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

BY

SORAN HAMA AZIZ AHMED

INTERNATIONAL ISLAMIC UNIVERSITY
MALAYSIA

2013

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

BY

SORAN HAMA AZIZ AHMED

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

Kulliyyah of Architectural and Environmental Design
International Islamic University Malaysia

JULY 2013

# 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 ($\Delta T$) 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 ($\Delta T$). The simulation results showed that, the maximum ($\Delta T$) 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 ($\Delta T$)، 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 ($\Delta T$). ونتائج المحاكاة (simulation) تبينت أن الحد الأقصى لـ $\Delta T$ 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.

..................................................
Md. Najib Ibrahim
Supervisor

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

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.

..................................................
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 ……………………..

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

# DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

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

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 a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

Affirmed by Soran Hama Aziz Ahmed.

……………………………  ………………..
Signature  Date

*To My Beloved Wife Talar*

# ACKNOWLEDGEMENTS

*First and the most, I would like to express sincere gratitude to Allah, the Almighty, for giving me the strength and the sustenance while undertaking this study.*

*I wish to thank International Islamic University Malaysia for offering me to doing Master in Building Services Engineering.*

*Also I would like to express sincere thanks to my supervisor, Professor Md. Najib Ibrahim, for his constructive guidance, encouragement, continuous support, patience, and friendly response. I learnt a lot from his scientific attitude, sharp thinking, and broad knowledge during my master study and dissertation.*

*I would like to extend my appreciation and respect to my co-supervisor, Asst. Prof. Dr. Aliyah Nur Zafirah Sanusi for her constant support and contribution.*

*Finally and most importantly, I would like to thank my loving wife, Talar, for her continuous support with her love during my study, I will never walk alone without her.*

# TABLE OF CONTENTS

Abstract………………………………………………………………………... ii
Abstract in Arabic…………………………………………………………... iii
Approval Page……………………………………………………………… iv
Declaration Page…………………………………………………………… v
Copyright Page……………………………………………………………... vi
Dedication…………………………………………………………………... vii
Acknowledgements…………………………………………………………. viii
List of Tables………………………………………………………………... xi
List of Figures………………………………………………………………. xii
List of Symbols……………………………………………………………... xv

**CHAPTER ONE: INTRODUCTION……………………………………… 1**
  1.1 Introduction…………………………………………………….… 1
  1.2 Background……………………………………………………… 2
  1.3 Problem Statement……………………………………………….. 7
  1.4 Research Objectives……………………………………………… 8
  1.5 Research Methodology..…………………………………………… 9
  1.6 Scope and Limitation…..…………………………...…………… 9
  1.7 Thesis Organization……………………………………………… 9

**CHAPTER TWO: LITERATURE REVIEW……………………………… 11**
  2.1 Earth-To-Air Heat Exchanger as Passive Cooling Strategy……... 11
    2.1.1 Heat Transfer in the Earth & EAHE……………………... 12
      2.1.1.1 Heat transfer in the Earth……………………… 12
      2.1.1.2 Heat transfer in Earth-to-Air Heat Exchanger……. 15
    2.1.2 Definition of Terms and Synonyms……………………... 18
  2.2 EAHE Field Experiments………………….…………………. 19
    2.2.1 Field Experimental According To Climates……..……… 19
      2.2.1.1 Temperate countries……………………………… 19
      2.2.1.2 Hot and arid countries…………………….……… 20
      2.2.1.3 Hot and humid countries………………………….. 21
    2.2.2 Field Experimental According to Type of Research…….. 21
      2.2.2.1 System performance…………...………………….. 22
      2.2.2.2 Incorporate EAHE to HVAC Systems…………… 23
      2.2.2.3 Soil investigation………………………………….. 24
      2.2.2.4 Parametric study ………………………………….. 24
  2.3 EAHE Computational Simulations………………………………. 26
    2.3.1 Numerical simulation…………………………………….. 26
    2.3.2 Computational Simulation………………………………... 27
    2.3.3 EnergyPlus Program……………………………………... 28
  2.4 Application of Earth-To-Air Heat Exchanger…………………… 32
    2.4.1 Schwerzenbacherhof Commercial Building…….............. 33

2.4.1.1 Component description………………………….. 34
2.4.1.2 Control strategy……………………………………. 36
2.4.1.3 Measured performance……………………………. 37
2.4.2 Mediå School, Grong, Norway…………………………... 38
2.4.2.1 Component description………………………….. 38
2.4.2.2 Control strategy…………………………………... 41
2.4.3 Centre for Sustainable Energy Technologies at the University of Nottingham, Ningbo- China………………. 42
2.4.3.1 Description of the Earth-tube ventilation system… 43
2.4.3.2 Investigation result on the system……………….... 44
2.4.4 Experimental Shed at the International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia……………... 46
2.4.4.1 Field Work Site…………………………………... 46
2.4.4.2 Description of the Experimental Shed……………. 47
2.4.4.3 Experiment Results………………………………. 49
2.4.4.3.1 Soil Temperature……….……………… 49
2.4.4.3.2 Earth-to-Air Heat Exchanger Results….. 50
2.4.4.4 Computational Simulation Investigation…………. 51
2.5 Conclusion…………………………………………………….. 52

**CHAPTER THREE: METHODOLOGY…………………………………... 53**
3.1 Earthtube Simulation Models……………………………………. 53
3.2 Simulation Set Up In EnergyPlus……………………………….... 57
3.2.1 Input data file (IDF) in EnergyPlus………………………… 58
3.3 Research Procedures……………………………………………... 62

**CHAPTER FOUR: SIMULATION RESULTS AND DISCUSSION…….. 65**
4.1 Simulation 1: Influence of Pipe Diameter………………………. 65
4.2 Simulation 2: Influence of Air Velocity………………………… 69
4.3 Simulation 3: Influence of Underground Pipe Depth…………… 71
4.4 Simulation 4: Influence of Pipe Length ………………………… 73
4.5 Conclusion………………………………………………………. 76

**CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS……. 77**
5.1 Parametric Study……. …………………………………………. 77
5.2 Recommendations for Further Study……………………………. 78

**BIBLIOGRAPHY……………………………………………………………….. 79**

# LIST OF TABLES

| Table No. | | Page No. |
|---|---|---|
| 2.1 | EAHE system synonyms | 18 |
| 2.2 | Simulation programs used for Earth-to-Air Heat Exchanger research | 28 |
| 2.3 | Comparisons of HVAC Features and Capabilities | 31 |
| 2.4 | Details of parameters used in April/May 2009 | 48 |
| 2.5 | Shallow and Deep Soil Temperature | 49 |
| 3.1 | Input data of Site: Ground Temperature: Shallow and Deep in EnergyPlus file | 59 |
| 3.2 | Basic Set Up in Energy Plus program files in Zone Airflow class list, ZoneEarthtube column | 61 |
| 3.3 | Input parameters used for simulations | 61 |
| 3.4 | Conversion table to convert air velocity to air flow rate | 62 |

# LIST OF FIGURES

Figure No. Page No.

1.1 Building with an Earth-to-Air Heat Exchanger 4

1.2 Breakdown chart of the energy load in an office building in Malaysia 7

2.1 Typical ground temperature profiles at different seasons 14

2.2 Typical annual temperature variations at different depths 14

2.3 The cooling process of EAHE in Psychrometric chart 17

2.4 Overall EnergyPlus Structure 29

2.5 The Schwerzenbacherhof office and industrial building 33

2.6 Schematic of Schwerzenbacherhof building ventilation systems 34

2.7 General layout and construction detail of the EAHE system in Schwerzenbacherhof building 35

2.8 Detailed section of the watertight concrete duct of 30 cm wall thickness and the pipe seals 35

2.9 Schwerzenbacherhof building - Schematic of the ground coupled and ventilation systems 36

2.10 Mediå school layout 38

2.11 Schematic cross section of Mediå school 39

2.12 ETAHE’s intake tower of Mediå school 40

2.13 Air distribution duct of Mediå school 41

2.14 Centre for Sustainable Energy Technologies building at the University of Nottingham, Ningbo- China 43

Figure No. Page No.

2.15 Earth-tube ventilation system construction in the CSET building 44

2.16 CSET building, heating system schematic diagram 45

2.17 CSET building, cooling system schematic diagram 46

2.18 Field work site location (red dot) within International Islamic University Malaysia campus 47

2.19 EAHE experiment set up 48

2.20 Trend of Temperatures at 1.0m Depth 50

2.21 Comparison of field work and EnergyPlus (Data obtained in May) 51

2.22 Comparison of field work and EnergyPlus (Data obtained in June) 52

3.1 Simulation Procedure Flowchart 64

4.1 Effect of pipe diameters on $T_{po}$ for a typical summer day 66

4.2 Effect of pipe diameters on $T_{po}$ from 11.00am to 8.00pm 67

4.3 Effect of pipe diameters on cooling potential ($\Delta T$) 68

4.4 Part A, Effect of air velocity on $T_{po}$ for a typical summer day; Part B, is a portion of part A during 11.00am to 8.00pm and without $T_{am}$ 69

4.5 Effect of Air velocity on cooling potential ($\Delta T$) 70

4.6 Effect of pipe underground depth on $T_{po}$ for a typical summer day 72

4.7 Effect of pipe depth on cooling potential ($\Delta T$) 73

4.8 Effect of pipe length on hourly variations of $T_{po}$ for a typical summer day 74

4.9 Effect of pipe length on $T_{po}$ for a typical summer day from 10.00am to 9.00pm 75

4.10 Effect of pipe length on cooling potential ($\Delta T$) 76

# LIST OF SYMBOLS

| | |
|---|---|
| $\rho_s$ | 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 |
| $\alpha_s$ | 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 |
| $\Delta T$ | ($T_{am} - T_{po}$), °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).

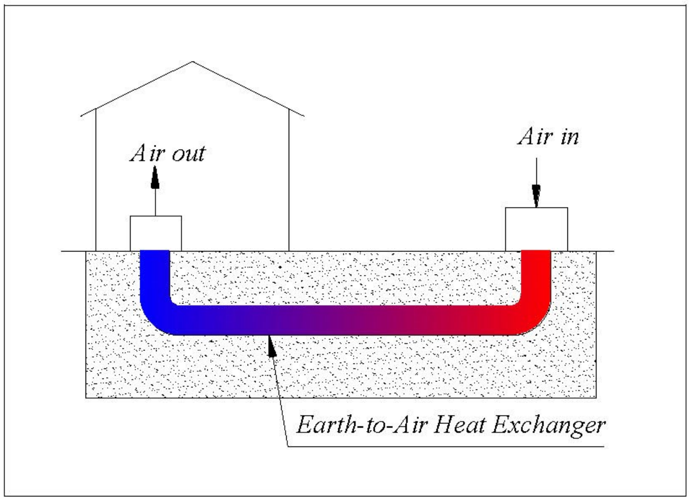

Figure 1.1: Building with an Earth-to-Air Heat Exchanger

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).

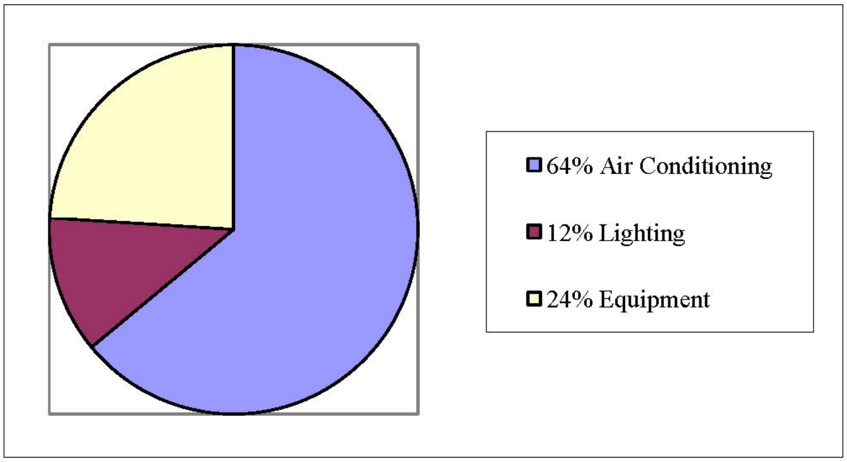

Figure 1.2: Breakdown chart of the energy load in an office building in Malaysia (Source: Chan, 2004).

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 $\Delta T$ of the EAHE system.
iii. To determine the configuration of the Earth-to-Air Heat Exchanger that would achieve optimum cooling potential ($\Delta T$).

## 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.

# CHAPTER TWO

# LITERATURE REVIEW

This chapter intends to elaborate the Earth-to-Air Heat Exchanger (EAHE) system as a passive cooling technology. The emphasis of this chapter is on explaining the transferring process of air through earth (soil) which consumes heat. This chapter also defines and describes the terms relevant to the area of study – the air cooling systems. Following to that, the chapter then presents a literature on the fieldwork and experimental studies based on different climates and by various types of research conducted around the world. The computational simulation method for investigating EAHE is also presented later, as well as positive features of the simulation program (EnergyPlus) which has been used for this study. Finally this chapter presents examples of existing building (commercial as well as residential) that use this technique of passive cooling system.

## 2.1 EARTH-TO-AIR HEAT EXCHANGERS AS PASSIVE COOLING STRATEGY

As mentioned earlier, the earth as source of the energy system can be employed through three methods of cooling the air: *Direct*, *Indirect*, and *Isolated* (Min, 2004; Jian, 2009). In the direct system, the building envelope is attached to the earth and conduction is through the building elements, mainly walls and floor that regulates the indoor temperature. Malaysia naturally has a low air velocity (speed of breeze) throughout the year, and employing a *direct* earth system/contact to the building method would definitely minimize the ventilation into the building. Therefore considering the potential consequences of direct earth contact, ground cooling was projected to be little risky (Sanusi, 2012). In the indirect system, such as in Earth-to-Air heat Exchanger (EAHE), the air is brought inside the building after being processes from the earth (soil). The isolated system uses earth temperatures to increase the efficiency of heat pump by moderating temperatures at the condensing coil; a geothermal heat pump is an example of an isolated system. This study has chosen the indirect systems for the observation and under tropical climate in Malaysia. Since the Malaysian temperature is hot and humid, this study intends to bring alternatives for cooling systems in building.

