan pengurangan dalam keselesaan terma. Bagi meningkatkan tahap keselesaan terma, beberapa jenis alat penyejuk udara telah diperkenalkan. Sistem pengudaraan penukaran haba bumi merupakan alat yang digunakan untuk membekalkan udara sejuk atau panas ke dalam bangunan melalui kekonduksian terma tanah. Bagaimanapun, kualiti udara yang dibekalkan oleh sistem pengudaraan penukaran haba bumi ini tidak diketahui. Kebiasaannya, sistem pengudaraan penukaran haba bumi lebih menitikberatkan kesan penyejukan/pemanasan udara dan bukannya kualiti udara yang dihasilkan. Tambahan pula, belum ada lagi kajian yang dilakukan untuk mengkaji kualiti udara bagi sistem pengudaraan penukaran haba bumi. Laporan ini dihasilkan bertujuan untuk menentukan kualiti udara yang dihasilkan dari sistem pengudaraan penukaran haba bumi dan bagaimana penggunaan penapis boleh membantu dalam meningkatkan kualiti udara. Model kecil bagi sistem pengudaraan penukaran haba bumi telah dibina, iaitu terdiri daripada paip Polyvinyl Klorida (PVC) sepanjang 2.5 m yang ditanam dengan keadaan mendatar dengan kedalaman sepanjang 0.5 m dan disertakan dengan blower/pam udara. Blower udara ini digunakan untuk membekalkan udara ke dalam paip yang ditanam. Penapis jenis kapas hijau telah disertakan ke dalam bahagian udara yang masuk ke dalam sistem. Sistem penapisan kemudiannya dinaiktaraf dengan menambah serbuk karbon teraktif di samping penapis kapas hijau untuk menentukan peningkatan kualiti udara dalam sistem pengudaraan penukaran haba bumi. Keputusan menunjukkan bahawa sistem pengudaraan penukaran haba bumi yang mudah boleh dibina untuk pengurangan suhu sebanyak 0.3°C. Suhu turut dikurangkan kepada jumlah yang maksimum iaitu sebanyak 2.9°C dengan adanya lampiran penapis. Tambahan pula, bagi kualiti udara yang menurun, lampiran penapis boleh membantu memperbaiki kualiti udara yang dibekalkan melalui sistem pengudaraan penukaran haba bumi untuk semua parameter yang dikaji sehingga 93%. Penggunaan sistem pengudaraan penukaran haba bumi dengan sistem penapisan karbon teraktif boleh mengurangkan suhu bangunan dalaman, ekonomi, serta meningkatkan kualiti udara dalam kediaman.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

°C	Temperature
CO_2	Carbon Dioxide

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BS	British Standard
EAHE	Earth Air Heat Exchanger
HEPA	High Efficiency Particulate Air
ISO	International Organizational for Standardization
NASA	National Aeronautics and Space Administration
PVC	Polyvinyl Chloride
VOC	Volatile Organic Compound
XRD	X-ray Diffraction

CHAPTER 1:

INTRODUCTION

1.1 INTRODUCTION

A range of human activities, such as the burning of fossil fuels, industrial activities and the cutting down of forest for agricultural purposes and urbanization, are substantially escalating the concentrations of greenhouse gases in the atmosphere, thereby upsetting the atmospheric chemical balance (Aizebeokhai, 2009). The earth's atmosphere creates natural greenhouse effect which keeps the earth's surface warmer. The warm temperature in the earth was caused by mainly global warming and the excessive production of carbon dioxide (CO_2) gas. These events thus lead to the thermal comfort requirements and cooling energy demand for residential buildings (De Paepe and Janssens, 2002).

Cultural differences and traditions contributed in the development and usage of building materials apart dictating architectural design and landscaping (Sulaiman and Rodzi, 2008). One of the significant objectives of designing buildings was to ensure the thermal comfort to its occupants. Thermal comfort was defined as the state of mind which expressed satisfaction with the thermal environment (ISO 7730). Thermal comfort referred to as a condition of mind that was satisfied with its thermal environment whereas the term thermal environment refers to the surrounding environment within which the subject operates or lives in.

