APPROPRIATE PIPE MATERIALS FOR EARTH-AIR-PIPE HEAT EXCHANGER (EAPHE) SYSTEM FOR TEMPERATURE REDUCTION VIA COMPUTER SIMULATION IN HOT-HUMID CLIMATES

BY

AMINUDDIN BIN MOHD NOOR

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

Kulliyah of Architectural and Environmental Design
International Islamic University Malaysia

MAY 2015

ABSTRACT

The implementation of earth-air pipe heat exchanger (EAPHE) system as a passive cooling technology for both residential and commercial buildings in the hot and humid climate of Malaysia is relatively new. To date this technology has not been implemented in Malaysia, although it is proven in many studies particularly in drier climates, that it has the potential to reduce energy consumption for passive cooling system for the country. Thinner on the ground are the potentials of the appropriate pipe materials for the EAPHE system. The objectives of the research are to study the potential of temperature reduction between ambient temperature at pipe inlet and at outlet utilizing the EAPHE system and to find the most appropriate pipe material for the EAPHE system. Finally the research intends to find the most appropriate pipe materials that will predict the optimum air temperature reduction through parametric studies for achieving thermal comfort. The study utilizes the EnergyPlus simulation program to investigate the performances of three pipe materials system: single pipe material, hybrid pipes and insulated hybrid pipes system. Through an exhaustive enumeration process, the study found that the insulated hybrid pipes with water system (Polyethylene + Water + Polyethylene) reduces the air at the outlet with a 6.233°C difference than at the inlet indicating promising cooling and energy savings potentials.

ملخص البحث

إنَّ وضع نظام (earth-air pipe heat exchanger-EAPHE) قيد التنفيذ كنظام تبريد –غير مُعتَمِد على ميكانيكات خارجية في الأبنية السكنية والتجارية في طقس ماليزيا الحار والرطب، يعتبر حديث نسبياً. إلى تاريخ اليوم هذه التقنية لم يتم تنفيذها في ماليزيا، على الرغم من أنه ثبت في دراسات عدة- وخصوصاً في مناخات أكثر جفافاً- أنها تُمكِّن من تخفيض استهلاك الطاقة في أنظمة التبريد –الغير مُعتَمِدة على ميكانيكات خارجية. الاحتمالات غير كثيرة للمواد المناسبة المُكوِّنة للأنابيب لنظام (EAPHE). إنَّ أهداف البحث هي دراسةُ كوامن تخفيضِ الحرارة المُتوَاجِدة عِندَّ مدخل الأنبوب ومخرجه، وتوظيف نظام (EAPHE)، وإيجاد المواد المُكوِّنة للأنبوب والأكثر مناسبة. آخراً، البحث يهدف إلى إيجاد المواد المُكوِّنة للأنبوب والأكثر مناسبة والتي تتنبأ بدرجة تخفيض الهواء المُثلى من خلال الدراسات التجريبية التي ترنو إلى الوصول إلى رفاهية حرارية. البحث يُوَّظِف (EnergyPlus simulation program) لاستقصاء أداء ثلاثة أنظمة أنابيب: الأنبوب المصنوع من مادة واحدة، والأنبوب الهجين، والأنبوب الهجين –المعزول. من خلال عملية تعداد شاملة، كشفَ البحث أنَّ الأنابيبَ الهجينة المعزولة مع نظام المياه (Polyethylene+Water+Polyethylene) تُخَفِّضُ الهواء عند المخرج بفارق 6.233 درجة سيليسوس مقارنةً مع المدخل، مما يُبَشِّرُ باحتمالات تبريد وترشيد للطاقة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standard 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

…..……………..……...…
Noor Aziah Mohd Ariffin
Supervisor

…………………….……...
Aliyah Nur Zafirah Sanusi
Co-Supervisor

I certify that I have read this study and that in my opinion, it conforms to acceptable standard 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.

……………………………
Zuraini Denan
Examiner

This dissertation was submitted to the Department of Architecture and is accepted as a fulfilment of the requirement for the degree of Master of Science in Building Services Engineering.

……………………………
Rosniza Othman
Head, Department of Architecture

This dissertation was submitted to the Kulliyah of Architecture and Environmental Design and it is accepted as a fulfilment of the requirement for the degree of Master of Science in Building Services Engineering

………………………..……
Khairuddin Abdul Rashid
Dean, Kulliyah 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.