In indirect systems, the Earth-to air-heat exchangers (EAHE) system uses metal or plastic pipe in the ground through which air passes from one end to another (see Figure 1.1 in Chapter 1). During winter season, the air travels through the pipe gets its warmness from the surrounding soil and enters the space as warm air. In a similar way, in summers (hot season) air travels through the pipe and receives coolness from the soil and enters the room as bit cool air than the surrounding air outside (Mihalakakou et al., 1995; Santamouris, 1995).

### 2.1.1 HEAT TRANSFER IN THE EARTH & EAHE

#### *2.1.1.1 Heat transfer in the Earth*

Ground is the most favorable thermal medium for buildings, due to its massive capacity and availability. Somehow the stable ground temperature has made it an effective heat source as heat sink. That could be measured in some building energy conservation (Jian, 2009).

From ground surface to a hundred meter in-depth, heat transfer process takes place in various forms. At the ground surface, heat transfer is caused by short/long wave radiation, evapotranspiration, and convection. Conduction is the main form of heat transfer in the ground, except for those regions with presence of water. There are some other forms as well, like latent heat transfer through evaporation and condensation and sensible heat transfer by moisture transfer. Geothermal energy from the layers below the crust (the mantle and core) flows up heat constantly, but the heat transfer is negligible when analyzing the heat that flows in a shallow region, e.g. depth less than 20 meters (Rybach and Sanner, 2000 in Jian, 2009).

When analyzing the natural heat flow in the shallow ground, one can simply examine the ground as semi-infinite medium and describe the heat conduction using Fourier's law (shown in Equation 2.1). Ground surface temperature records can be used to solve this equation but their availability is very limited due to the lack of field measurements. Similar to ambient air temperature, daily average ground surface temperature follow a sinusoid deviates with time, and their yearly amplitude is nearly equal to that of the ambient air. Such information can also help to solve Equation 2.1 and to obtain an undisturbed ground temperature at depth *z* and at time, *t* as shown in Equation 2.2 (Labs 1979 in Jian, 2009).

$$\rho_s c_{p,s} \frac{\partial T_s}{\partial t} = \frac{\partial}{\partial z}\left(k_s \frac{dT_s}{dz}\right) \tag{Eq. 2.1}$$

$$T_{z,t} = T_m - A_s \cdot \exp\left[-z\left(\frac{\pi}{365 a_s}\right)^{0.5}\right] \cos\left\{\frac{2\pi}{365}\left[t - t_o - \frac{z}{2}\left(\frac{365}{\pi a_s}\right)^{0.5}\right]\right\} \tag{Eq. 2.2}$$

Figure 2.1 and Figure 2.2 show demonstrates the typical ground temperature under different function of time and depths. As far as ground temperature is concerned, an EAHE should ideally be installed as deep as possible to prevent temperature variations. However, the excavation cost for laying an EAHE deeper may not be economical. In existing applications, EAHEs are usually buried 1-4 m below the ground surface.

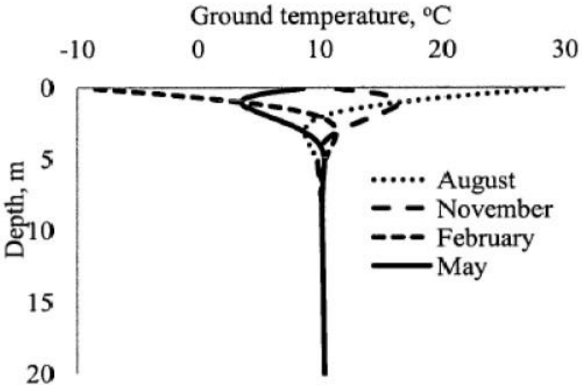

Figure 2.1: Typical ground temperature profiles at different seasons (Source: Jian, 2009).

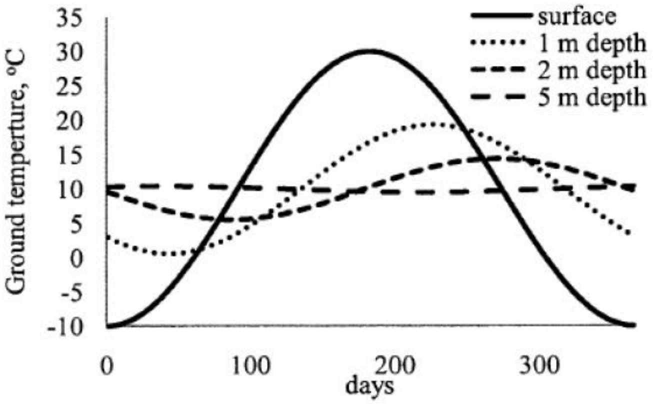

Figure 2.2: Typical annual temperature variations at different depths (Source: Jian, 2009).

#### *2.1.1.2 Heat transfer in Earth-to-Air Heat Exchanger*

The Earth-to-Air Heat Exchanger system works with a long buried pipe in ground with one end opened at an ambient for air intake and the other end at the space to be provided with cool air. The pipe is buried underground at the depth that could give most efficient results. This technology uses the ground as a heat sink for cooling purposes in warm countries where the channeled ambient air, via the buried pipe, transfers excess heat to the ground by convection. There should be adequate air flow into the buried pipe intake to produce cool air at the other end for occupants' thermal comfort. A fan blower is required at intake point of the buried pipe to stimulate the air flow from one end to another (Sanusi, 2012).

In summer, the soil temperature below a two meter depth is close to the annual ambient air temperature (see Figure 2.2). And as air passes through an EAHE, convective heat transfer takes place between the air and pipe surface. The enthalpy of the air and dry bulb temperature decreases along the flow direction.

If the pipe is long enough and the surface is cooler than the dew point temperature, condensation may take place. When no other cooling device is used, the air conditioning processes can be employed (see the Psychrometric chart in Figure 2.3). The ambient air condition from point 1 to point 2, the air is cooled with a constant humidity ratio. Depending on the size of pipe cross-sectional and air speed, relative humidity (RH) distribution at a cross section could affect the condensation condition. If the cross sectional size is small and the air velocity is large, the RH would be close to uniformity, and point 2 would be on the 100% RH curve. However, if the air RH at the cross section has a large variation, the boundary layer air would condense first even though the average air condition has not reached saturation.

Point 3 is determined by the duct surface temperature. If the duct length is infinite, the cooling and dehumidification process will continue from Point 2 to point 3. However, in practice point 3′ will be the EAHE outlet for air condition. The air temperature may increase slightly to reach the point 4 due to heat gained during distribution. Finally, the indoor load changes the air condition from Point 4 to 5. It should be noted that two assumptions are made for the process from Point 2 to 3. The first one is that the pipe is long enough so that the air has been saturated. Due to space limitation, the duct lengths are depended on projects. The second assumption is that the duct surface temperature is not much elevated by the warm air, and the Point 3 is determined based on an undisturbed ground temperature. However, in practice, the heat transfer between the air and the pipe surface is a dynamic process. When the air is cooled, the heat is transferred to the pipe wall, consequently the wall temperatures are warmed up (Jian, 2009). Therefore the cooling performance of an EAHE is mainly determined by the dry cooling process from Point 1 to 2.

Figure 2.3 shows the cooling process of Earth-to-Air Heat Exchangers in Psychrometric chart. Point 1: outdoor air condition; Point 2: transition condition (condensation starts); Point 3: pipe surface condition; Point 3′: EAHE outlet condition; Point 4: room supply air condition; Point 5: room air condition.

As shown in Psychrometric chart, the changes in air condition from Point 1 to 2 are due to sensible heat exchange and they are the main processes determining EAHE performance. The heat transferred is in the form of convection, and its intensity is significantly depending on the air flow rate and temperature differences between the air and the pipe surface. That is where the current study focuses on.

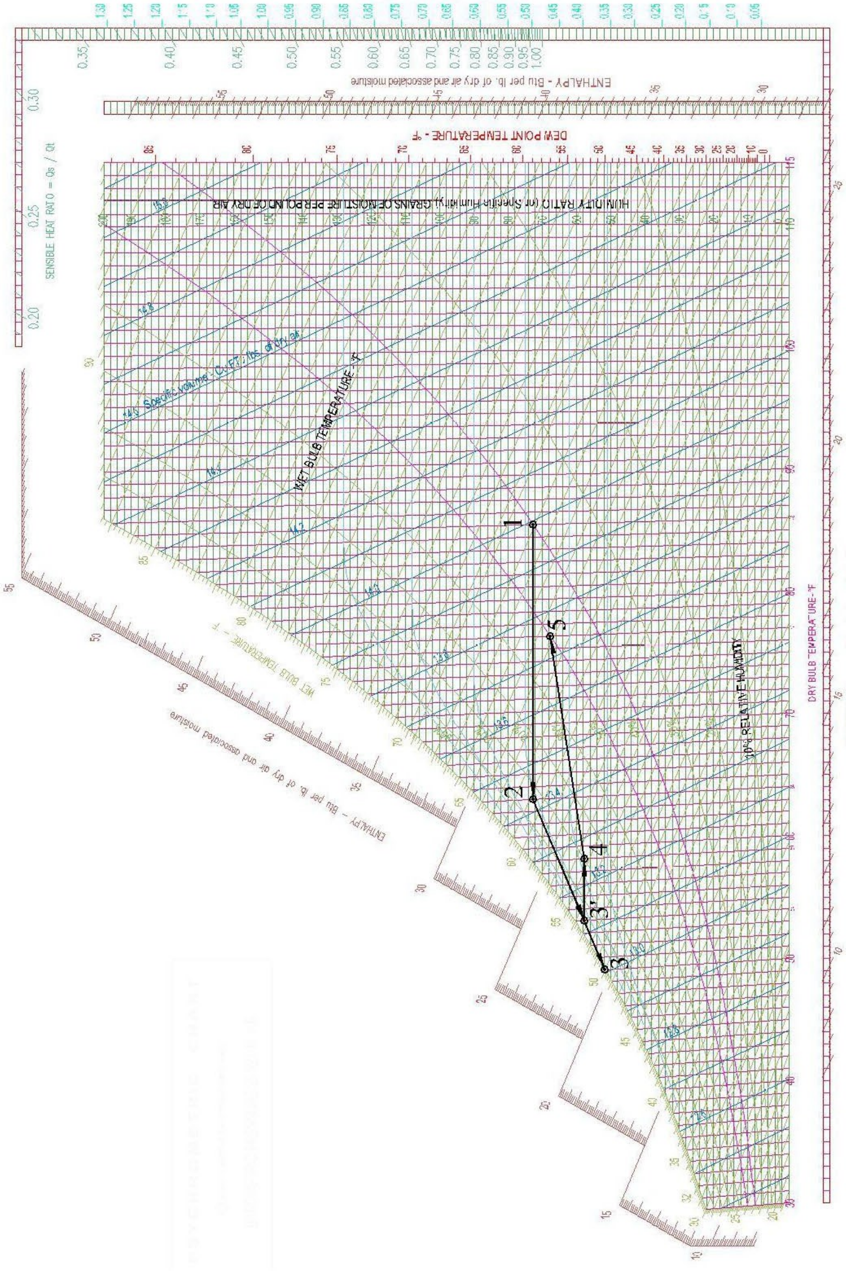

Figure 2.3: The cooling process of EAHE in Psychrometric chart (source: Mu, L. 1982 in Jian, 2009).

### 2.1.2 DEFINITION OF TERMS AND SYNONYMS

In this study, the intended system for investigation is defined as 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, 2012; Mihalakakou et al., 1995; Santamouris, 1995; Min, 2004; Al-Ajmia, 2006; Ghosal and Tiwari, 2006; Kwang and Richard, 2008; Jian, 2009; Gyuyoung et al., 2009; and Fabrizio et al., 2011).

After reviewing the literature, we found out that this system is mostly known as Earth-to-Air Heat Exchanger (EAHE) system (Mihalakakou et al., 1995), (Santamouris et al., 1995), (Jian et al., 2005), (Al-Ajmia et al., 2006), (Ghosal et al., 2004), (Min, 2004), (Ghosal. et al., 2006), (Gyuyoung Yoon et al., 2009), Jian Zhang, 2009), and (Fabrizio et al., 2011). In this study, we use Earth-to-Air Heat Exchanger (EAHE) as the name of the system. In the Table 2.1 presenting more system names (synonyms) that other researchers used for the same system.

Table 2.1
EAHE system synonyms

| S | System Name | Researcher |
|---|---|---|
| 1 | Earth pipe cooling technology | (Sanusi. et al., 2012); |
| 2 | Earth tube system | (Jacovides et al., 1995; Kwang and Richard, 2008); |
| 3 | Earth-air-pipe system (EAPS) | (Huijun et al., 2007); |
| 4 | Earth tube heat exchanger (ETHE) | (Miroslaw, 2011; Trombe et al., 1991) |
| 5 | Underground air pipe air conditioning system | (Sawhney et al., 1999), |
| 6 | Buried pipe systems | (Hollmuller & Bernard, 2000); |
| 7 | Earth–air–tunnel system | (Rakesh et al, 2003); and |
| 8 | Earth-tube ventilation system | (Darkwa J. et al, 2011) |

Earth-to-Air Heat Exchanger system uses either an open or closed-loop configuration. In an open-loop system, the outdoor air is drawn into the tube and delivers directly to the inside of the building which has the end point. This system provides ventilation while cooling the building from inside. In a closed-loop system, interior air circulates through the earth cooling tubes. A closed loop does not exchange air with the outside; instead it re-circulates the indoor air through the earth cooling tubes. This makes the closed loop system more efficient than an open loop design, since it does not require as high a degree of dehumidification as an open loop system (Goswami and Biseli, 1993).

## 2.2 EAHE FIELD EXPERIMENTS

### 2.2.1 Field Experimental According To Climates

#### *2.2.1.1 Temperate countries*

Kwang and Richard (2008) conducted parametric study of EAHE in USA at four different locations (Spokane, WA: mild and dry; Peoria, IL: mild and wet; Phoenix, AZ: hot and dry; Key West, FL: hot and wet). They reported that when the system is properly designed, an earth tube was shown to save more than 50% of the total cooling load, depending on the weather and soil conditions. They concluded that Peoria and Spokane are the better places for the utilization of earth tubes than Key West and Phoenix which have higher soil temperatures and the earth tube inlet temperature. Although the earth tube alone cannot replace conventional air-conditioning system in these case studies, it can significantly reduce the cooling load in buildings (Kwang and Richard. 2008).