As to increase the thermal comfort and reducing the temperature, traditional cooling and heating system may be sufficient due to the availability. Appliances such as cooling fan, ventilators and air conditioners were preferred to maintain a thermally comfortable indoor environment (Sulaiman and Rodzi, 2008). Buildings, residential or offices mainly use energy to obtain comfort for its inhabitants. Some strategies for urban areas and buildings can provide natural ventilation and save energy. Natural ventilation was the most effective passive cooling technique that can provide cooling during both day and night, while night ventilation was a very effective strategy in hot climates (Asimakopoulos *et al.* 2001). Sulaiman and Rodzi, (2008) stated by that there were five concepts for cooling strategy and four concepts for day lighting strategy, which were:

The cooling strategy:

i. Solar control: Protection of the building from direct solar radiation.
ii. Ventilation: Expelling and replacing unwanted hot air.
iii. Internal gain minimization: Reducing heat from occupants, equipments with an artificial lighting.
iv. External gains avoidance: Protection from unnecessary heat by infiltration or conduction through the envelope.
v. Natural cooling: Improving natural ventilation by acting on the external air.

The day lighting strategy:

i. Penetration: Collection of natural light inside the building.
ii. Distribution: homogeneous spreading of light into the spaces or focusing.
iii. Protect: Decreasing by external shading apparatus the sun's rays infiltration into the building.
iv. Comfort: Control light penetration by movable screens to avoid discomfort. Ventilation was necessary for ensuring a good indoor air quality and also has a prevailing impact on energy consumption in buildings.

Nicol (2007) stated that a proper and precise description of the interior climate was vital in determining the efficiency of a building as it will not only ensure the comfort of its occupants but also affected the energy consumption and its sustainability. It was evident that urban areas without high climatic quality consumed more energy for air conditioning during warmer season and even more electricity for lighting appliances (Bitan, 1992). Following these consequences, a new system of more efficient, environmentally safe, and more durable was needed to replace the current system. Additionally, energy has become more expensive and will continue to be so, to a level that optimal use of resources has become a primary concern today (Sigrimis and Rerras, 1996). To optimize the energy consumption of buildings, several passive techniques were nowadays introduced. Commonly, solar energy was directly or indirectly used to supply electrical energy. Sometimes solar gains inside the building were prevented as to lessen the number of air conditioning unit. In most cases, several passive measures were combined (Zhao, 2004).

Air cooling or/and heating in Earth Air Heat Exchanger (EAHE) was introduced for reduction of ventilation heat loss and for improvement of thermal comfort in a building (Pavel, 2008). EAHE also contributed in the lowering of energy consumption. EAHE was a system that allowed 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 (Sharan, 2004). Solar energy may be fully utilized with the EAHE. Tubes or pipes were buried inside or into the ground, through which air is drawn (Zhao, 2004). Due to the high thermal inertia of the soil, the temperature fluctuations at the ground surface exposed to the exterior climate were damped deeper in the ground. Further a time lag occurred between the temperature fluctuations in the ground and at the surface. Hence at a sufficient depth, the ground temperature would be lowered than the outside air temperature whereas the air was thus cooled in warmer surroundings and heated in cooler surroundings (Santamouris, 1996).

Ghosal and Tiwari (2004) found that increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe, and increasing depth of ground up to 4 m were the parameters controlling greenhouse air temperature using the EAHE. Bansal *et al.* (2010) investigated the performance analysis of EAHE for summer cooling in Jaipur, India using 23.42 m long and 2–5 m/s flow rate for steel and PVC pipes achieved cooling in the range of 8.0–12.7°C. The research proved that performance of system was not significantly affected by the material of buried pipe instead it was significantly affected by the velocity of air fluid (Chel, 2010; Tiwari, 2010).

Nonetheless, it was found from the literatures that there were conflicting reports on air quality in EAHE. In the literatures, the natural ventilation systems seemed to be an alternative; however their driving forces, i.e. wind and/or buoyancy cannot always deliver pleasing airflow rates (Jian, 2005; Fariborz, 2005). Some subject to the matters, while some assuring that air quality does not seemed to be a problem, with conditions: the system was properly designed, installed, operated and constantly undergone maintenance. Formal research indicated that EAHE decrease building ventilation air pollution (Kriesi, 2011). Rabindra (2004) stated that the EAHE was found not to support the growth of bacteria and fungi thus making the air safer for humans to inhale. It resulted that the use of EAHE not only helped save the energy but also helped to reduce the air pollution by reducing bacteria and fungi.

