EARTH-TO-AIR HEAT EXCHANGER SYSTEM SIMULATION STUDY FOR IIUM GOMBAK

BY

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A dissertation submitted in fulfilment of the requirement for the degree of Masters of Science in Building Services Engineering

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ABSTRACT

This study elucidates the usage of the Earth-to-Air Heat Exchanger (EAHE) system. The emphasis is on replacing the conventional air conditioning systems with the EAHE technology, as low energy cooling system for residential and commercial buildings in Malaysia. The turnover in the usage will contribute to reducing electric-energy consumption and minimize environmental impact caused by the high usage of electrical appliances for cooling in the buildings. The EAHE technology uses simple methods of transferring the air from its intake into the ground through a pipe, and it releases the air from its outlet into a building or a room. The air travels through the pipe and gives away some heat to the surrounding underground soil, and then enters into the room as cool air. To fulfill the requirements of the empirical investigations, this research utilized the EnergyPlus program to simulate the EAHE system, based on ASHRAE weather database and data collected in previous field studies at the IIUM Gombak Campus, Kuala Lumpur, Malaysia. This study went through some meta-analysis and observations on the cooling potential (ΔT) which represents the difference between ambient air temperature (T_{am}) and pipe outlet air temperature (T_{po}). The research also observed the influence of other factors such as pipe diameter, air velocity, pipe-depth, and pipe-length on the cooling potential (ΔT). The simulation results showed that, the maximum (ΔT) achieved by utilizing the EAHE was 3.57 °C at 2:00 pm. The PVC pipe is required to achieve the aforementioned reduction of 0.075 m (3 inches) in diameter, 50 m long, and placed 1.0 m deep underground, with an air velocity of 1 $m.s^{-1}$.

ملخص البحث

إنّ هذه الدراسة تسلط الضوء على استخدام نظام المبادل الحراري من الأرض إلى الهواء (EAHE)، وينصب تركيز الدراسة على استبدال أنظمة تكييف الهواء التقليدية بتكنولوجيا EAHE كنظام التبريد للمباني السكنية والتجارية في ماليزيا. يسهم هذا النظام المستخدم في الحد من استهلاك الطاقة الكهربائية ويقلل أيضاً من التأثير البيئي بسبب استخدام المفرط للأجهزة الكهربائية للتبريد في المباني. يستعمل التكنولوجيا EAHE أساليب بسيطة لنقل الهواء من مدخله إلى الأرض خلال أنابيب ويحرر الهواء من مخرجه إلى داخل المبنى أو الغرفة. عندما ينتقل الهواء عن طريق الأنبوب يفقد بعض الحرارة إلى التربة المحيطة بها تحت الأرض، ثم يدخل إلى الغرفة كهواء باردٍ. وللتغلب على متطلبات التطبيقات التجريبية، يستخدم هذا البحث برنامج EnergyPlus ليحاكي (simulate) نظام EAHE. استناداً إلى قاعدة بيانات الطقس ASHRAE والبيانات التي تم جمعها في الدراسات الميدانية السابقة في حرم الجامعة الاسلامية الدولية، في كومباك، كوالا لمبور، ماليزيا. وقد مرت هذه الدراسة على بحوث واستنتاجات ودراسات سابقة حول تأثير تبريد (ΔT)، الذي هو الفرق بين درجة حرارة الهواء المحيط (T_{am}) ودرجة حرارة الهواء الخارج من الأنبوب (T_{po}) . وقد لاحظ البحث أيضا تأثيرات أخرى مثل قطر الأنبوب، وسرعة الهواء، وعمق الأنبوب، وأخيراً طول الأنبوب على تأثير التبريد (ΔT). ونتائج المحاكاة (simulation) تبينت أن الحد الأقصى لـ ΔT المكتسبة من EAHE كان ٣,٥٦ درجة مئوية عند ٢,٠٠ مساء. فالأنبوب البلاستيكي اللازم للحصول على درجة الانخفاض المذكورة سابقاً يكون بقطر ٠,٠٧٥متر، وبطول ٥٠ متر وعمق متر واحد تحت الأرض مع سرعة الهواء ١ متر/ ثانية.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Building Services Engineering.

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Md. Najib Ibrahim
Supervisor

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Science in Building Services Engineering.

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Maisarah Ali
Examiner

This dissertation was submitted to the Kulliyyah of Architecture and Environmental Design and is accepted as a partial fulfilment of the requirements for the degree of Master of Science in Building Services Engineering.