Fabrizio et al. (2011) evaluated the energy performances achievable using EAHE in different Italian climates (i.e. Naples, Rome, & Milan). They found-out that the best energy performances resides within wet/humid soil, and for the coldest climates (Milan) there is maximum energy savings about 44%, in terms of thermal energy and about 37% for primary energy. For cold climates such as Milan, the achievable indoor thermal conditions are good (about 90% of the summer diurnal time characterized by indoor temperature lower than 30°C). On contrary with reference to Naples and Rome, the indoor summer temperature experiments using EAHX coupled to ventilation aren't fully satisfactory. Anyhow, the use of the active cooling can be reduced noticeably (Fabrizio et al., 2011).

Ghosal and Tiwari (2006) integrated the EAHE with the greenhouse located in Delhi, India. The climate of that place is multiple, as it remains hot and dry for five months, warm and humid for three months, moderate for one month and cold for three months. The results they achieved has 7–8 °C rise and 5–6 °C reduction of temperatures for the greenhouse air for the winter and for the summer period, respectively.

#### *2.2.1.2 Hot and arid countries*

Al-Ajmia et al., (2006) predicted the outlet air temperature and cooling potential of EAHE in a hot and arid climate in Kuwait. They found that there is potential need for this system to make a useful contribution to energy saving in Kuwait. And this system can also be used in similar desert climates in other locations as well (Al-Ajmia et al., 2006). Vikas et al., (2010) analyzed the performance of the system in dry climate of the Western India in Ajmer, and reported that the Earth-to-Air Heat Exchanger systems can be used to reduce the cooling load of buildings in summer.

#### *2.2.1.3 Hot and humid countries*

Darkwa (2011) evaluated the EAHE system as an energy saving technology for a typical hot and humid location in Ningbo, China. He proved that this system has the potential to become effective energy saving technologies in buildings. Min (2004) analyzed application of EAHE in Montreal, Canadian climate. This region is always humid. He found that in winter, the EAHE system may preheat the outdoor air up to 10°C from December to March. While in summer day, a typical EAHE system may pre-cool outdoor air up to 10°C from July to September. The finding proves the usefulness of this technique for passive cooling (Min, 2004).

Malaysia is a tropical country which has hot and humid climate throughout the year. The application of EAHE system is still at a primitive stage, and there is limited research and investigation on this technology in Malaysia. Sanusi (2012) conducted a field experimental investigation to record soil temperature in Kuala Lumpur at different depths and also investigated the viability of EAHE system. His work primarily focuses on how the system can reduce the hot temperature in Malaysia during daytime, which will result in reduction of the electric energy consumption as well.

In this study, the investigate of Earth-to-Air Heat Exchanger system was conducted under Malaysian climate condition using EnergyPlus as energy simulation program and also using the actual soil data recorded by Sanusi (2012) to test the system with different conditions.

### 2.2.2 Field Experimental According to Type of Research

Previous researchers studied various aspects of Earth-to-Air Heat Exchanger system with factors such as estimation under different conditions and the viability in different climates around the world. As mentioned in the previous section (section 2.2.1), the investigation of potential of soil temperature, system performance, economic aspect, and parametric are essential part this study, which is intended be assessed and elaborated.

#### *2.2.2.1 System performance*

System performance is another part of same research area with different aspect that many of the researchers have studied so far and concluded with different findings. For instance, Rakesh et al., (2003) developed a numerical model to predict energy conservation potential of EAHE system and passive thermal performance of a non-air-conditioned building. Al-Ajmia et al., (2006) predicted the cooling loads of the air conditioned dwelling with and without the assistance of the EAHE. Vikas et al., (2010) analyzed the thermal performance and cooling capacity of the EAHE system that can be used to reduce the cooling load of buildings in summer. Trombe et al. (1991) analyzed that buried pipes for individual house has a sufficient potential for conditioning outside air. Huijun et al. (2007) obtained a daily cooling capacity of air up to 74.6 kWh from an earth–air–pipe system installed in Southern China. Miroslaw et al., (2001) presented the results of computer simulations and experimental investigations of thermal performance of earth tube heat exchanger. Darkwa et al., (2011) evaluated theoretically and practically an earth-tube ventilation system. Furthermore Fabrizio et al., (2011) and Kwang et al., (2006) studied the performance of the system and energy conservation capability.

#### *2.2.2.2 Incorporating of EAHE to HVAC Systems*

Fabrizio et al. (2011) evaluated the energy performance achievable by incorporating the EAHE to HVAC systems, as a pre cooling/heating for intake fresh air. The possible indoor thermal comfort conditions for the modeled office building was well thermally insulated with efficient heating and cooling systems in summer when the building was not air-conditioned. Fabrizio et al., (2011) provided with diurnal ventilation coupled to EAHE plus night-time ventilation. Gyuyoung et al., (2009) installed nine PVC pipes with a diameter of 0.5 m in the heating, ventilating and air-conditioning (HVAC) system to fulfill the required quantity of fresh air in a welfare institute built in Japan. Darkwa et al., (2011) used a network of six underground thermo pipes to draw in air fresh through an air handling unit (AHU) into the building, which is the main source of fresh air supply to the research laboratory in the Centre for Sustainable Energy Technologies at the University of Nottingham, Ningbo China. Sawhney et al., (1999) studied the thermal performance of the underground air pipe air conditioning system in recirculation mode to air condition eight rooms in a guest house at the Institute Ghosi, and analyzed the cooling potential of the system. It is observed that reasonably good thermal comfort conditions can be produced in the building with such a system (Sawhney et al., 1999).

The EAHE system has been implemented in many different types of building and greenhouses as well. This system has also been tested in different formats around the world. Trombe et al., (1991) Santamouris et al., (1995), Hollmuller et al., (2000), Ghosal et al., (2004 and 2006), and Vikas et al., (2010) studied the EAHE system with similar practices to be implemented in buildings and greenhouses.

#### *2.2.2.3 Soil investigation*

Soil investigation is another facet which directly correlates with the EAHE system to predict the potential changes into air that passes when we use it. Al-Ajmia et al., (2006) presented a mathematical model for predicting Kuwait's sub-surface soil temperatures, and validated measurement of ground temperatures. The sub-surface temperature model then was used in conjunction with the EAHE model and a model of a typical Kuwaiti dwelling to estimate energy performances. Jacovides et al., (1995) developed a complete numerical model to the predict the air and the soil temperatures at the field under a building that the model described the simultaneous heat and mass transfer inside an earth-tube system and into the soil by taking into account the soil's natural thermal stratification. Sanusi (2012) investigated the temperature of air and soil at a test site in Malaysia and obtained that the soil temperature 6°C and 9°C lower than the maximum ambient temperature during wet and dry season respectively. Min (2004) presented transient control volume model to investigate the transient soil heat rejection around an EAHE.

#### *2.2.2.4 Parametric study*

Trombe et al., (1991) presented first experimental results of a study performed on buried pipes for individual house air cooling system in summer. He analyzed influences on the system caused by different parameters such as air flow rate, and working management of heat exchanger system. 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 parametric studies for the EAHE 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. Vikas et al., (2010) and Fabrizio et al., (2011) investigated on various kinds of pipe materials and analyzed their effects on the system performance. Kwang and Richard (2008) developed a new module after implementing 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 summer season. Sanusi (2012) also conducted a parametric study on the Malaysian climate by using the same EnergyPlus program.

Based on various published literature, it is proved that the Earth-to-Air Heat Exchanger performance is affected by the following four major parameters:

i. Pipe length;
ii. Pipe diameter;
iii. Depth of the buried pipe; and
iv. Air flow rate or velocity within the pipe.

Many researchers have found that similar changes in air temperature when it passes from the buried pipe. There is decrease in the temperature with increasing pipe length, decreasing pipe diameter, decreasing air velocity in the pipe and increasing depths (Kwang and Richard, 2008; Vikas et al., 2010; Ghosal et al., 2006; Huijun et al., 2007; Santamouris et al., 1995).

Apart from that, different pipe materials have also been studied, such as metallic materials, plastic and concrete pipes. The investigation has shown that the performance of the EAHE system is not significantly affected by the material of the buried pipe or leads to close similarity of energy performance. In fact, due to the less thickness of the tubes (pipe), the different thermal conductivity values scarcely influence the heat exchange, if the right depths and lengths are used (Vikas et al., 2010; Fabrizio et al., 2011). The other parameters like soil surface condition, arrangement of system or layout of multiple pipes, and system working management are also having their effects on the EAHE performance as well. This study focuses just on the pipe diameter, air velocity, pipe depth, and pipe length as the main parameters of Earth-to-Air Heat Exchangers system.

## 2.3 EAHE COMPUTATIONAL SIMULATIONS

### *2.3.1 Numerical simulation*

Al-Ajmia et al., (2006) developed a theoretical model of an EAHE system. They examined the outlet air temperature and cooling potential of these devices in a hot and arid climate. The model is validated against other published models and shows a good agreement. Mihalakakou et al., (1995) presented a new numerical model for the prediction of the thermal performance of the earth to the air heat exchangers. The proposed model has been developed by analyzing temperature data of the circulated air at pipe's outlet using a systematic parametrical process. Four variables are influencing the thermal performance of the earth to air heat exchangers, and they have been taken into account: The pipe length, pipe radius, velocity of the air inside the tube and depth of the buried pipe below earth surface. The algorithm developed in previous researches is suitable for the calculating the exit air temperature and also the cooling potential of the system. The numerical model was validated against an extensive set of experimental data. This indicated that the model can accurately predict the temperature and the humidity of the circulating air, and also the distribution of temperature and moisture in the soil and the overall thermal performance of the earth to air heat exchangers.

Min (2004) investigated the transient soil heat rejection around an EAHE system process. He developed one dimension steady-state model by combining a control volume model with an analytical solution to predict the EAHE outlet temperature, relative humidity and condensation. The model is validated against two sets of published experimental data, and the agreement between the experimental data and the theoretical results was reasonably good. Gyuyoung et al., (2009) proposed a different design procedure for EAHE system which consists of multiple pipes with a close arrangement. They developed a numerical model for multi-cool/heat tube system and it was verified after having some field measurements. The characteristics of heat that transfers from multiple tubes have thermal interference between adjacent tubes, and they were examined by numerical simulations. This prediction method of using approximation expressions is available under the analyzed range of design parameters. It is also available with the variable soil properties and regions. The method is very simple and it is useful to make a decision for proper tube intervals at a given underground space for cool/heat tube systems.

### *2.3.2 Computational Simulation*

After reviewing the literature, this study found that the most common simulation programs used for Earth-to-Air Heat Exchanger systems are TRNSYS, FLUENT, MATLAB, CFD and EnergyPlus. In the Table 2.3 summarizes all those researchers and the program they have used for their investigations on Earth-to-Air Heat Exchanger system.

Table 2.2
Simulation programs used for Earth-to-Air Heat Exchanger research

| Simulation Program | Researchers, Year |
|---|---|
| TRNSYS | Mihalakakou G. et al., 1995; Jacovides C. P. et al., 1995; Santamouris M. et al., 1995; Pierre Hollmuller et al., 2000 and 2005; and Al-Ajmia F. et al., 2006. |
| FLUENT | Vikas Bansal et al., 2010;<br>Darkwa et al., 2011 |
| MATLAB | Rakesh Kumara et al., 2003; Ghosal. et al., 2004; and Ghosal et al., 2006 |
| CFD | Jian Zhang et al., 2005; Huijun Wu et al., 2007; and Jian, 2009 |
| EnergyPlus | Kwang et al., 2008; Miroslaw Z. et al., 2011; Fabrizio et al., 2011; and Sanusi., 2012 |

### *2.3.3 EnergyPlus Program*

EnergyPlus was launched in 1995. This endeavor brought the development of a new energy analysis program. Originally it was intended to be a combination of the best features of the BLAST (Building Loads Analysis and System Thermodynamics) and DOE-2 programs. These programs were developed and released in the late 1970s and early 1980s as energy and load simulation tools. These two programs attempted to solve the same problem from two slightly different perspectives. Both, the BLAST and DOE–2, were written in older version of FORTRAN and used features that eventually went out of date in new compilers, but FORTRAN90 was used for the initial release of EnergyPlus. The use of FORTRAN90 as the programming language for EnergyPlus also allows for the creation of a well-organized, modular program structure that facilitates adding new features and links to other programs (Richard et al., 2000).

Neither BLAST nor DOE–2 is able to correctly handle the feedback from HVAC system to the zone conditions. The speed of development of new technology in the HVAC field has far outpaced the ability of the support and development groups of both programs to keep these programs currently updated and viable. This is the key issue in the existence of EnergyPlus (Getting Started with EnergyPlus, 2012).

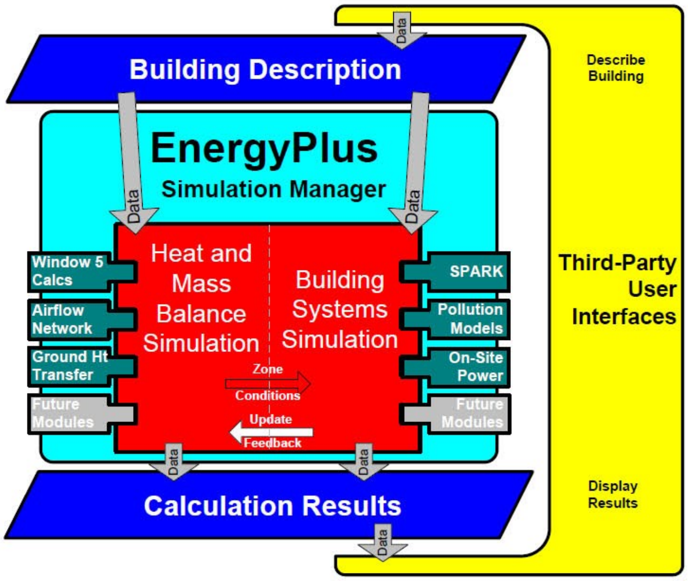

Figure 2.4: Overall EnergyPlus Structure

As shown in Figure 2.4, there are three basic components to EnergyPlus, a Simulation Manager, a Heat and Mass Balance Simulation module (based on IBLAST), and a new Building Systems Simulation module. The Simulation Manager controls the entire simulation process. The Building Systems Simulation Manager handles communication between the heat balance engine and the HVAC water and air loops and their attached components (coils, boilers, chillers, pumps, fans, etc.) The hardwired ‘template’ systems (VAV, Constant Volume Reheat, etc.) of DOE–2 and BLAST have been replaced with user-configurable heating and cooling equipment components. This gives users much more flexibility in matching their simulation to the actual system configurations. The Building Systems Simulation Manager also manages data communication between the HVAC modules, input data, and output data structures (Richard et al., 2000).