Since the pollutants exist in the indoor environment, it was vital to intake a certain amount of fresh air, but the fresh air volume standards will have a direct impact on the indoor air quality control. Moreover, the level of the new air load played an import role on the building thermal environment quality and building energy conservation (Sun and Xu, 2011). Studies by Health Canada (1987) suggested that CO_2 concentrations above 1800 mg/m3 (1000 ppm) were suggestive that there was a scarce supply of fresh air, although complaints have been documented at concentrations as low as 1100 mg/m3 (600 ppm). Besides lowering the surrounding temperature and reducing the usage of air conditioning units, the air quality of the EAHE should be taken into consideration.

1.2 PROBLEM STATEMENT

Global warming and the excessive emission of CO_2 due to human activities 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. In order to improve the thermal comfort inside the buildings' interior, the usage of appliances such as cooling fans, ventilators, and air conditioners were chosen. However, the usage of these appliances contributed to the energy consumption as well as the electricity costs. Therefore, to overcome this problem, EAHE system was introduced. This system is capable of reducing the temperature inside the buildings' interior, reducing the emission of CO_2 gas as well as reducing the installation of air conditioning units. The system also contributes in the lowering of the energy consumption and also the electricity costs. However, the quality of air from the system was not known. Thus, this study was done to determine whether there is improvement in the air quality performance of the EAHE system with filters attached to the system.

1.3 SCOPE OF STUDY

This study is to analyze the performance of air quality drawn from the EAHE system. A pilot scale model was designed to perform the analysis; by utilizing a straight pipe, where the filters were attached at the air outlet, while the air blower was equipped at the air inlet. This is the basic design for EAHE system. Polyvinyl Chloride (PVC) pipe was used of 2.50 m in length and it was buried in 0.50 m depth in the soil. The pipe for the EAHE model was required to satisfy the following conditions; a uniform internal/external diameter in the axial direction (20 mm); surrounding soils (original soil) were homogeneous and its thermal conductivity was constant in value; soil temperature near the pipe was not influenced by the pipe, so the surface temperature of the pipe was uniform in the axial direction; and convective flow inside the pipe was thermally and hydro-dynamically developed. The filters used were of two types: (1) Green cotton filter without activated carbon, (2) Green cotton filter attached with activated carbon. Measurements will be taken to determine the quality of air drawn from the EAHE system. The quality of air was measured by the multi-gas detector equipment which was able to present and calculate the amount of various gases in the surrounding air. The EAHE model was installed at the vacant land site located behind Block W of Universiti Malaysia Pahang (UMP), Gambang. The study was scheduled from the early of February 2013 until the end of June 2013. The aspects looked into were the efficiency of those filters to improve the air quality drawn out, by providing air defilement at the air inlet of the EAHE system.

1.4 OBJECTIVES OF STUDY

1) To investigate the performance characteristics of the EAHE for the effect of cooling for buildings' interior temperature;
2) To gain insight into the air quality performance of the EAHE system, and
3) To determine the improvement of air quality for a passive Earth Air Heat Exchanger (EAHE) system.

1.5 THESIS LAYOUT

This thesis consists of five consecutive chapters. Chapter 2 presents the literature reviews conducted related to the study undertaken. This chapter includes global warming, thermal comfort, cooling application, energy consumption of EAHE, air quality and activated carbon filter.

Chapter 3 is methodology. This chapter explains the methodologies adopted in this study. This chapter covers all steps and procedures required for the site preparation, determination of soil properties (specific gravity, initial water content, Atterberg limit, particle size distribution and soil mineral properties), design of the EAHE model and main testing.

Chapter 4 consists of results and discussions obtained from the study. This chapter includes the results obtained through the series of tests done in the determination of soil properties which consist of specific gravity, particle size distribution, initial water content, Atterberg limit, the particle size distribution and also soil mineral properties. This chapter also covers the results obtained from the main tests and the discussions related to the results obtained from the study.

Chapter 5 is the conclusion and recommendations. This chapter summarizes the whole purpose of this study and also the recommendations for the future works in improving the results obtained.

CHAPTER 2:

LITERATURE REVIEWS

2.1 GLOBAL WARMING

Aizebeokhai (2009) stated that the human activities such as burning of fossil fuels, urbanization and industrial activities and deforestation leads to the increasing concentration of the greenhouse gases in the earth atmosphere. This thus contributed to the global warming and also climate changes.