….....
Khairuddin Abdul Rashid
Dean, Kulliyyah of
Architecture and
Environmental Design

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Soran Hama Aziz Ahmed

Signature …… Date ……..

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DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

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Signature Date

To My Beloved Wife Talar

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ρ_s	soil density, kg/m^3
$c_{p,s}$	soil specific heat capacity, J/(kg·°C)
t	time, day
z	ground depth, m
k_s	soil thermal conductivity, W/(m.°C)
$T_{s,m}$	annual mean ground temperature, °C
T_s	ground temperature, °C
A_s	amplitude of daily mean ground surface temperature in a year, °C
t_0	phase constant since the beginning of the year of the lowest average ground surface temperature, day
α_s	soil thermal diffusivity, m^2/day
T_{am}	ambient temperature, °C
T_{po}	pipe outlet air temperature, °C
$T_{z,t}$	the temperature at any depth (z) and time (t) , °C
ΔT	$(T_{am} - T_{po})$, °C
$T_a(y)$	air temperature inside the tube at the distance y from the tube inlet, °C

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The electric energy consumption has become a challenging issue in the world. Most probably because the electricity production increases the greenhouse gas (GHG) emission which is considered as main reason for global warming. Apart from these concerns, overpopulation is also creating pressures to produce more electricity. These issues have to be overcome by exploring of new energy sources, and to review the old non-efficient energy production methods. The old power plants are rapidly removed and replaced by new and more efficient plants. The attention is shifting toward using natural energy has also gradually taking into consideration. Moreover, efficient use of energy and reduction in consumption of electricity, and environmental concerns are pushing the trend to change and bring new methods to the usage of energy as well.

The Earth-to-Air Heat Exchanger (EAHE) is an air conditioning system that is designed to process the air from one end (intake) to another (supply) through a pipe placed underground. This process also requires air blower (probably a fan) that stimulates air with pressure to move from one end to another (Sanusi, 2012). One end of the pipe is opened at the ambient place for air intake, while the other end is placed at the space that needs cold air. This technology uses earth to bring changes into the air temperature and heat drops when the air channels from ambient intake passes through buried pipe and ejects to the other side with a lower temperature.

Using Earth-to-Air Heat Exchanger as a cooling system for offices and residential houses and other buildings will greatly contribute in reducing the electric

energy consumption. As a result, those negative impacts on environment caused by electric air-conditioning systems in buildings will be reduced.

The EAHE system is not a new practice. And there are many of literature available in this area (see Mihalakakou et al.,1995; Santamouris , 1995; Min, 2004; Al-Ajmia F., 2006; Ghosal M.K. and Tiwari 2006; Kwang and Richard K, 2008; Jian, 2009; Gyuyoung et al., 2009; Fabrizio Ascione et al., 2011). The fact is that the system is not been commonly practiced in the developed or even developing countries. This system is not practiced in Malaysia as well. Since the system is very environment friendly cooling system and consumes very low electricity (i.e. running fan only), this study aims at exploring the system parameters that provide optimum performance under different conditions.

1.2 BACKGROUND

Electrical energy is the main source being that operate equipment that bring comfort in many buildings with pleasing temperature and light level. Be it residential (house/apartment) or commercial buildings, energy is considered as main source to foster comfort equipments (including all those using electricity). In tropical climates, air conditioning is widely employed in both residential and commercial buildings to provide comfortable room temperature. The cool temperature can easily be achieved by vapour compression air-conditioning equipments, but due to depletion of the ozone layer caused by chlorofluorocarbons (CFCs) and also because of the need to reduce high usage of electric energy consumption, several alternatives techniques are currently being explored and utilized. One the alternative is the Earth-to-Air Heat Exchanger (EAHE) system. It uses soil as a heat sink and air to transmit the heat while passing through the medium (pipe) towards other space that requires the cooling.

Because of the high thermal inertia of the soil, the air temperature differs from inside the ground and surface exposed to the exterior climate. Therefore at a sufficient depth the ground temperature is lower than the outside air temperature in summer and higher in winter. In tropical region, the ground temperature that comforts the human ranges from 27°C to 29°C. Naturally, the temperature in the underground differs from that above the ground. Thus stable and comfortable environment of the ground at the depth of 4-5m can be used to create thermal comfort conditions in living spaces (Sawhney, et al., 1999). This is due to a large thermal mass of earth provides a very stable thermal condition, even if a large amount of heat is discarded or withdrawn from these depths.