The current goals for EnergyPlus has far exceed from those initial ideas. Like its parent programs, EnergyPlus is an energy analysis and thermal load simulation program, which has a modular structure aimed at greatly simplifying the further enhancement of the program by the original development team and other researchers. The simulation program in which the earth tube module was implemented is EnergyPlus. Since the EneryPlus is considered to be the next-generation building performance simulation program, it combines the best features of DOE-2 and BLAST. As a result, it has the great flexibility and capabilities for the comprehensive building simulation. The integrated solution managers in EnergyPlus are of three types: the surface heat balance manager, the air heat balance manager and the building systems simulation manager (Richard et al., 2000).

The Table 2.3 shows a contrast of major features and capabilities of EnergyPlus, BLAST, DOE–2, and IBLAST (a research version of the BLAST program). The availability of specific model for EAHE in a program which is called 'Earth Tube' is an important attribute when attempting to investigate whether or not the EAHE should be used for a particular building and for a particular region. It also determines the most optimal combination with regard to depth, length, radius, and air velocity (Kwang and Richard, 2008).

Table 2.3
Comparisons of HVAC Features and Capabilities (Richard et al., 2000)

| HVAC Systems and Equipment Feature | DOE-2 | BLAST | IBLAST | EnergyPlus |
|---|---|---|---|---|
| Fluid Loops<br>· Connect primary equipment and coils<br>· Hot water loops, chilled water and condenser loops, refrigerant Loops | Yes | No | No | Yes |
| Air Loops<br>· Connect fans, coils, mixing boxes, zones | No | No | No | Yes |
| User-configurable HVAC systems | No | No | No | Yes |
| Hardwired Template HVAC systems | Yes | Yes | Yes | No |
| High-Temperature Radiant Heating<br>· Gas/electric heaters, wall radiators | No | Yes | No | Yes |
| Low-Temperature Radiant Heating/Cooling<br>· Heated floor/ceiling<br>· Cooled ceiling | No | No | Yes | Yes |
| Atmospheric Pollution Calculation<br>· CO2, SOx, NOx, CO, particulate matter and hydrocarbon production<br>· On-site and at power plant<br>· Calculate reductions in greenhouse gases | Yes | Yes | No | Yes |
| SPARK Connection | No | No | No | Yes |
| TRNSYS Connection | No | No | No | Yes |

In this study the feature in EnergyPlus that is use to design for EAHE, called Earth Tube Model. The earth tube model provides a simple earth tube that uses a complex ground heat transfer to establish the temperature of the soil at the depth of the earth tube (EnergyPlus Engineering Reference, 2012).

Kwang and Richard (2008) developed a new model for EnergyPlus program to simulate the Earth-to-Air Heat Exchanger. They validated the model with theoretical and experimental data, which showed satisfactory result. Later they carried out parametric analysis to investigate the effect of pipe radius, pipe length, air flow rate and pipe depth on the overall performance of the EAHE, under various conditions during summer season. Miroslaw et al., (2011) used EnergyPlus as energy simulation software to estimate the cooling potential of EAHE in residential buildings in different

Polish climatic conditions. Their experimental data and calculations results indicate that EAHE proves solution for energy saving in residential buildings.

Fabrizio et al., (2011) experimented the achievable energy performances using EAHE for an air-conditioned building in three different Italian climates, i.e. Naples, Rome, and Milan in both winter and summer seasons. The experiments were conducted to that on the functioning of the system within some boundary conditions, such as the typology of soil, tube material, tube length and depth, velocity of the air crossing the tube, ventilation airflow rates, control modes. They carried out the investigation using EnergyPlus and CalcSoilSurfTemp. The EAHE has shown the highest efficiency for cold climates both in winter and summer.

In Malaysian climate conditions, Sanusi (2012) has conducted the both, field experimental and computational investigation on EAHE systems using the EnergyPlus program. The program data contemporized with the field work data and the results showed that there is a potential benefit of using EAHE. Therefore, this confirms the EnergyPlus as a reliable tool to investigate EAHE in Malaysia (Sanusi, 2012). For that reason, this current study also relies on EnergyPlus program to simulate Earth-to-Air Heat Exchanger system and its implementation in Malaysia.

## 2.4 APPLICATION OF EARTH-TO-AIR HEAT EXCHANGERS

In this section, four buildings that utilize the Earth-to-Air Heat Exchanger are reviewed. The first one is a conventional mechanically ventilated building, and the others are hybrid ventilated. The review is focused on the system configurations, operations, and performance.

### 2.4.1 Schwerzenbacherhof Commercial Building

The Schwerzenbacherhof building is a commercial building located near Zurich, Switzerland. The building has a heating energy consumption of 144 MJ/m$^2$ per year for an area of 8050 m$^2$. To understand process of lowering the temperature with feasible available options, it went through a major case study in the Annex 28 August 1998 Low Energy Cooling which was conducted by the International Energy Agency (IEA) Energy Conservation in Buildings, and the Community Systems (ECBCS) Programme that carries out research and development activities toward near-zero energy and carbon emissions in the built environment (see IEA-ECBCS 1998). In Figure 2.5, it shows the building’s cooling system with air inlet duct. The air cooling system was designed to have two paths for fresh air intake into the building. The system can either pass the air through the EAHE system installed in the building or air handling units (by-bypassing EAHE), as shown in Figure 2.6 (Paolo and Roberto, 2009).

Figure 2.5: The Schwerzenbacherhof office and industrial building.

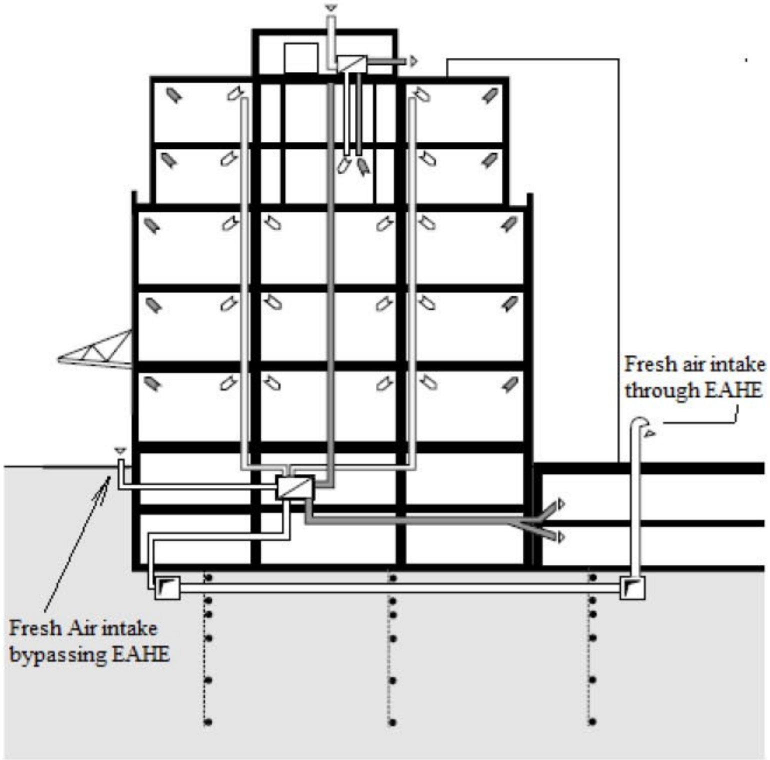

Figure 2.6 Schematic diagram of Schwerzenbacherhof building ventilation system (Hollmuller, 2002).

#### *2.4.1.1 Component description*

The depth of EAHE system is 6m beneath the ground surface, and 75 cm below the building's unheated second basement. The pipe-system uses 43 m (in total) high-density polyethylene pipes installed in parallel with inclination of 1% (see Figure 2.7). Each of them is 23m in length and 230mm in diameter, and the mean axial distance between two pipes is set to 1160mm. The distribution channel for the air it connects with the two large concrete ducts constructed before and after the pipe system. The drainage to the sewage system is provided in the intake-side concrete duct (see Figure 2.8). The variations in the airflow rate are observed during summer and winter in office hours. In summer, the rate is 18,000m$^3$/h whereas in winter it is 12,000m$^3$/h. To avoid the deficiency in the system, the airflow is maintained by two fans in the system, as shown in Figure 2.9.

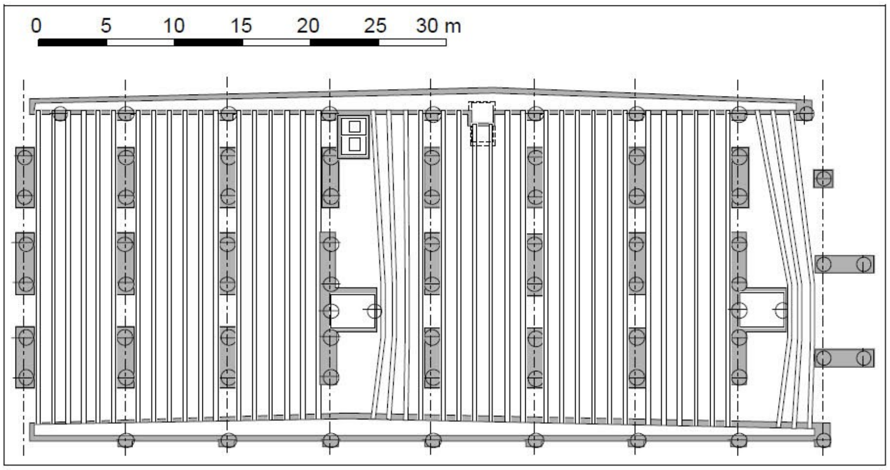

Figure 2.7: General layout and construction detail of the EAHE system in Schwerzenbacherhof building (Hollmuller, 2002).

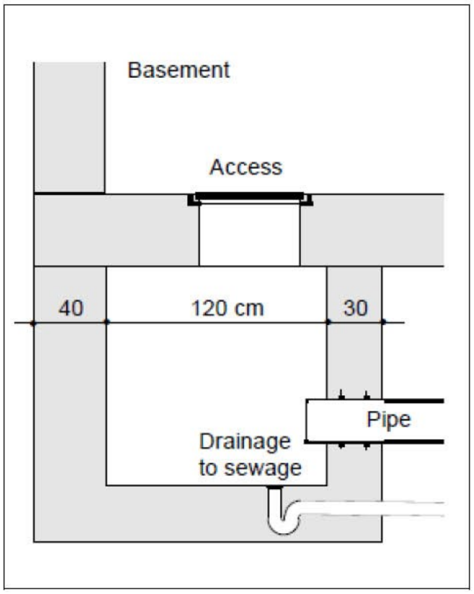

Figure 2.8: Detailed section of the watertight concrete duct of 30 cm wall thickness and the pipe seals (Hollmuller, 2002).

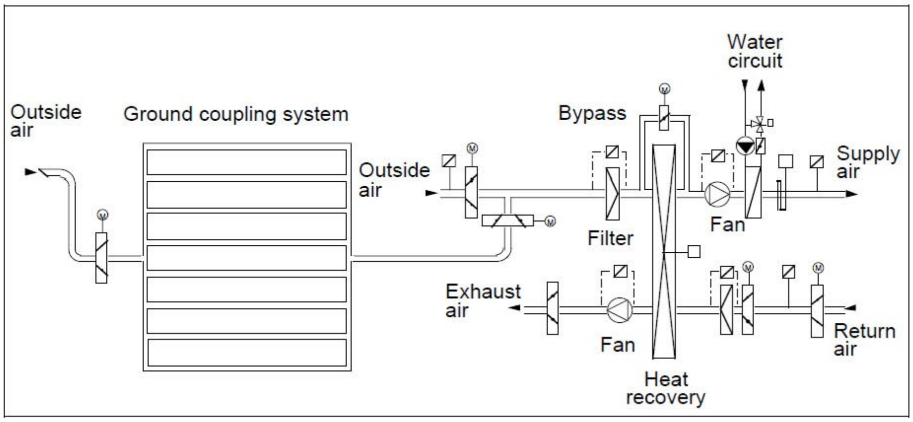

Figure 2.9: Schwerzenbacherhof building - Schematic of the ground coupled and ventilation systems (Hollmuller, 2002).

The EAHE provides about 1/3 of total cooling demand, and the rest is provided by night cooling of the thermal mass. Thus it can be assumed that the EAHE system is effective during the daytime, and when the night air cooling is insufficient for the rooms (see Liddarnent, 2000).

#### *2.4.1.2 Control strategy*

The EAHE system automation activates the system when the temperature exceeds 22°C, especially in day time of summer season. As the system is assigned, it cools the air down as it passes from the pipes of EAHE and then it is supplied to the required rooms. In the case when the outdoor temperature is lower than 22 °C (usually after mid-night), the system diverts the air from EAHE system and takes the fresh air directly from outside to the rooms. In winters the system works quite opposite. When the ambient temperature falls down, the EAHE starts works in providing preheating. Then the outlet air from EAHE passes through the same process and transfers heat from the exhaust air to the outlet air inside rooms. The use of the EAHE system during winter time also helps to cool the ground for the next summer and to prevent freezing of the heat recovery unit.

#### *2.4.1.3 Measured performance*

The reason this study selected Schwerzenbacherhof building as a case study for investigating the performance of EAHE system is because of its low energy cooling measure in the IEA-ECBCS Annex 28 project Liddament (2000). In that project, one year monitoring program was conducted. The parameters that were monitored from the EAHE system were; the upper soil temperature (75 cm above the pipe bed), lower soil temperature (600 cm beneath pipe bed) and inlet/outlet air temperatures and humidity.

From the monitoring program, Liddament (2000) reported the following as conclusions of the overall performance:

- The measured heating demand is 150 kW at -8°C. Without EAHE, the estimated load would be 240 kW. The EAHE itself can meet a peak demand of 60 kW.
- The measured heating energy consumption was 144 MJ/m2 per year is well below the Swiss Standard, at the time of 240 MJ/$m^2$ per year.
- The measured electrical current to operate the ventilation system was 23 MJ/$m^2$ per year which, again, was well below a conventional requirement of 90 MJ/$m^2$ per year.
- The maximum cooling rate was 54 kW at an outdoor supply temperature of 32°C. Comfort cooling was achieved at all times.

### 2.4.2 Mediå School, Grong, Norway

Mediå school is a 1001 $m^2$ one-floor building located in Grong, Norway. It was one of the case studies in the IEA-ECBCS Annex 35, Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HybVent). Both of the building's layouts and schematic of the ventilation system are shown in Figures 2.10 and 2.11 respectively.