Global warming is interrelated to the climate changes. As stated by The National Aeronautics and Space Administration (NASA), climate change was defined as the shift in long-term, global weather patterns due to human action. Climate change includes any change regardless warming or cooling of temperature resulting from different factors, like deforestation or an increase in greenhouse gases. Global warming was one type of climate change, and it referred to the increasing temperature of the surface of Earth. Since 1880, the average surface temperature of the Earth has increased by roughly 0.9 degrees Fahrenheit, but its increasing rate was faster than that, depending on the topographical location (Bernabo, 1987). Figure 2.1a shown below the rate of emission of CO_2 gas in the past years.

Greenhouse gases also contributed to the greenhouse effect, an overall warming of the Earth as atmospheric gases trap electromagnetic radiation from the sun that would otherwise have been reflected back out into space (NASA). Some greenhouse gases were produced in natural processes, like forest fires, animal manure and respiration, or volcanic eruptions. However, the majority of new greenhouse gases were produced from industrial processes and energy production. The major greenhouse gases are consisting of carbon dioxide (CO_2), methane (CH_4), ozone (O_3), water vapour (H_20), nitrogen oxide (N_2O), and chlorofluorocarbons (CFCs). The atmospheric concentrations of greenhouse gases were significantly affected the global mean climate (Cangialosi, 2003). These gases were thought to affect the climate directly and indirectly with the exception of the water vapour, even though they constitute to only a small fraction of gases that make up the atmosphere over the last 10 to 100 years (Bernabo, 1987). Currently, NASA stated the composition of the atmosphere was mostly nitrogen and oxygen, with just 0.033 percent carbon dioxide and all other gases accounting for even less (Figure 2.1b).

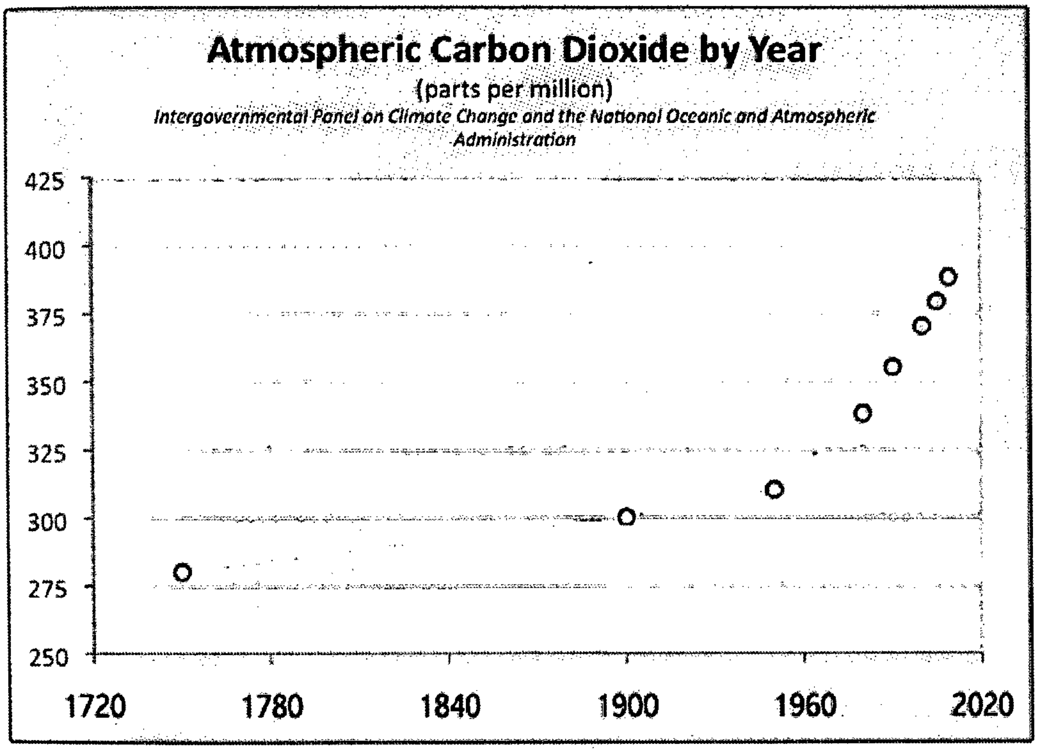

Figure 2.1a: Rate of Carbon Dioxide (CO_2) gas

Source: NASA (2010)