The application of earth as a component of the cooling system can be employed through three different methods: the *direct*, *indirect*, and *isolated* method (Min, 2004). In the direct system, the building is surrounded with the earth, and air conduction is through the building elements (primarily walls and floor) that regulate the indoor temperature of particular place. In the indirect system, the building interior is conditioned by air brought through the earth using techniques, such as Earth-to-Air heat Exchanger (EAHE). The isolated system uses earth temperatures to increase the efficiency of a heat pump by moderating temperatures at the condensing coil. A geothermal heat pump is an example of an isolated system. This study focuses on the cooling systems carried-out though indirect method system.

In indirect systems, i.e. Earth-to air-heat exchanger (EAHE), metal or plastic pipe is placed in the ground through which air passes (see Figure 1.1). During cooling season, as air travels through the pipe, it consumes some of its heat into the surrounding soil and enters the room at different temperature that cools the room. Similarly, during winter season, the air travels through the pipe and receives heat from

the soil and enters the room with warm air (Mihalakakou et al., 1995; Santamouris, 1995; Min, 2004; Al-Ajmia, 2006; Ghosal and Tiwari, 2006; Kwang & Richard, 2008; Jian, 2009; Gyuyoung et al., 2009; Fabrizio et al, 2011).

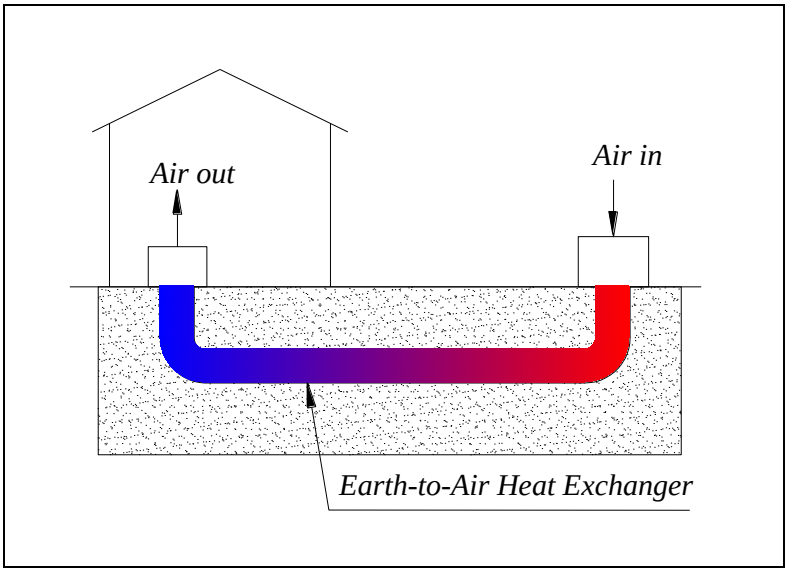

Figure 1.1: Building with an Earth-to-Air Heat Exchanger

According to the literature, there are different names given to this system. Each has its own description, for instance, Sanusi (2012) calls this the earth-to-air heat exchanger as Earth-pipe cooling technology, Kwang and Richard (2008) calls Earth-tube system, Earth-air-pipe system (EAPS) by Huijun (2007), Earth-tube heat exchanger (ETHE) by Miroslaw et al., (2011), Underground air pipe air conditioning system by Sawhney et al., (1999), and Buried-pipe systems by Hollmuller & Bernard (2000). Previous researchers have studied various aspects of Earth-to-air heat exchanger. The system studied and applied on different climates in different part of the world. For instance, Al-Ajmia et al., (2006) observed in a hot arid temperature

climate in Kuwait, Kwang & Richard (2008) in the United State of America at four different locations: Spokane, Washington (mild and dry); Peoria, Illinois (mild and wet); Phoenix, Ausa (hot and dry); and in Key West, Florida (hot and wet). Fabrizio et al., (2011) observed in different Italian climates and Sanusi (2012) in Malaysian tropical climate (which is hot and wet). Darkwa (2011) observed a typical hot and humid location in Ningbo-China, Ghosal and Tiwari (2006) in Delhi, India. Vikas et al., (2010) in dry climate of the Western India Ajmer, Min (2004) in Montreal-Canadian climate which is practically always warm and humid, Hollmuller and Bernard (2000) in cold central European regions.