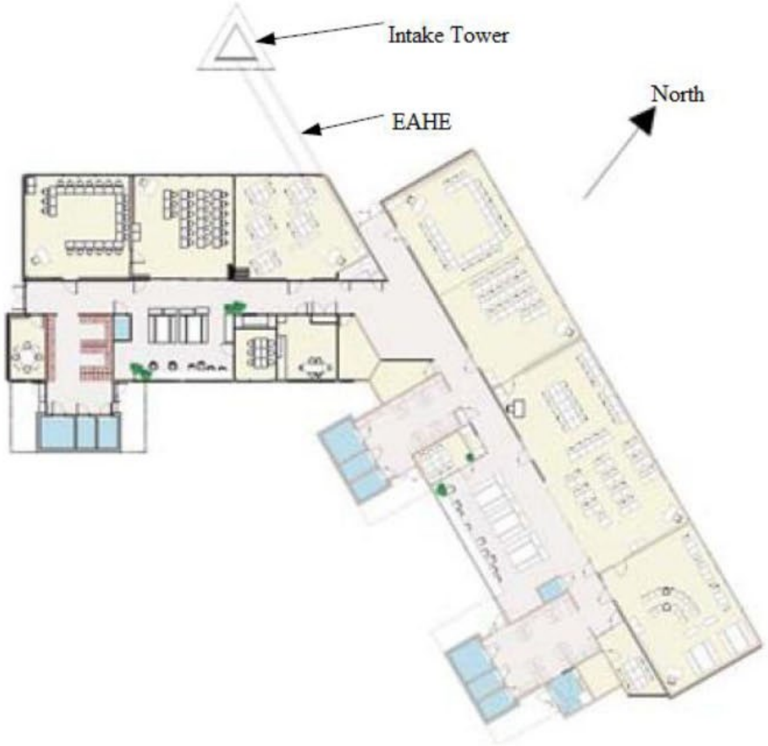

Figure 2.10: Mediå school layout (Paolo and Roberto, 2009).

#### *2.4.2.1 Component description*

An air intake tower for the EAHE system is located on north of the building and stands with 35° slope, as shown in Figure 2.12. The height from the tower is approximately 6m from the base. On each side of the tower, there is an opening which is covered by a metal shield to protect duct from precipitation. Behind the shield, each opening is equipped with a one way damper that allows the air to enter when it is pressurized.

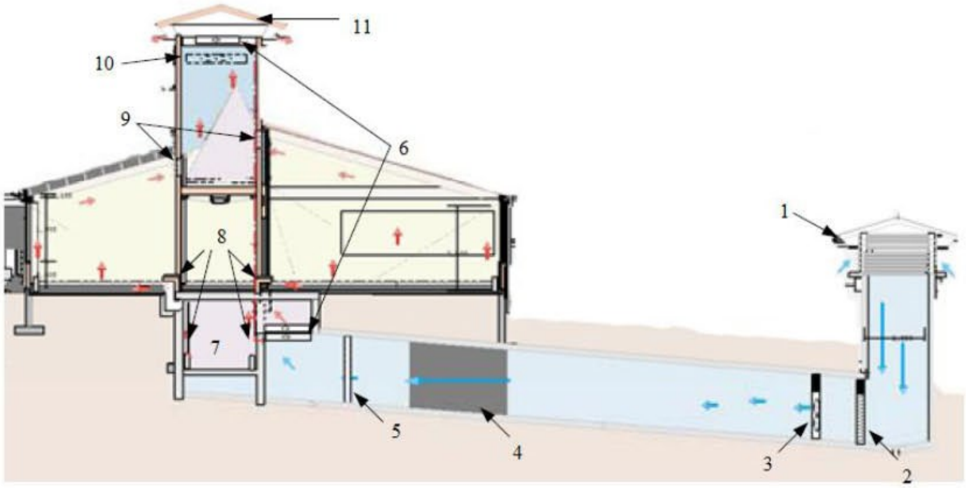

Figure 2.11: Schematic cross section of Mediå school showing air flow paths and location of components 1: triangular intake tower with openings and vents, 2: damper, 3: supply fan, 4: sound absorber, 5: filter, 6: exchangers for supply air preheating using run-round heat recovery via a circulating water-glycol mixture as well as additional reheating, 7: air distribution duct, 8: units for noise attenuation plus openings and grilles for supply of ventilation air to the classrooms, 9: dampers for extracting exhaust ventilation air from the classrooms, 10: extract fan, 11: triangular roof tower with exhaust vents (Paolo and Roberto, 2009).

After passing the air from the intake tower, the downward airflow is led to a horizontal layout of 1.5 m×2m high into concrete air intake duct. In total this will be approximately 1.5m below the earth surface (see Figure 2.11). In order to control the airflow, a damper is installed at the beginning of the duct. A frequency-controlled variable-speed propeller the fan with a diameter of 1.4m, and is located 1.5m away from the damper on the leeward side which is interlinked with the damper opening position. A noise absorber is also installed and located 6.3m from the fan. Six fine filter blocks are installed at the end of the duct. The total distance from the damper to the filters is 11.1 m. The duct has 5% incline to the inlet direction to allow cleaning. Drainage is located at the base of the air intake tower.

Figure 2.12: ETAHE's intake tower of Mediå school (Paolo and Roberto, 2009).

As it can be seen from the Figure 2.13, the air vertically passes through two overlapped heat exchangers after leaving the intake duct and then enters into 2.2m by 2m horizontal air distribution duct. This duct has two branches which are below the building's corridor. From this intake duct, the air can also divert and bypass the heat exchangers by flowing through two "summer" doors beside the exchangers. Figure 2.13 (right side) shows the distribution duct which has the air supply paths that are attached to the walls into the ground level of classrooms. These paths suppress sound transmission between rooms and ensure even supply air temperatures to all rooms.

Figure 2.13: Air distribution duct of Mediå school (Left photo shows heat exchangers and "summer" doors. Right photo shows the supply air paths) (Paolo and Roberto, 2009).

#### *2.4.2.2 Control strategy*

The control strategy of HVAC system is monitored and controlled by a centralized supervisory system called the Building Energy Management System (BEMS). This system has sensors which are measuring the $CO_2$ obsession and the temperature in most classrooms. The temperature in the distribution duct is set with 19°C. This is ensured by the two heat exchangers at the end of the air intake ducts. The EAHE preheats air in winters. And in summers the building does not have any other cooling system function but the EAHE system. The ventilation is primarily controlled by the differences between the classrooms' $CO_2$ levels and their set temperature. However, when the room temperature exceeds a set value of 24°C, the ventilation airflow increases air pressure to avoid further rise in the temperature. The supply fan is activated by the BEMS when air changes rate are required. When the two heat exchangers are not needed, the bypass doors can be manually opened to reduce the pressure loss.

### 2.4.3 Centre for Sustainable Energy Technologies at the University of Nottingham, Ningbo- China

The Centre for Sustainable Energy Technologies (CSET) building is a landmark collaborative project between the United Kingdom and China to address some of the major issues affecting sustainable development in China (see Figure 2.14). Being a centre of excellence in research and teaching, the CSET also play a key role in the proposed Virtual Academy for Sustainable Cities, outlined under the Memorandum of Understanding in January 2008. It has been designed to minimize environmental impacts by promoting energy efficiency, generating its own energy from renewable sources, and using locally available materials with lowest embodied energy. The main function of the building is to provide a specialist research laboratory for staff and post-graduate students within the new Centre for Sustainable Energy Technologies. It is linked with the laboratory facilities and will assist in conducting workshops for fabrication of experimental rigs etc., and the development of new components (The Centre for Sustainable Energy Technologies (n.d)).

Figure 2.14: Centre for Sustainable Energy Technologies building at the University of Nottingham, Ningbo- China. (Source: Sergio, n.d.).

#### *2.4.3.1 Description of the Earth-tube ventilation system*

Figure 2.15 to 2.17 show the system that represents the main source of fresh air supply into the research laboratory in the Centre for Sustainable Energy Technologies (CSET) at the University of Nottingham, Ningbo, China. It uses a network of six underground thermo-pipes to transfer the fresh air through air handling unit (AHU) into the building. The pipes are made from a special formulated polypropylene material which optimizes heat when air is transferred from the ground. Additionally, the pipes has unique antimicrobial layer made from silver particles to prevent microbial growth. Each pipe measures the lengths of 50m in length and 400mm in diameter, and is laid below ground level at a gradient of 1.5–3m gradient to enable condensate to be collected in a sump. The high longitudinal rigidity of the pipes is meant to prevent sagging, thereby helping condensation to be safely discharged and avoiding formation of puddles at the lowest points. Even though the manufacturers recommend that the pipes should be laid in bare soil, it is worth mentioning that they were laid on a medium textured concrete foundation due to the unsettling nature of the soil at the site (Darkwa et al., 2011).

Figure 2.15: Earth-tube ventilation system construction in the CSET building (Darkwa et al., 2011).

### *2.4.3.2 Investigation result on the system*

Darkwa et al., (2011) theoretically and practically evaluated the technique of earth-tube ventilation system as an energy saving technology. The results have shown that the system has the positive stances to become an effective energy saving technology in buildings. For instance in March and July 2010, the EAHE system was able to contribute 62% and 86% during the peak heating and cooling loads respectively, and also achieved corresponding coefficient of performances (COPs) of 3.2 and 3.53, respectively. The average relative humidity level in the heating period was reduced by

10%, whereas in summer the average humidity level increased by 15% and was attributed to high level of latent heat exchanges within the earth-tube.

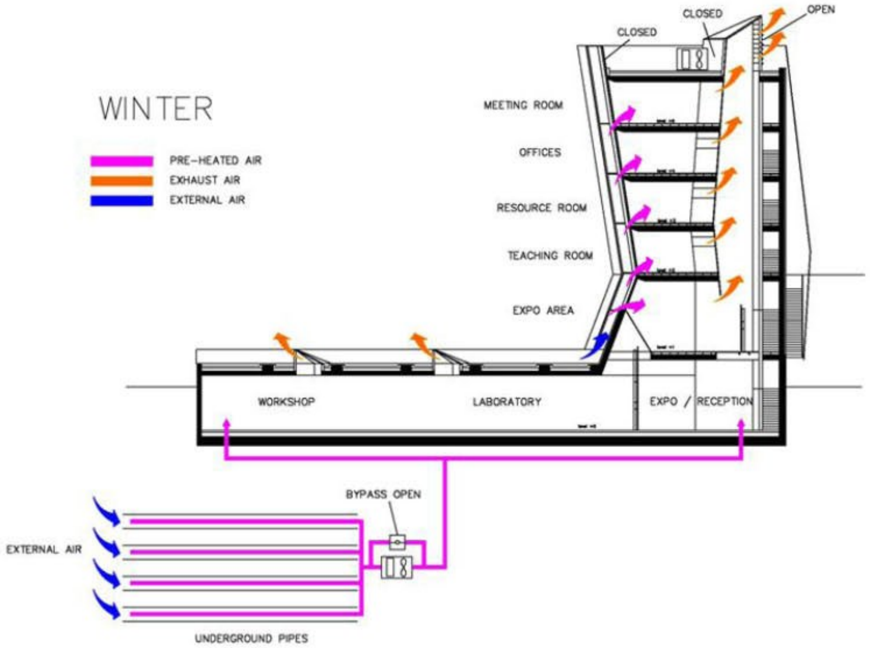

Figure 2.16: CSET building, heating system schematic diagram (Source: Sergio, n.d.).

The overall performance of the system is found to be encouraging also for typical hot and humid locations, where there are certain conditions of soil (wet, freezing and dry soils) which could affect its thermal to perform better (Darkwa et al., 2011).

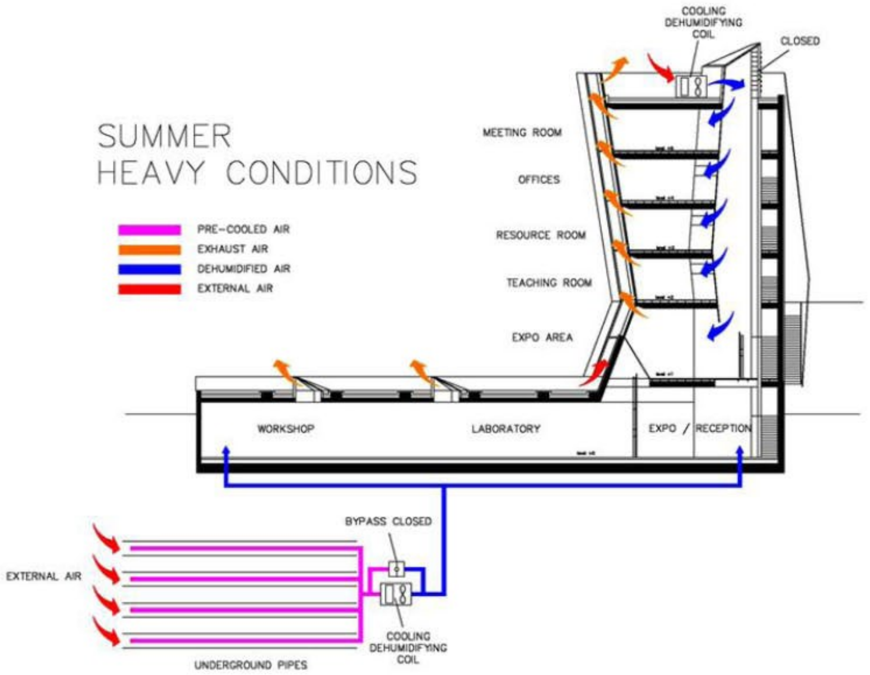

Figure 2.17: CSET building, cooling system schematic diagram (Source: Sergio, n.d.).

### 2.4.4 Experimental Shed at the International Islamic University Malaysia (IIUM), Kuala Lumpur, Malaysia

#### *2.4.4.1 Field Work Site*

Sanusi (2012) constructed a shed to conduct a field experiment in the campus of the International Islamic University Malaysia (IIUM), Gombak, Selangor, Malaysia (3°17’ 60 N and longitude 101° 46’ 60 E). Figure 2.18 show the experiment site (red dot).