Aminuddin Bin Mohd Noor

Signature ……………………………….. Date ………………………..

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE FOR UNPUBLISHED RESEARCH

APPROPRIATE PIPE MATERIALS FOR EARTH-AIR-PIPE HEAT EXCHANGER (EAPHE) SYSTEM FOR TEMPERATURE REDUCTION VIA COMPUTER SIMULATION IN HOT-HUMID CLIMATES

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below.

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.

3. The IIUM library will have the right to make, store in retrieval system and supply copier of this unpublished research if requested by other universities or research libraries.

Affirmed by Aminuddin Bin Mohd Noor

……………………………..	……………………………..
Signature	Date

To My Beloved Wife Hara

and Children Fareed, Firdauz, Sofea and Aisyah.

ACKNOWLEDGEMENTS

بسم الله الرحمن الرحيم

First and the most, I would like to express sincere gratitude to Allah, the Almighty, Alhamdulillah, for giving me the strength and the sustenance while undertaking this study. I wish to thank International Islamic University Malaysia (IIUM) for offering me to do Master Science in Building Services Engineering (MSBSE).

I would like to express my sincere thanks to my supervisor, Asst. Prof. Dr. Noor Aziah Mohd Ariffin for her encouragement, constructive guidance, continuous support, patience and friendly response. I learnt a lot from her expertise, brilliant ideas, her sharp thinking and broad knowledge during my dissertation process.

I would like to extend my appreciation and respect to my co-supervisor, Dr.Aliyah Nur Zafirah Sanusi for her information support, sharing ideas and contribution. Last but not least, special thanks to my respective lecturer, Professor Md Najib Ibrahim for initiating this topic and giving his ideas, valuable knowledge and encouragement during the earlier stage of my dissertation and study.

Finally and most importantly, I would like to thank my loving wife, Hara for her continuous prayers and support with her love during my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

ρ_s	Soil density, kg/m^3
$C_{p,s}$	Soil specific heat capacity, J/(kg^{o}C)
t	Time, day
z	Ground depth, m
k_s	Soil thermal conductivity, W/(mK)
$T_{s,m}$	Annual mean ground temperature, ^{o}C
T_s	ground temperature, ^{o}C
A_s	Amplitude of daily mean
t_o	phase constant since the beginning of the year of the lowest average ground surface temperature, day.
α_s	Soil thermal diffusivity, m2/day
T_{am}	ambient temperature, ^{o}C
T_{opt}	Optimum temperature ^{o}C
T_{po}	pipe outlet air temperature, ^{o}C
ΔTR	temperature reduction ($T_{am} – T_{po}$), ^{o}C
Z,t	the temperature at any depth (z) and time (t), ^{o}C
ΔT	temperature difference = (T_{opt}) – (T_{po}) K
$T_a(y)$	air temperature inside the tube at the distance y from the tube inlet, ^{o}C

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

The main contention of this study is to look for the optimum pipe material for an Earth-air-pipe-heat exchanger (EAPHE) system in hot humid condition of Malaysia. Although many studies on EAPHE have been conducted in many parts of the world, but studies on establishing the most appropriate pipe material for a particular climate is lacking. Most of the researchers chose the type of pipe material to conduct their study, among others the reason are based on locally and easily available material, cost constraints and durability.

However a process of elimination of the optimum type of the material is rarely conducted. In Malaysia, the only known research of this nature was conducted by Sanusi (2012) using Polyethylene (PE) as the pipe material and her choosing this material is based on the above, as mentioned previously. This study intends to systematically find the best pipe material through the process of the elimination using exhaustive enumeration of six (6) possible pipe materials available in Malaysia (PVC, PE, steel, Clay, Concrete and Copper).

The weather in Malaysia is increasingly hotter compared to the years before. Mostly is due to the effects of global warming. According to Fredolin, Juneng and Ahmad (2007) the temperature has been steadily increasing over the last 40 years. The temperature hikes range from 0.5% to 1.5% depending on the location. In Malaysia, the capital city of Kuala Lumpur is reported to have undergone the highest increase compared to other cities. Figure 1.1 shows the trend of Kuala Lumpur yearly means temperature recorded from 1990 to 2010 (source: Malaysian Meteorological Service department).