Another aspect of EAHE is the study of cooling performance of the systems. However many researchers (Al-Ajmia et al.,2006; Rakesh et al.,2003; Vikas et al.,2010; Trombe A. et al.,1991; Huijun Wu et al., 2007; Miroslaw et al., 2001; Darkwa et al.,2011. Fabrizio Ascione et al.,2011; Gyuyoung et al.,2009; Darkwa et al., 2011; Sawhney et al., 1999) studied the system that concerned with HVAC system as a pre cooling or heating for intake fresh air.

Additional to that, many others (Trombe et al.,1991; Santamouris et al.,1995; Sawhney et al.,1999; Hollmuller et al.,2000; Ghosal et al.,2006; Gyuyoung et al., 2009; Ghosal et al.,2004; Vikas et al., 2010; Fabrizio Ascione et al.,2011) have studied the system which can be implemented in building or greenhouse. Using soil as a main component of the system (the EAHE) is investigated as potential source by Al-Ajmia et al., (2006); Jacovides et al., (1995); Sanusi (2012); and Min (2004). In addition, Rakesh et al., (2003); Vikas et al., (2010); Darkwa et al., (2011); Fabrizio et al., (2011); and Kwang et al., (2006) studied the performance of this system and its capability to an energy conservation.

The study on parameters, such as pipe and its diameter, pipe length, pipe material, depth of buried pipe, and air flow rate or velocity is another aspect of EAHE that has also been studied so far. Trombe et al., (1991) presented experimental results of a study performed on buried pipes for individual house air cooling in summer. He analyzed influences of parameters like air-flow rate and working management of heat exchanger system. On the other hand, Mihalakakou et al., (1995) presented a new parametrical model for the prediction of the thermal performance of the earth to air heat exchangers. Ghosal and Tiwari (2006) performed a parametric study on the EAHE system coupled with the greenhouse. They illustrated the effects of buried pipe length, pipe diameter, mass flow rate of air, depth of ground and types of soil on the greenhouse air temperatures. Further, Kwang and Richard K (2008) developed a new module and implemented it in the EnergyPlus program for the simulation of earth tubes. They carried out a parametric analysis 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 during cooling season. Moreover Vikas et al., (2010) and Fabrizio et al., (2011) conducted a study using different pipe materials to observe the performance and difference it makes on air temperature.

Sanusi (2012) studied the parameters on the Malaysian climate in both field experiment and simulation using EnergyPlus program. This study tried to extend the investigation by EnergyPlus program to simulate a wide range of parametric sizes to obtain the optimum geometrical size of the system for Malaysian climate. But the impact of these parametric under different condition (i.e. electric air-conditioning system) in Malaysia still remains unexplained clearly. Hence this research focuses on answering queries in the prospective of reducing electricity usage through alternative system – the EAHE which is environment friendly and cost effective.

1.3 PROBLEM STATEMENT

In 2004, a report showed a large increase in electric-energy consumption in residential and commercial buildings in Malaysia (see Chan, 2004). It demonstrated that the energy consumption in Malaysia in the year 2000 tripled the amount of energy consumption in the year 1990. The major cause found is the usage of electrical energy by air-conditioning systems in buildings in Malaysia. The warm and humid climate of the country causes a need to build cooling systems. The majority of buildings in Malaysia are dependent to the usage of air-conditioning systems to achieve indoor comfortable environment, particularly in non-residential buildings (Sanusi, 2012). In 2003, Danida and ECO-Energy Systems conducted an energy audit on a 987m^2 single storey office buildings in Malaysia and the report stated that 64% of the energy consumed was for air-conditioning alone (Figure 1.2) (Chan, 2004).