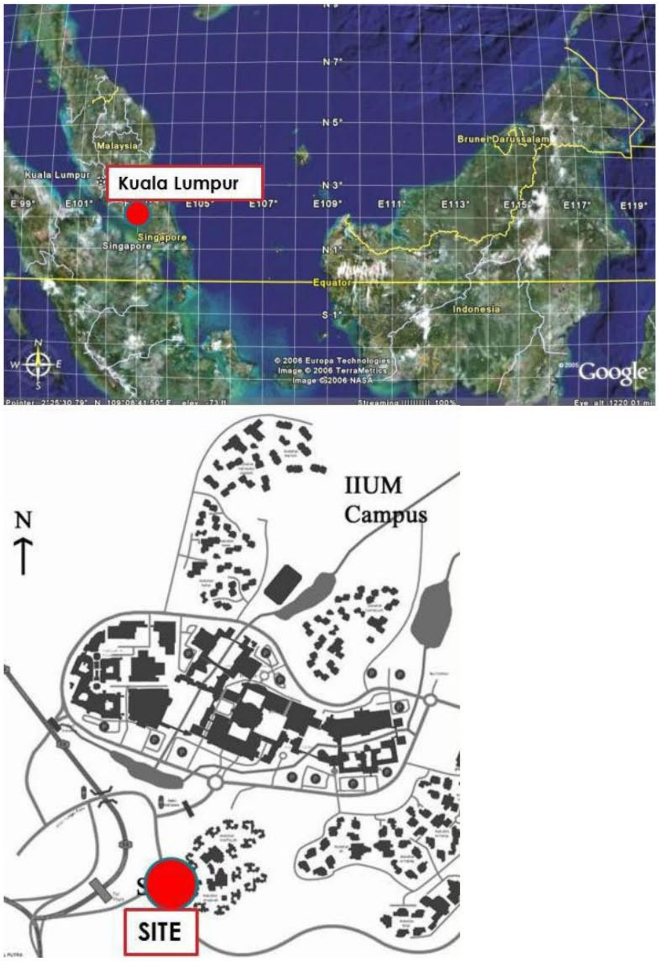

Figure 2.18: International Islamic University Malaysia campus.

The experiment consisted of two stages; the first stage was concerned with recording the soil temperature at various depths up to 5m. The second stage was concerned with the investigation of the performance of Earth-to-Air Heat Exchanger systems.

### *2.4.4.2 Description of the Experimental Shed*

The shed is an 8 $m^3$ single space building with a pitched roof, two windows and one door. The EAHE experiment set up includes the burial of long pipes into the ground and the construction of an experiment shed (see Figure 2.19). A multi-speed centrifugal fan was installed to the intake pipe's header. The centrifugal fan draws outside air and supplies it to the shed through the aforementioned pipes. The details of the parameters are shown in Table 2.4

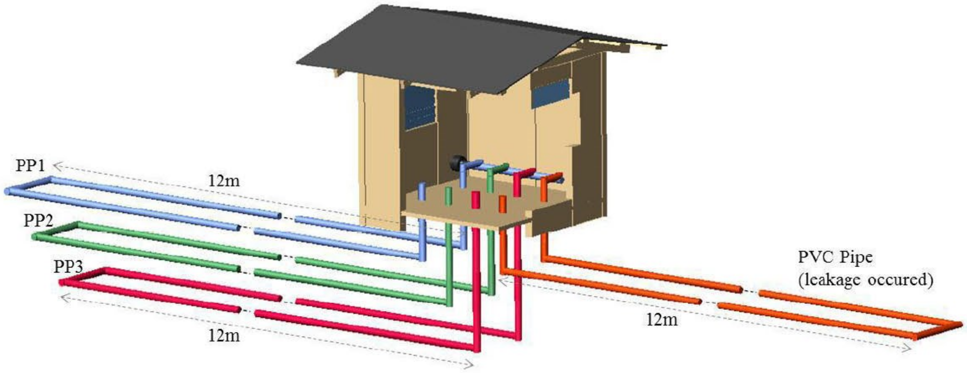

Figure 2.19: EAHE experiment set up.

Table 2.4
Field experiment parameters used in April/May 2009.

| **Parameters** | **Detail description** |
|---|---|
| Depth | 0.5m, 1.0m, and 1.5m |
| Length | 25m |
| Pipe Diameter | Polyethylene = 7.36 cm<br>PVC = 10.2 cm |
| Pipe Thickness | Polyethylene = 0.82 cm<br>PVC = 0.2 cm |
| Air Speed | 5.62 m/s |
| Materials | Polyethylene Pipe and PVC pipe |

#### *2.4.4.3 Experiment Results*

##### 2.4.4.3.1 Soil Temperature

The soil temperature data was measured for a period of one year. The data was used in the EnergyPlus simulation software later. The shallow ground temperature inputs were obtained at 0.5m depths, whereas the deep soil temperature inputs were obtained at 4m depths. The monthly shallow and deep soil temperatures measured at 0.5m and 3-4m depths respectively, are shown in Table 2.5.

Table 2.5
Shallow and Deep Soil Temperature:

| Month | Ground Temperature: Shallow (°C) | Ground Temperature: Deep (3-4m depth) (°C) |
|---|---|---|
| January | 27.8 | 29.4 |
| February | 28.6 | 29.4 |
| March | 29.8 | 29.4 |
| April | 30.1 | 29.4 |
| May | 30.2 | 29.4 |
| June | 29.8 | 29.4 |
| July | 29.3 | 29.4 |
| August | 29.3 | 29.4 |
| September | 29.1 | 29.4 |
| October | 29.3 | 29.4 |
| November | 28.8 | 29.4 |
| December | 28.5 | 29.4 |

The model Earth Tube in EnergyPlus calculates three essential parameters (annual mean ground surface temperature, amplitude of the annual soil surface temperature variation and phase constant of the soil surface), deriving from Weather File. Those three parameters are a prerequisite for a successful simulation of the EAHE system. But the real measured soil temperature data will be use instead for all soil related inputs. This data set was used in the simulation experiment that forms the backbone of this research.

*2.4.4.3.2 Earth-to-Air Heat Exchanger performance at 1 m depth*

The experiments during the hot and dry season were carried out at 1.0 m depth on 25 m length pipe. The fan blower provides an air flow through the pipe at a constant speed of $5.6 m.s^{-1}$.

The soil temperatures were measured in two days ranged from 29.9°C to 30.0°C. The temperatures at the inlet and outlet of the buried pipe ranged from 24.4°C to 37.0°C and from 24.7°C to 31.2°C respectively (see Figure 2.21). The maximum reduction in temperature was found to be 6.9°C and it occurred during the day when the fan blower was operating. The average maximum reduction in temperature over a two-day period was found to be 6.0°C.

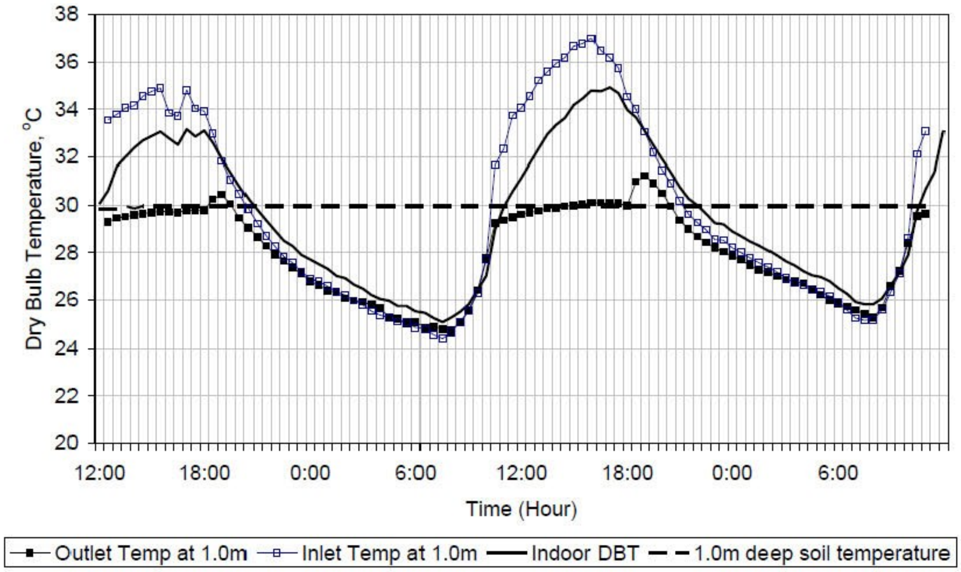

Figure 2.20: Trend of Temperatures at 1.0m Depth.

#### *2.4.4.4 Computational Simulation Investigation*

Further investigation was carried out on the same experiment by computational simulation using the EnergyPlus software. EnergyPlus data was consistent with the field work data, and therefore, this confirms that EnergyPlus is a reliable software to investigate Earth-to-Air Heat Exchangers in Malaysia. The following graphs (Figure 2.23 and Figure 2.24) show the comparison between the data obtained in the field work and the data predicted by EnergyPlus. The graphs show that the data obtained from the EnergyPlus simulation software are very consistent with the data obtained from the actual field investigation.

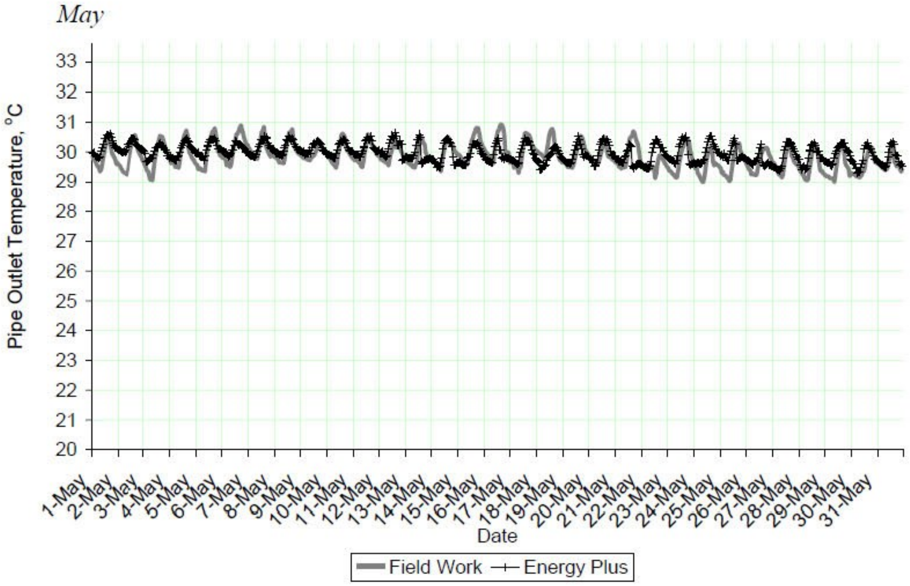

Figure 2.21: Comparison of field work and EnergyPlus (Data obtained in May)

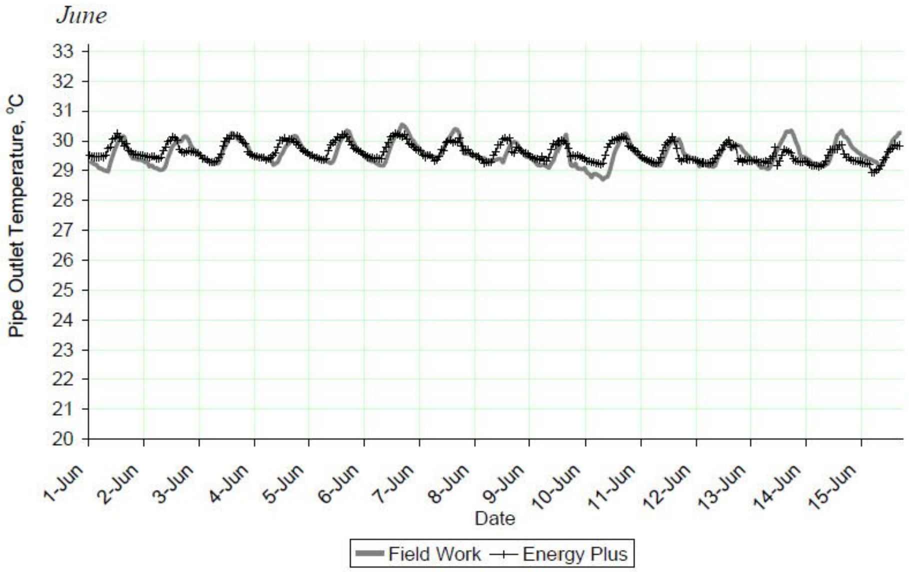

Figure 2.22: Comparison of field work and EnergyPlus (Data obtained in June)

## 2.5 CONCLUSION

This review highlights the potential of EAHE systems as a viable passive cooling technology for buildings. Therefore it is certainly an area worthy of the interest it garnered by researchers. Many investigations have been conducted on such systems at different climatic and environmental contexts, and on various aspects, by both site experiments and computational simulation studies. It has been proven as a feasible system that can be implemented within Heating Ventilation and Air Conditioning (HVAC) systems. Performing parametric studies is vital for choosing the optimal configuration of an EAHE system. Such studies will help researchers determine important parameters such as pipe diameter, air velocity, pipe depth, and pipe length for a given building within a particular climatic context. EnergyPlus can be considered reliable simulation software for investigating EAHE systems. Finally Malaysian soil has the potential to be used as a heat sink for EHAE systems.

# CHAPTER THREE

# METHODOLOGY

The methodology chapter actually describes the numerical model of the Earth Tube. The model is sculpted in EnergyPlus system coupled with two heat transfer processes the heat transfer by convection between the pipe of inner surface and air flowing in the pipe, and the heat transfer by conduction between the pipe outer surface and the surrounding soil. Then this research setup the procedures of Earth-to-Air Heat Exchanger of EnergyPlus by outlining required input fields in order to simulate the Earth-to-Air Heat Exchanger, including the design of the entire system and the building in which the system is to be installed. Finally, the research procedures are applied to conduct the study.

## 3.1 EARTHTUBE SIMULATION MODELS

In this study, the EnergyPlus simulation software Version 7.1.0 (2012) is used to analyze a wide range of the EAHE system's parameters to obtain the maximum temperature difference $\Delta T$ between ambient and pipe-outlet air temperature, in hot and humid climate in Malaysia. The software (EnergyPlus) is capable of offering features of two software DOE-2 and BLAST, simultaneously. Both the analysis on energy and simulate thermal load for building has been taken into consideration. In addition to that, EnergyPlus also tabulates the output temperatures of the building.