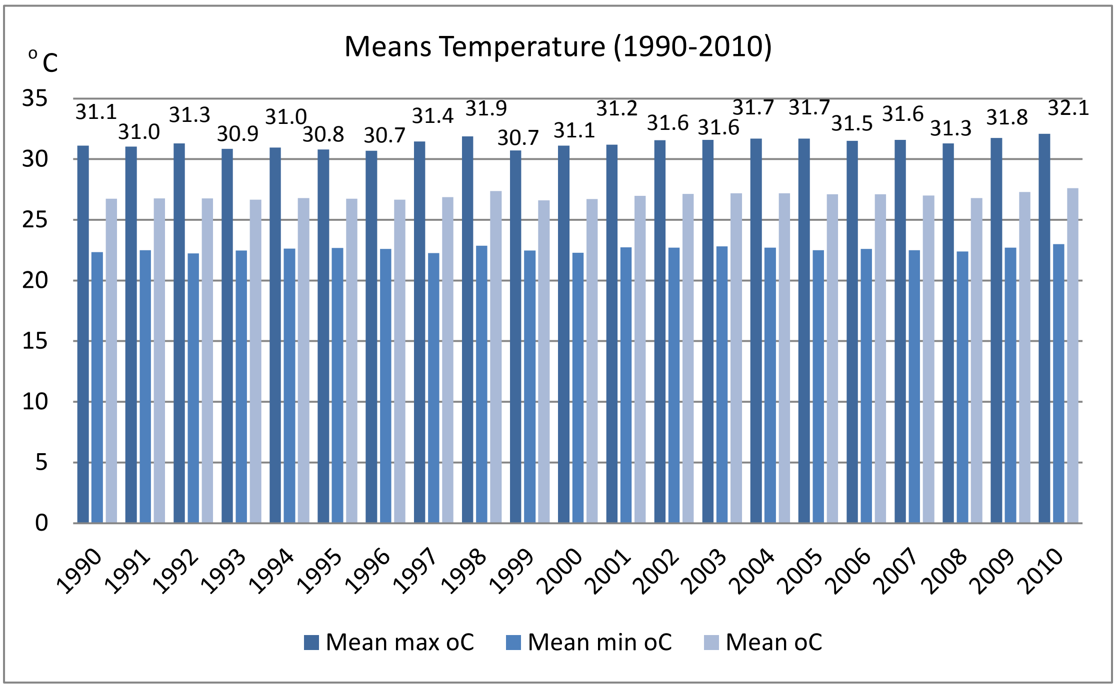

Figure 1.1: Yearly means temperature in Kuala Lumpur (1990-2010)

It shows the increment in yearly means (max) temperature for the past last 20 years. Many scientist claimed that the weather temperature recently have been uncertain due to the effect of greenhouse gases. The steady rise of the temperature globally, correlates with the high rise of energy for cooling especially in the hotter climates. Due to the ambient temperature increment, one of the most important global challenges nowadays is saving energy that is used for cooling purposes. Electricity consumption in Malaysia is recorded as the second highest among ASEAN members (Tang, 2008) indicating a need for studies for alternative provision of cooling for buildings.

Chin (2012) stated that the forecasted growth for electricity has shown an increase of 3.7% in 2012 compared to 3.1% in 2011. This growth has been driven by strong demand from the commercial and domestic sectors. For the period until 2020, the average projected demand for electricity is expected to grow at 3.1%. Based on this forecast, the country is going to need even more energy as it strives to grow towards a high-income economy.

Electricity consumption in Malaysia have increase between 1980 and 2009 (Hussain and Othman, 2011). Most residential and commercial buildings in Malaysia are using air-conditioning system to ensure the body comfort of its occupants is achieved. According to Kubota, Jeong, Toe, and Ossen (2011) the total number of households with air-conditioning in Malaysia has tremendously increased up to 16.2% in 2000. In regard to temperature extremes, an increasing trend of the daily minimum temperature is clearly established for most meteorological stations (Mohan, 2010).