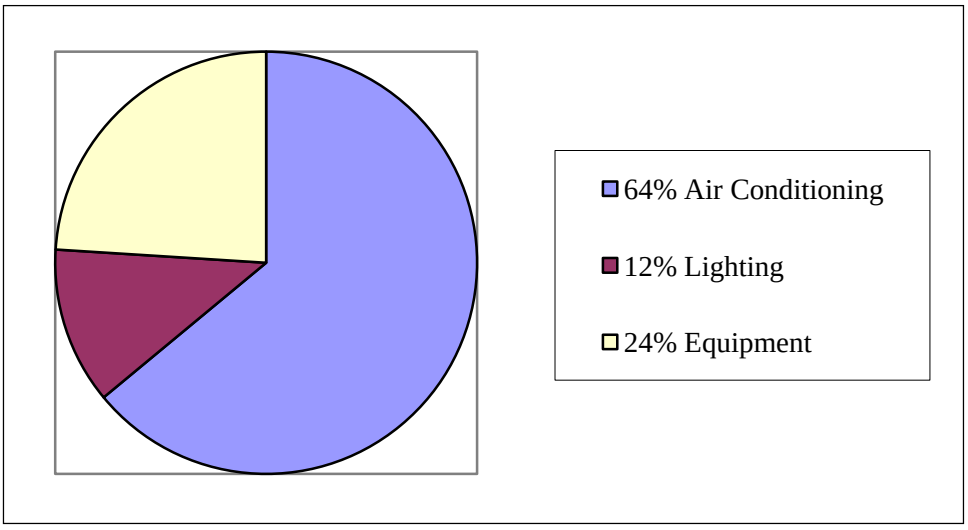

Figure 1.2: Breakdown chart of the energy load in an office building in Malaysia (Source: Chan, 2004).

It is believed that using Earth-to-Air Heat Exchanger (EAHE) cooling system in commercial (office) buildings in Malaysia will contribute in reducing electric-energy consumption. As a result, it will minimize the negative impacts of building on environment. EAHE system is not very common cooling system technology in Malaysia, probably because of little awareness about its benefits. In fact, there is limited research in this field in respect to Malaysian climate.

Sanusi (2012) conducted an investigation in Kuala Lumpur, and she reported that at 1m underground the soil temperatures are 6°C and 9°C lower than the ambient temperature during wet and dry season, respectively. In addition to this, the maximum temperature reduction was 6.4°C and 6.9°C through EAHE for 3 inches (diameter) polyethylene pipe of 25m in length with air velocity of $5.6ms^{-1}$ at 0.5m underground, and 1.0m and 1.5m depths during the wet and dry season, respectively. The results showed that there is potential benefit of using EAHE to provide low-cost energy cooling system in Malaysia. Furthermore selected parametric study on the same experiments was carried out using Energy Plus programme. Energy Plus data agreed with the field work data and therefore this validates that the EnergyPlus is reliable software to investigate earth pipe cooling in Malaysia (Sanusi, 2012). This research - an extension of the previous computational simulation conducted by Sanusi, 2012 – will investigate the effect of other parameters.

1.4 RESEARCH OBJECTIVES

In order to find the optimum geometrical size of the EAHE in the Malaysian context, this research investigates the differences between ambient air temperature (T_{am}), and pipe-outlet air temperature (T_{po}). Hence this study sets following objectives:

i. To determine the time when the pipe-outlet air temperatures (T_{po}) is lower than ambient air temperature (T_{am}).

ii. To determine the influence of pipe diameter, air velocity, pipe depth, and pipe length on the cooling potential ΔT of the EAHE system.

iii. To determine the configuration of the Earth-to-Air Heat Exchanger that would achieve optimum cooling potential (ΔT).

1.5 RESEARCH METHODOLOGY

This study will investigate the effect of other parameters. EnergyPlus program will be used for simulations since Sanusi (2012) had verified the program agreed with field data. The data from Sanusi (2012) and ASHRAE will be used as input to the program. This research will also use some assumptions.

1.6 SCOPE AND LIMITATIONS

In this study data from Sanusi (2012) and ASHRAE will be used. The local climatic data for Gombak will not be collected. Instead it is assumed the data from ASHRAE is valid for Gombak Campus. The study also assumed several parameters available as standard data in EnergyPlus as valid. Ideally the data collected on site should be used.

1.7 THESIS ORGANIZATION

The dissertation is comprised of five chapters. Chapter 1 provides an introduction to the research and area, and elaborates the research background, problem statement, aim and objectives of the research. Chapter 2 is literature review. It begins with the introduction to the literature on Earth-to-Air Heat Exchanger as passive cooling technology and explains about the heat transfer process in the earth and the system

itself. Followed by presenting a background on both field experimental and computational simulation studies based on different climates and various type of research conducted around the world.

Chapter 3 discusses the research methodology. It describes particular model in EnergyPlus program, followed by the setup procedure of Earth-to-Air Heat Exchanger within the program. Finally, Chapter3 also presents the model required data on which the simulation can rely. In Chapter 4, it mentions about the simulation results, which consists of four simulations for the parameters (pipe diameter, air velocity, pipe depth, and pipe length), and analyzes their effects on the system as well.

Chapter 5 is the concluding chapter of this thesis. This chapter shows the simulation results which summarizes and compares with the original objectives of the study. Finally the recommendations are provide for future study on EAHE.