The Earth tube model used in EnergyPlus processes the air and transfers heat into the ground and sets air temperature up to the soil temperature in the depth surrounding the buried pipe (EnergyPlus Engineering Reference, 2012). The Earth tube was modeled as two coupled heat transfer processes, which are, heat transfer by convection between the pipe inner surface and air flowing in the pipe, and heat transfer by conduction between the pipe outer surface and the surrounded soil. The following assumptions were applied to analyze the Earth-to-Air Heat Exchanger system (Al-Ajmia et al., 2006):

a. The soil properties surrounding the pipe are isotropic, with homogenous thermal conductivity in all ground strata.
b. Thermal resistance due to tube thickness is negligible (pipe thickness is very small).
c. The ground surface temperature can be equated to the ambient air temperature, which equals the tube inlet air temperature.
d. The pipe is of uniform cross-section.
e. The thermal effect of soil temperature in the pipe vicinity is negligible after a distance ‘r’ from the pipe outer surface, where ‘r’ is the pipe radius.

Assuming a homogeneous soil of constant thermal diffusivity, the temperature at any depth (z) and time (t) can be estimated by the following expression. The prediction accuracy of the undisturbed soil temperature is very sensitive to the values of the input parameters in the equation (Al-Ajmia et al., 2006; EnergyPlus Engineering Reference, 2012).

$$T_{z,t} = T_m - A_s \cdot \exp\left[-z\left(\frac{\pi}{365a_s}\right)^{0.5}\right]\cos\left\{\frac{2\pi}{365}\left[\mathrm{t}-\mathrm{t_o}-\frac{\mathrm{z}}{2}\left(\frac{365}{\pi a_s}\right)^{0.5}\right]\right\} \qquad \text{Eq. 3.1}$$

By integrating the expression with respect to depth, the average temperature of a vertical soil profile ranging between depth $z_1$ and $z_2$ (°C) can be determined as follows:

$$T_{z_1,z_2,t} = T_m + \frac{A_s}{(z_2 - z_1)\gamma\sqrt{2}} \left\{ e^{-\gamma z_1} cos\left[\frac{2\pi}{365}\,(t - t_0 - z_1 L - 45.6)\right] - e^{-\gamma z_2} cos\left[\frac{2\pi}{365}\,(t - t_0 - z_2 L - 45.6)\right]\right\} \quad \text{Eq.3.2}$$

where

$$\gamma = (\pi / 365\alpha_s)^{1/2}$$

$$L = \frac{1}{2}(365 / \pi\alpha_s)^{1/2}$$

As the final step with regard to the heat transfer between soil and earth tube system, thermal conductivity of air (W/m°C), $k_{air}$, and kinetic viscosity of air ($m^2/s$), $\upsilon$, should be calculated first.

$K_{air} = 0.02442 + (10^{-4}\,(0.6992\,T_a))$

$\upsilon = 10^{-4}\,(0.1335 + 0.000925\,T_a)$

By using the values of thermal conductivity of air, $k_{air}$, and kinetic viscosity of air, $\upsilon$, the convective heat transfer coefficient at the inner pipe surface ($W/m^{2}{}^\circ C$), $h_c$ , can be evaluated. It is a function of Reynolds number, Re, and Nusselt number, Nu, where:

$$h_c = \frac{Nu k_{air}}{2r_1}$$

$$Nu = \frac{(f_a/2)(Re - 1000)Pr}{1 + 12.7(f_a/2)^{1/2}\,(Pr^{2/3} - 1)}$$

$$f_a = (1.58 \ln Re - 3.28)^{-2}$$

$$Re = \frac{2r_1\,V_a}{v}$$

$$Pr = \frac{v}{a_{air}}$$

where $r_l$ is inner pipe radius (m), and $V_a$ is average pipe air velocity (m/s).

After determining the convective heat transfer coefficient, and in order to calculate the heat transfer between the earth tube and the surrounding soil, the overall heat transfer coefficient should be determined using the following three thermal resistance values *Rc*, *Rp* and *Rs*.

$$R_c = \frac{1}{2\pi r_1 h_c}$$

$$R_p = \frac{1}{2\pi k_p} \ln \frac{r_1 + r_2}{r_1}$$

$$R_s = \frac{1}{2\pi k_s} \ln \frac{r_1 + r_2 + r_3}{r_1 + r_2}$$

Where $R_c$ is thermal resistance due to convection heat transfer between the air in the pipe and the pipe inner surface (°C/W), $R_p$ is thermal resistance due to conduction heat transfer between the pipe inner and outer surface (°C/W), and $R_s$ is thermal resistance due to conduction heat transfer between the pipe outer surface and undisturbed soil (°C/W). In addition, $r_2$ is pipe thickness (m), $r_3$ is distance between the pipe outer surface and undisturbed soil (m), and $L$ is pipe length (m). Finally, heat balance between surrounding soil and air stream passed through the tube is described by the following equation, and is used to determine outlet air temperature (Jacovides and Mihalakakou, 1995).

$$U_t\,[\,T_a(y) - T_{z,t}\,]dy = -m_a\,C_a\,[dT_a(y)] \qquad \text{Eq. 3.3}$$

where

$$U_t = \frac{1}{R_t}$$

$$R_t = R_c + R_p + R_s$$

Where $U_t$ is overall heat transfer coefficient of the whole earth tube system (W/C-m), $T_a(y)$ is air temperature of the pipe at the distance y from the pipe inlet (°C), and $m_a$ is mass flow rate of ambient air through pipe (kg/s). $Ca$ is specific heat of air (J/kg°C) and $R_t$ is total thermal resistance between pipe air and soil (m-C/W).

Initial condition of inlet air temperature is equal to the ambient air temperature. Outlet air temperature is finally evaluated by solving the heat transfer equation (Eq.3.3). By solving for air temperature inside the pipe $T_a(y)$, the following earth tube inlet air temperature (defined as the air leaving the earth tube and entering the space in this study) can be finally obtained (Kwang and Richard, 2008; Fabrizio et al., 2011).

In case $T_{am} > T_{z,t}$ $\quad T_a(y) = T_{z,t} + exp\ (A)$

In case $T_{am} = T_{z,t}$ $\quad T_a(y) = T_{z,t}$

In case $T_{am} < T_{z,t}$ $\quad T_a(y) = T_{z,t} - exp\ (A)$

where

$$A = \frac{\dot{m}_a C_a \ln|T_{am} - T_{z,t}| - U_t L}{\dot{m}_a C_a}$$

## 3.2 SIMULATION SET UP IN ENERGYPLUS

The required configuration to simulate the Earth-to-Air Heat Exchanger includes the design of the system and the building in which the system is to be installed. As the fan pressure rises, its efficiency to move the air inside the Earth tube system becomes vibrant. Moreover, the tool required the normalize soil surface temperature, the amplitude of soil surface temperature, and the phase constant of soil surface temperature. For the simulation of the Earth tube, a weather data file is mandatory, and without that the Earth tube system will not operate efficiently (EnergyPlus Input Output Reference, 2012). The weather data used by Energy Plus software contains the monthly soil temperature at several depths, hourly dry bulb temperature, hourly dew point temperature, and relative humidity. Kuala Lumpur weather file which used in this study obtained directly from U.S. Department of Energy Website which is originally from Source Data (c) 2001 American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Inc., Atlanta, GA, USA.

In most cases, having weather data is sufficient to predict soil temperature using external module that came with Energy Plus software. While Average Soil Surface Temperature, Amplitude of Soil Surface Temperature, and Phase Constant of Soil Surface Temperature $T_m$, $A_s$, and $t_0$ respectively are calculated by the CalcSoilSurfTemp program, and these factors are inputs for EnergyPlus. In this study, the real data for all soil properties input were placed in the program, which were obtained from experiment records (Sanusi, 2012). The soil temperature data was measured in the field experiment site throughout one whole year, and these were used in Energy Plus study.

### 3.2.1 Input data file (IDF) in EnergyPlus

The input data is classified in a range of class lists. However, only 7 class lists are applicable to simulate the EAHE system. Within each 7 class lists, there are various numbers of input data.

**i. The 1st class list is Simulation Parameters**.

Within this class list, inputs given were Energy Plus version. Simulation is controlled by the sizing period and weather file run periods, and the number of data in an hour. Since the data recorded in field work were hourly, the number of data in an hour was set to 1 in Energy Plus.

ii. **The 2nd class list is Location and Climate of the experiment site.**

This includes input of the site latitude, longitude, time zone and elevation above sea level. The input in this class list continues with the sizing period of the file. This is followed by the run period which was also set to the same month as the sizing period. This class also includes the monthly soil temperature at shallow (0.5m) and deep (3-4m) depths (see Table 3.1).

iii. **The 3rd class list is Schedules.**

This is used to determine the operation of the fan blower, whether it is operating all day or at certain hours of a day. In this study, the fan operation is set to 24 hours.

Table 3.1

Input data of Site: Ground Temperature: Shallow and Deep in Energy Plus file

| Month | Ground Temperature: Shallow (°C) | Ground Temperature: Deep (3-4m depth) (°C) |
|---|---|---|
| January | 27.8 | 29.4 |
| February | 28.6 | 29.4 |
| March | 29.8 | 29.4 |
| April | 30.1 | 29.4 |
| May | 30.2 | 29.4 |
| June | 29.8 | 29.4 |
| July | 29.3 | 29.4 |
| August | 29.3 | 29.4 |
| September | 29.1 | 29.4 |
| October | 29.3 | 29.4 |
| November | 28.8 | 29.4 |
| December | 28.5 | 29.4 |

(Source: Sanusi 2012)

**iv. The 4th class list is Surface Construction Elements.**

This class list starts with inputs of all building materials used with a full set of each material's thermal properties. The thermal properties include the material's roughness, thickness, conductivity, density, specific heat, thermal absorptance, solar absorptance and visible absorptance.

**v. The 5th class list is Thermal Zones and Surfaces.**

In this class list, all building surfaces are given its own vertex coordinates that form the building walls, floor, roof, windows and door. All the building surfaces form the building to be measured, which in EnergyPlus, is called thermal zone. In this study, there is only one thermal zone since the experiment building is a single space building with centrally 2 pitched roof, two windows and one door.

**vi. The 6th class list is Zone Airflow**

This contains the specific input of the Earth Pipe design (see Table 3.2). In this study the real data for all soil properties input was used in the program which obtained from experiment records such as Average Soil Surface Temperature, Amplitude of Soil Surface Temperature, and Phase Constant of Soil Surface Temperature (Sanusi, 2012).

Table 3.2
Basic Set Up in Energy Plus program files in Zone Airflow class list, ZoneEarthtube column.

| Parameters | Values | |
|---|---|---|
| Schedule Name | Fan Blower Operates All Day (24 hours) | |
| Design flow rate | Table 3.4 | |
| Minimum Zone Temperature when Cooling | 20°C | (Sanusi, 2012) |
| Maximum Zone temperature when Heating | 50°C | |
| Earthtube Type | Intake | |
| Fan pressure rise | 520 Pascal | |
| Fan Total Efficiency | 0.85 | |
| Pipe Radius | Table 3.3 | |
| Pipe Thickness | Table 3.3 | |
| Pipe Length | Table 3.3 | |
| Pipe Thermal Conductivity | 0.19 W/m·k | |
| Pipe Depth Under Ground Surface | Table 3.3 | (Sanusi, 2012) |
| Soil Condition | Heavy and Damp | |
| Average Soil Surface Temperature | 29.21°C | |
| Amplitude of Soil Surface Temperature | 1.642°C | |
| Phase Constant of Soil Surface Temperature | 350 days | |

Table 3.3
Input parameters used for simulations

| V1 | | | V2 | V3 | V4 |
|---|---|---|---|---|---|
| Nominal Pipe Size (inches) | Pipe Radius (m) | Pipe Thickness (m) | Air Velocity | Pipe Depth (m) | Pipe Length (m) |
| 1 | 0.0127 | 0.003378 | 1 | 1 | 12.5 |
| 2 | 0.0254 | 0.003912 | 2 | 1.5 | 25 |
| 3 | 0.0381 | 0.005486 | 4 | 2 | 40 |
| 4 | 0.0508 | 0.00602 | 6 | 2.5 | 50 |
| 5 | 0.0635 | 0.006553 | 8 | 3 | 60 |
| 6 | 0.0762 | 0.007112 | 10 | 3.5 | 70 |
| 8 | 0.1016 | 0.008179 | | 4 | 80 |
| 10 | 0.127 | 0.009271 | | | |
| 12 | 0.1524 | 0.010312 | | | |

Table 3.4
Conversion table to convert air velocity to air flow rate.

| Nominal Pipe Size m (inch) | Flow rate at different velocities ($m^3.s^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 1 $m.s^{-1}$ | 2 $m.s^{-1}$ | 4 $m.s^{-1}$ | 6 $m.s^{-1}$ | 8 $m.s^{-1}$ | 10 $m.s^{-1}$ |
| 0.025 (1) | 0.00051 | 0.00101 | 0.00203 | 0.00304 | 0.00405 | 0.00506 |
| 0.05 (2) | 0.00203 | 0.00405 | 0.00810 | 0.01215 | 0.01621 | 0.02026 |
| 0.075 (3) | 0.00456 | 0.00912 | 0.01823 | 0.02735 | 0.03646 | 0.04558 |
| 0.10 (4) | 0.00810 | 0.01621 | 0.03241 | 0.04862 | 0.06483 | 0.08103 |
| 0.125 (5) | 0.01266 | 0.02532 | 0.05065 | 0.07597 | 0.10129 | 0.12661 |
| 0.15 (6) | 0.01823 | 0.03646 | 0.07293 | 0.10939 | 0.14586 | 0.18232 |
| 0.20 (8) | 0.03241 | 0.06483 | 0.12965 | 0.19448 | 0.25930 | 0.32413 |
| 0.25 (10) | 0.05065 | 0.10129 | 0.20258 | 0.30387 | 0.40516 | 0.50645 |
| 0.30 (12) | 0.07293 | 0.14586 | 0.29172 | 0.43757 | 0.58343 | 0.72929 |

**vii. The 7th class list is Output Reporting.**

Once all input have been recorded, the simulation was carried out using the EP-Launch programme. In this programme, the Input Data File (IDF) and Malaysia weather file were selected before the simulation commencement.