According to ASHRAE 55-2004, most people will feel comfortable when the indoor temperature is around 22^{o}C to 27^{o}C and the relative humidity is between 40% and 60% in range. Even when using the adaptive approach of the thermal comfort where the comfort range can be increased to be between 24^{o}C -30^{o}C (Noor Aziah, 2008) it is still quite hard for people to be comfortable naturally in the Malaysia climate. The use of passive and low energy strategies for cooling of buildings is an alternative method for providing comfortable indoor environments with low energy use.

Cooling the outdoor air through underground pipes by means of an Earth Air Pipe Heat Exchanger (EAPHE) has been established for many years to have potential for ‘decreasing’ a building’s demand. An EAPHE is a system in which heat transfer occurs between the soil and air-flowing through the tube which are laid underground of certain depth where temperature of soil remains nearly constant throughout the year. As hot air flows through the length of the EAPHE, heat is transferred from the earth to the air and it gets cooled resulting in the air temperature at the outlet of the earth–air–pipes to be much lower than that of the ambient. EAPHE uses soil as a heat sink for cooling purposes where the heat is removed and dissipated back into the ground with air as the heat transfer medium for space cooling. The excess heat for the EAPHE system is transferred to the ground by conduction. The cooler outlet air from the EAPHE can be directly used for space cooling if its temperature is low enough with adequate air flow to provide end user thermal comfort. Alternatively, the outlet air may be cooled further by association with the building's heating, ventilation and air-conditioning (HVAC) system. Therefore, the uses of EAPHE incorporated with HVAC system can contribute to the reduction in energy consumption by decreasing the cooling load and demand of the HVAC system.

Sharan, Sahu and Jaghav (2001) stated that EAPHE is widely used in Europe and North America to condition (cool and heat) the air for use in livestock buildings and greenhouses and yet is good option for human residence.

The consistent environment of the ground can be used to create thermal comfort conditions in living spaces either by directly or indirectly coupling the ground at certain depths to the building (Figure 1.2). In indirect coupling, air is channeled through the pipes buried in the ground, conditioned and circulated through the living spaces. Air passing through pipes can be drawn either from ambient (single pass system) or from the conditioned space itself (recirculation system).

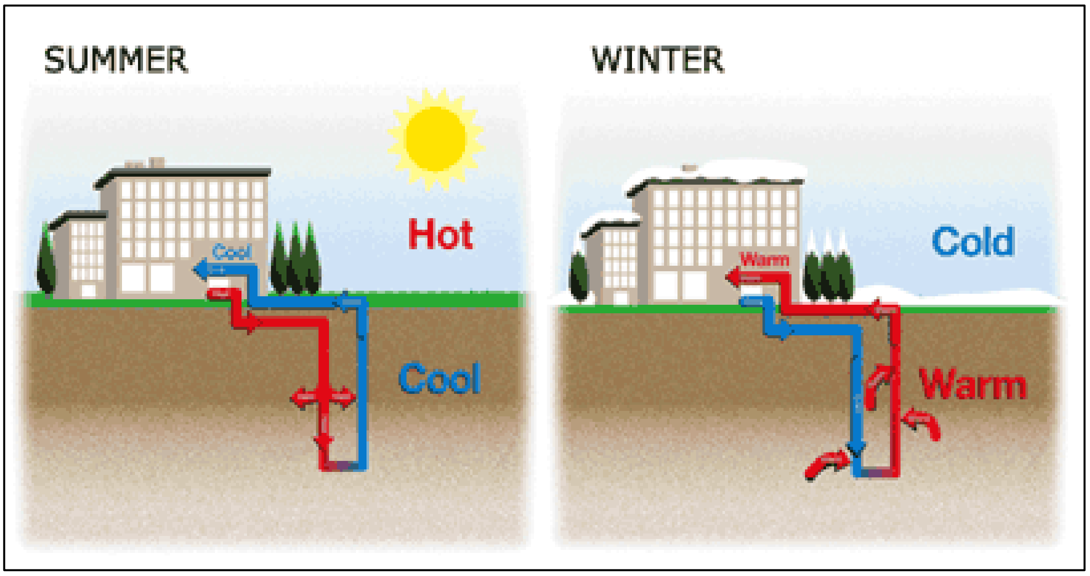

Figure 1.2: Cooling and heating condition during Summer and Winter.
(Source: www.top-alternative-energy.)