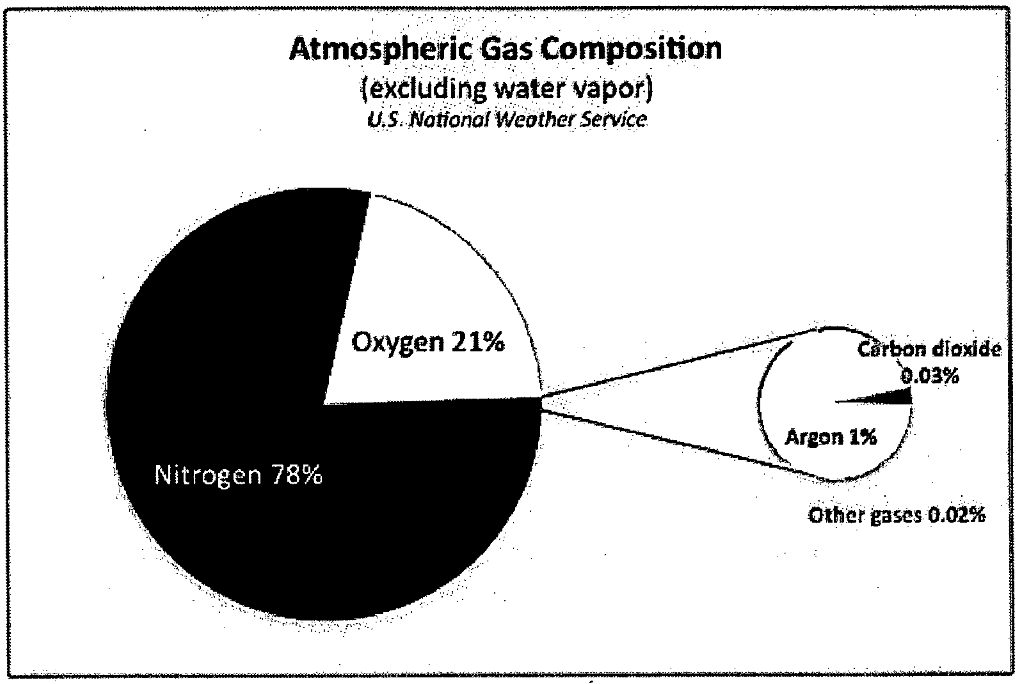

Figure 2.1b: Atmospheric Gas Composition

Source: NASA (2010)

2.2 THERMAL COMFORT

Due to the increasing of the earth temperature, the requiring needs of the thermal comfort were increasing. Sulaiman and Rodzi, 2008 studied that climate and man in both indoor and outdoor areas were interrelated. By means, the thermal comfort plays a significant role in making an area inhabitable and well adapted for daily existence.

An internationally-accepted definition of thermal comfort as used by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), was that condition of mind which expresses satisfaction with the thermal environment (ISO 7330). The thermal comfort were mainly affected by air temperature, radiant temperature, relative humidity, air velocity, activity and clothing. Thermal comfort can also be defined as the search into the comfort levels of individuals in an environment that is familiar and under control, is conducive to comfort and makes people less sensitive to temperature (Oseland, 1995).

However, the effects of the global warming and climate changes can be modified by the use of various controls. The means of controlling the internal environment were usually available to building occupants. In naturally ventilated buildings, greater control over thermal environment and ventilation could be obtained by using common means of control such as the opening or closing of windows, doors, blinds, fans, thermostat adjustments and to some extent lights. The control over lighting and direct solar gain depends on the individual's control over the use of light switching and blinds (Raja; Nicol; McCartney; Humphreys, 2001).

Apart from the natural ventilation method of windows, doors and mechanical ventilation, the cooling appliances such as fan, exhaust fan and air conditioner unit were also approached. It was found that the usage of cooling applications were capable in increasing the thermal comfort as the temperature of the earth increasing.

2.3 COOLING APPLICATION

Cooling applications were widely used as they are cheap and capable of lowering the warmer temperature as well as improving the thermal comfort (Krzaczek and Tejchman, 2012). Some of the cooling appliances included were fan, mist cooling fan, and also air conditioners unit.