Various simplified models are presented in the following literature reviews. Bansal and Sodha (1986) evaluated a large earth-air tunnel system meant to provide thermal comfort inside a whole building complex at one of the hospitals in India. They found out that the cooling capacity of the tunnel was considerably greater than its heating capacity, thus able to provide considerable cooling for entire buildings of the hospital. They also reported that, during the summer period, the ambient temperature which was measured at the inlet of the tunnel varied between 24^{o}C and 43^{o}C, whereas the wet bulb temperature varied between 16.5^{o}C and 27.5^{o}C. The outlet air temperature from the tunnel, in contrast showed variations in temperature between 23^{o}C and 28^{o}C and in the wet bulb temperature, between 20.5^{o}C and 26.5^{o}C. It shows that the outlet air considerably cooled and moist with 75-89% relative humidity. During the winter period, it was observed that the outlet air temperature varied between 12^{o}C and 20^{o}C (dry bulb) whereas the ambient temperature varied between 4^{o}C and 21^{o}C with 59-76% relative humidity and no condensation happened in the system. The system can be seen to be an effective means of damping the ambient air temperature variations in addition to filtering out the effects of solar radiation. Thus able to provide considerable effective cooling for entire buildings in summer and an auxiliary heating is required in winter to maintain thermal comfort.

Santamouris, Mihalakakou, Argiriou and Asimakopoulos (1995b) investigated the use of buried pipe for energy conservation in cooling of agriculture greenhouse in Greece. The outcomes showed that, the system of buried pipe contribute in significantly reducing the indoor temperature during summer and vice versa during winter and the applicability of the system makes them an attractive investment with satisfactory results.

Goswami and Biseli (1993) demonstrated an open loop, underground air tunnel system as well as an indirect air tunnel system to improve the coefficient of performance (COP) of a heat pump or a refrigeration system whereby the open loop air tunnel system can operate with a COP as high as 1/3 higher compared to the conventional air conditioning system. As the result, the improvement was increased in COP by 300%.

Bansal, Misra, Agrawal and Mathur (2009 and 2010) presented an earth air heat exchanger model which was developed inside the FLUENT simulation program. They found that from 23.42 meter length and 0.15 meter diameter of the earth pipe, during winter and summer the air temperature reduction range are between 4.1^{o}C - 4.8^{o}C and 8.0^{o}C – 12.7^{o}C respectively which reflected to the potential of EAPHE performance.

Jacovides and Mihalakakou (1995) developed a complete numerical model to predict the air and soil temperature below the building by using TRNSYS which is a transient system simulation program with a modular structure. The simulation models of EAPH are based on algorithms describing the simultaneous transfer of heat and mass in soils with a temperature gradient. With the objective to present a more precise and validated transient, implicit numerical model based on the coupled and simultaneous transfer of heat and mass into soil and the pipe, they found out that the proposed model was validated and accurate against two experimental data sets.

Al-Ajmi, Loveday and Hanby (2006) simulated an EAPHE model to predict air outlet temperature reduction and cooling potential in hot and arid climate in Kuwait. The simulation results showed that the EAPHE could reduce up to 1700 W in the peak cooling load with air temperature reduction of 2.8^{o}C at outlet during summer and has potential to save up to 30% of energy demand during summer.

Mihalakakou, Santamouris, Asimakopoulos and Tselepidaki (1995) presented a parametrical model with varying parameters such as pipe length, pipe radius, air velocity inside the pipe and depth of the buried pipe below earth surface considerable that these parameters influencing the outlet temperature. The model was validated against the data which was obtained by an accurate numerical model describing the thermal performance of EAPHE system. They found out that there is a very good agreement between parametrical data and numerical data in order to predict the EAPHE thermal performance whereby the maximum difference between parametrical and numerical data does not exceeds 0.5^{o}C.

1.1 RESEARCH PROBLEM

The study is ascertaining that the earth air pipe heat exchanger buried underground can be an alternative technique as a passive cooling system for achieving thermal comfort in residential building in order to reduce its energy consumption in Malaysia. However the focus of this study is restricted to the studies of pipe materials only. The piping material of the EAPHE can be made from metal, concrete or plastic pipe which enable the air to travel and pass through the pipe length from inlet to the outlet in order to create conditioned air during cooling phase which entered the building. EAPHE technology has been used and implemented widely in Europe and USA for their residential and commercial buildings in order to reduce its energy consumption.