Fans were portable and came in a variety of shapes, sizes and features of being a table or floor model that oscillated. The oscillating feature was ideal as it enables a wider and better coverage of the room area and creates a breeze effect that can be felt in different corners of the room. The typical fans were upgraded to improve its performance in cooling the air flow. Mist or water vapour elements were added to the fans to provide more humidity to the air flows. This type of fan was usually used for the outdoor activities as it able to cover a large portion of areas.

Another cooling appliances widely used were air conditioners unit. The principle of air conditioning was to absorb energy in one place and release it in another place. The process requires an indoor unit, an outdoor unit and copper piping to connect both. Through the piping the refrigerant flowed from one unit to another. It was the refrigerant that absorbed the energy in one unit and releases it in the other. This process resulted in the heat inside the room being absorbed, and this means that the room is steadily cooled.

However the usage of these appliances consumed a lot of electricity. Almost 100% of the electricity was contributed by the usage of air conditioners unit (Bitan, 1992). It was apparent that urban areas without high climatic quality used more energy for air conditioning during heat and even more electricity for lighting purposes. This thus led to the installation on the EAHE system as the approach to cool the temperature besides reducing the electricity costs and energy consumption.

2.4 ENERGY CONSUMPTION

Proper and precise description of the interior climate was vital in determining the efficiency of a building as it was not only to ensure the comfort of its occupants but also affected the energy consumption and its sustainability (Nicol, 2007). Hence to overcome the increasing energy consumption, the current system was in urgency of being replaced by a more efficient system, but with economical aspect. Occasionally, energy has become more expensive and will continue to be so, to a level that optimal use of resources has become a primary concern today (Sigrimis and Rerras, 1996). To optimize the energy consumption of buildings, several passive techniques are nowadays introduced. Sometimes solar gains inside the building are prevented as to reduce the number of air conditioning unit. In most cases, several passive measures are combined (Zhao, 2004). Thus, a new method was introduced. Air cooling or/and heating in EAHE is introduced for reduction of ventilation heat loss and for improvement of thermal comfort in a building (Pavel, 2008). EAHE also contributes in the lowering of energy consumption. Thus stating that EAHE was capable of providing cooling effect into the building's interior as well as contributed in the lowering of the energy consumption.

2.5 EARTH AIR HEAT EXCHANGER (EAHE)

EAHE was a system that allowed 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 (Sharan, 2004). Solar energy can be fully utilized with the EAHE system. Tubes or pipes were buried inside or into the ground, through which air is drawn (Zhao, 2004). Due to the high thermal inertia of the soil, the temperature fluctuations at the ground surface exposed to the exterior climate were damped deeper in the ground. After a long time, the temperatures were fluctuated between the ground and at the surface. Hence at an adequate depth, the ground temperature will be lower than the outside air temperature whereas the air was thus cooled in warmer surroundings and heated in cooler surroundings (Santamouris, 1996).

There are also others factors affecting the efficiency of the EAHE system. Ghosal and Tiwari (2004) found that increasing pipe length, decreasing pipe diameter, decreasing mass flow rate of flowing air inside buried pipe, and increasing depth of ground up to 4 m are the factors involved in controlling the temperature using the EAHE. Bansal *et al.* (2010) investigated the performance analysis of EAHE for summer cooling in Jaipur, India using 23.42 m long and 2–5 m/s flow rate for steel and PVC pipes achieved cooling in the range of 8.0–12.7°C. The research proved that performance of system was not significantly affected by the material of buried pipe instead it was greatly affected by the velocity of air fluid (Chel, 2010; Tiwari, 2010).

Apparently, there were two different types of EAHE: the first type was with the air flowing inside the tube and the second type was with brine. A brine-ground heat exchanger operated in the same mode as the typical EAHE system and it was another option to preheat the ventilation air in the polluted areas. The system functioned by circulating the water inside the pipe/tube by using a pump that absorbed heat from the ground and then it entered a water-air heat exchanger. Inside the EAHE system, the energy accumulated by the circulating water was delivered to the ventilation air. For EAHE of this type, the length of the thermal channel was usually half of the air volume flow (Schwatzenberger, 2008).

However, it was found that there were contradictory reports on air quality in EAHE. In the literatures, the natural ventilation systems seemed to be an option; but their driving forces, i.e. wind and/or buoyancy cannot always deliver a pleasing air flow rates (Jian, 2005; Fariborz, 2005). Some subjected to the matters, while some assuring that air quality drawn from the EAHE does not seemed to be a problem, with circumstances, that the system was properly designed, installed, operated and constantly undergone maintenance. Formal research stated that EAHE minimized building ventilation air pollution (Kriesi, 2011). This was proved by Rabindra (2004) who stated that the EAHE was found not to support the growth of bacteria and fungi thus making the air safer for humans to inhale. This shows that the use of EAHE not only helped to save the energy but also helped to lessen the air pollution by reducing bacteria and fungi. Besides lowering the surrounding temperature and reducing the usage of air conditioning units, the air quality of the EAHE should be taken into consideration.

2.6 AIR QUALITY

Since the pollutants were abundant in the indoor environment, it was vital to intake a certain amount of fresh air, but the fresh air volume standards will consequence towards the indoor air quality control. Moreover, the level of the new air load played an import role on the building thermal environment quality and building energy conservation (Sun and Xu, 2011). Studies by Health Canada (1987) suggested that CO_2 concentrations above 1800 mg/m3 (1000 ppm) meant that there was an inadequate supply of fresh air, although there are complaints documented with concentrations as low as 1100 mg/m3 (600 ppm).

Flueckiger (1999) in his study of twelve EAHE varying in design, pipe material, size and age, stated that this study was performed because of concerns of the potential microbial growth in the buried pipe of the system. The results however demonstrated that no harmful growth occurred and that the airborne concentrations of viable spores and bacteria, with few exceptions, even decreased after channel through the system. He also mentioned that, based on these investigations the operation of EAHE was acceptable as long as regular controls were undertaken and if appropriate cleaning facilities were available.

According to the literature (Canadian Mortgage and Housing Corporation, 2011) properly conceived system will include smooth tubes possibly with anti-microbial coating, a sloping design collecting, tight joints, and proper filters at the air intake. Air will not be left sluggish in the tubes, and the filters will be replaced regularly. By fulfilling those requirements, the air of good quality was sure to have been delivered to the buildings' interior. Nevertheless, this may be contributable to a proper filtration system more than the fact that air was being drawn through an EAHE.

2.7 ACTIVATED CARBON FILTER

Activated carbon was a crude carbon which has only a few pores or holes, due to the original structure of the carbonaceous material. During activation, the black grains or carbons become lighter in weight and reduces in size. The more highly activated the carbon, the greater the surface and pore volume. It has been known since ancient times that carbon has the ability to purify air and water (Sontheimer; Crtittenden; Summers; Hubele; Roberts; Snoeyink, 1988). Ordinarily carbon, as normally produced, possessed to a slight degree the power to adsorb and hold contaminating materials. But by high temperature steam activation, the process employed in the manufacture of activated carbon, the adsorption capacity was increased a hundredfold or more (Marsh and Reinoso, 2006).

Activated carbons were chosen as it was high of potential environmental and energy benefits for air cleaning in ventilation systems (Sidheswaran; Destaillats; Sullivan; Cohn; Fisk, 2011). The parallel aims for the air cleaning system were to enable reduced indoor exposures to volatile organic compounds (VOCs) and to simultaneously allow reduced rates and energy consumption for outdoor air ventilation.

2.7.1 ADSORPTION PROPERTIES

Activated carbon cleaned and purified the air and gases through adsorption process (Ruhl, 1993). Adsorption involved a physical phenomenon which permitted the removal of contaminants from gases and liquids. The molecules of the contaminant were trapped and held by the internal surface of the adsorbent. Adsorption was a physical action based on molecular forces (Yu-Chun; Pen-Chi; Chin-Pao, 2001). When an air, gas or liquid containing impurities was brought into contact with it, the activated carbon attracted and held the impurities on its internal surfaces. Tsai (2004) stated that the degree of adsorption depended on the relationship between the carbon pore structures and the size and shape of the contaminating molecules.

Vanderborght and Grieken (1977) mentioned that the adsorption process was done by either moving the fluid (gas or liquid) through the carbon or moving the carbon through the fluid. The carbon can be used in either a fixed or moving bed. It can be contained in standard filter cells or packed into adsorber vessels or towers. The pollutants were adsorbed by the carbon grains which increased in weight by the amount they adsorbed. This continued until the capacity of the carbon was reached and then the pollutants were no longer adsorbed but were passed through the bed. At this point or before, the carbon must be replaced or reactivated.