## 3.3 RESEARCH PROCEDURES

To conduct this study, the following steps were taken as research procedure.

a) Review available literature on Earth-to-Air Heat Exchanger systems, and the parametric studies conducted by other researchers.

b) Study the EnergyPlus simulation program.

c) Construct the Earth tube system in EnergyPlus and input the required data.

d) Input the variables: V1: Pipe radius, V2: Air velocity, V3: Pipe depth underground surface, and V4: Pipe length as follows:

   i) Fixing the variables: V2, V3, & V4, varying V1: to find optimum pipe diameter.
   ii) Fixing the variables: V1, V3, & V4, varying V2: to find optimum air velocity.
   iii) Fixing the variables: V1, V2, & V4, varying V3: to find optimum pipe depth underground surface.
   iv) Fixing the variables: V1, V2, & V3, varying V4: to find optimum pipe length.
e) Convert the tabulated results into diagrammatic graphs.
f) Analyze the obtained results.

The flowchart in Figure 3.1 illustrates the simulation procedure for running the EnergyPlus program.

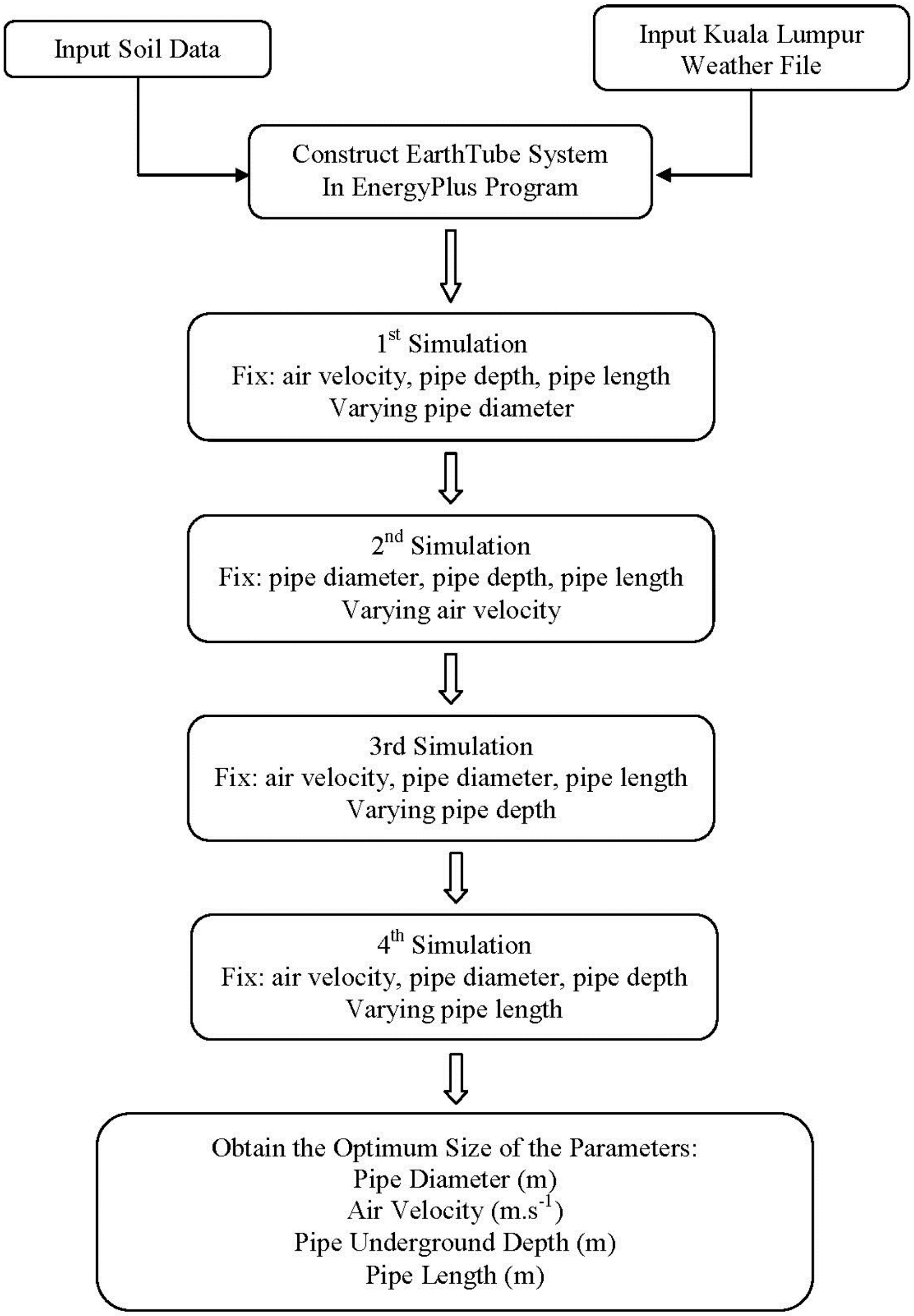

Figure 3.1: Flowchart of Methodology

# CHAPTER FOUR

# SIMULATION RESULTS AND DISCUSSION

This chapter presents the simulation results. It contains four processes for the main parameters namely pipe diameter, air velocity, pipe depth, and pipe length. The simulation is based on Kuala Lumpur Weather File data and the field soil data.

## 4.1 SIMULATION 1: INFLUENCE OF PIPE DIAMETER

The first simulation investigates the influence of different pipe diameter on the potential of EAHE system. The air velocity, pipe length and depth were set at 4 $ms^{-1}$, 50 m and 1 m respectively while the pipe diameter is varied from 0.025 m to 0.3 m (1 inch to 12 inches). However, simply increasing the pipe diameter under same air flow rate will decrease the air velocity inside the pipe, resulting in a decrease in the pipe-outlet air temperature ($T_{po}$). Therefore pipe diameter and air flow rate should be considered together. From Table 3.4 in Chapter 3 the flow rate of every single pipe size can selected at any rate of air velocity.

The effect of pipe diameters on the hourly variations of $T_{po}$ for a typical day in the month of June (the hot season) have been depicted in Figure 4.1. It can be observed that the fluctuations of the $T_{po}$ follow the variations of the ambient air temperatures ($T_{am}$) but decrease significantly in amplitude. From Figure 4.1 three patterns can be observed. First, all $T_{po}$ are lower than $T_{am}$ after 11.00am. Second, all $T_{po}$ is higher than the $T_{am}$ after 8.00pm. Third, $T_{am}$ peaks at around 2.00pm.

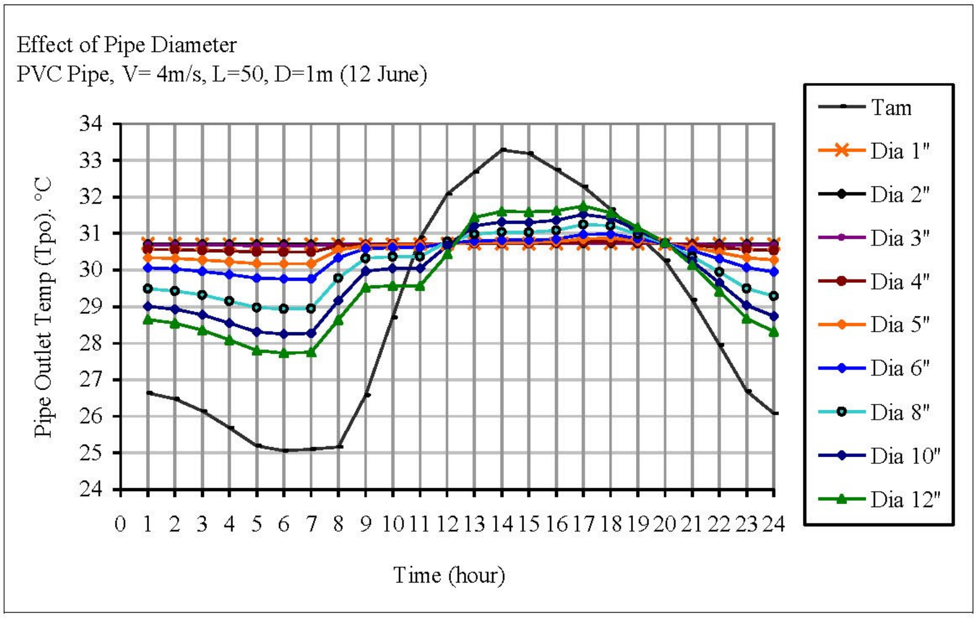

Figure 4.1: Effect of pipe diameters on $T_{po}$ on a typical summer day.

Moreover, from 11.00 am to 8.00 pm when the hourly ambient temperatures are higher than pipe-outlet temperatures, the the maximum temperature reduction was 2.55 °C and it occurred at smaller pipe sizes. There are two reasons behind this happening. First, when cross-section of pipe is small; the amount air in the center of the pipe gets closer to the surrounding soil. Hence this enables more efficient heat transfer and hence a closer temperature ranges to the surrounding soil temperature. Second, the effect of the pipe wall thickness. The smaller pipes have less wall thickness. When the pipe wall is thin, the heat transfers between the air inside the buried pipe and the soil surrounding the pipe increases.

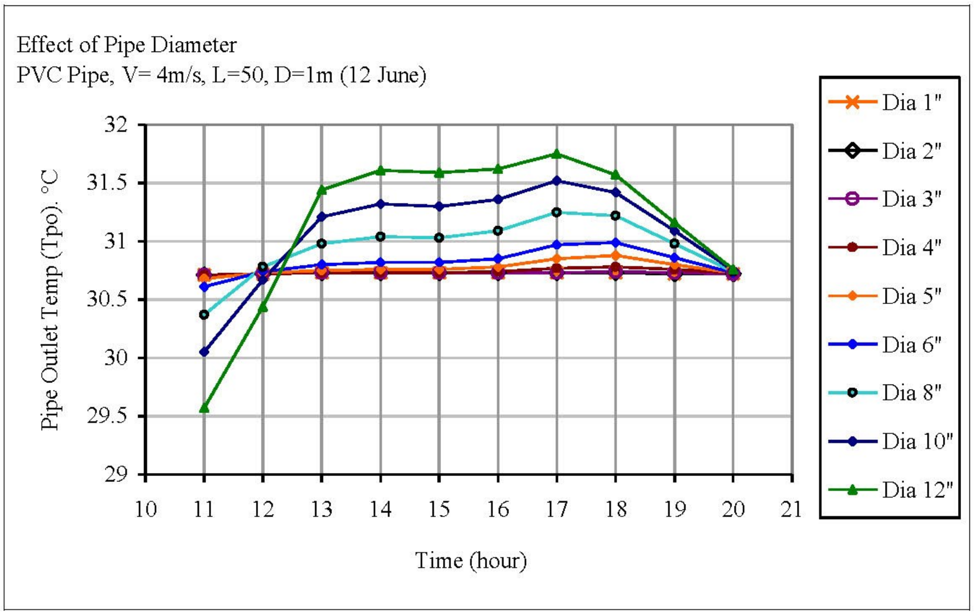

Figure 4.2: Effect of pipe diameters on $T_{po}$ from 11.00am to 8.00pm.

Figure 4.2 is similar to Fig 4.1 however the time axis shown is from 11.00am to 8.00pm only so that the effect of pipe diameter on the pipe-outlet air temperature more clearly. It can be seen that $T_{po}$ for the diameters 0.025m, 0.05m, and 0.075m (1, 2, and 3 inches) are equal. Therefore the 0.075m (3inches) pipe size can be considered as a functional diameter rather than 0.025m and 0.05m to reduce pressure drops and the fan power. The simulation results showed that $T_{po}$ at the diameter of 0.075m (3inches) is 1.15 °C cooler than that at 0.3m (12 inches) which is the bigger size used in the simulation.

The influence of pipe diameter is further analyzed, and is shown in Figure 4.3. The cooling potential is represented by the temperature difference ($\Delta T$) between ambient ($T_{am}$) and pipe-outlet air ($T_{po}$) temperatures. Two patterns were observed. First, the maximum $\Delta T$ occurred at 2.00 pm which is almost constant and around

2.55°C for the smaller pipes up to 0.075m (3 inches). This result agrees with a previous research (see Sanusi, 2012).

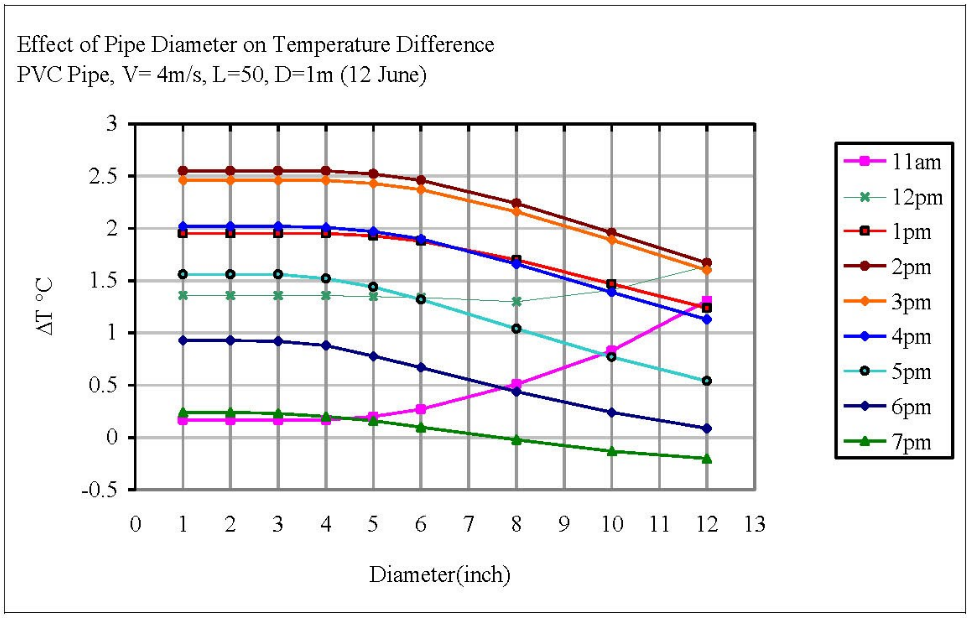

Figure 4.3: Effect of pipe diameters on cooling potential (ΔT).

Second, for the pipe sizes larger than 0.075m (3 inches), ΔT decreases with an increase in pipe diameter, in other words the ΔT is inversely proportional to pipe diameter for diameters larger than 0.075m (3 inches). For smaller pipe diameters ΔT does not significant. These results also agree with previous research (see Santamouris et al, 1995, Ghosal et al, 2006, Huijun et al, 2007, Kwang & Richard, 2008, 2012).

## 4.2 SIMULATION 2: INFLUENCE OF AIR VELOCITY

The second simulation investigates the effect of air velocity on $T_{po}$. Figure 4.4 shows the hourly variation of $T_{po}$ as a function of air velocity at $1 m.s^{-1}$ to $10 m.s^{-1}$ for a typical day in June (hot and dry season).

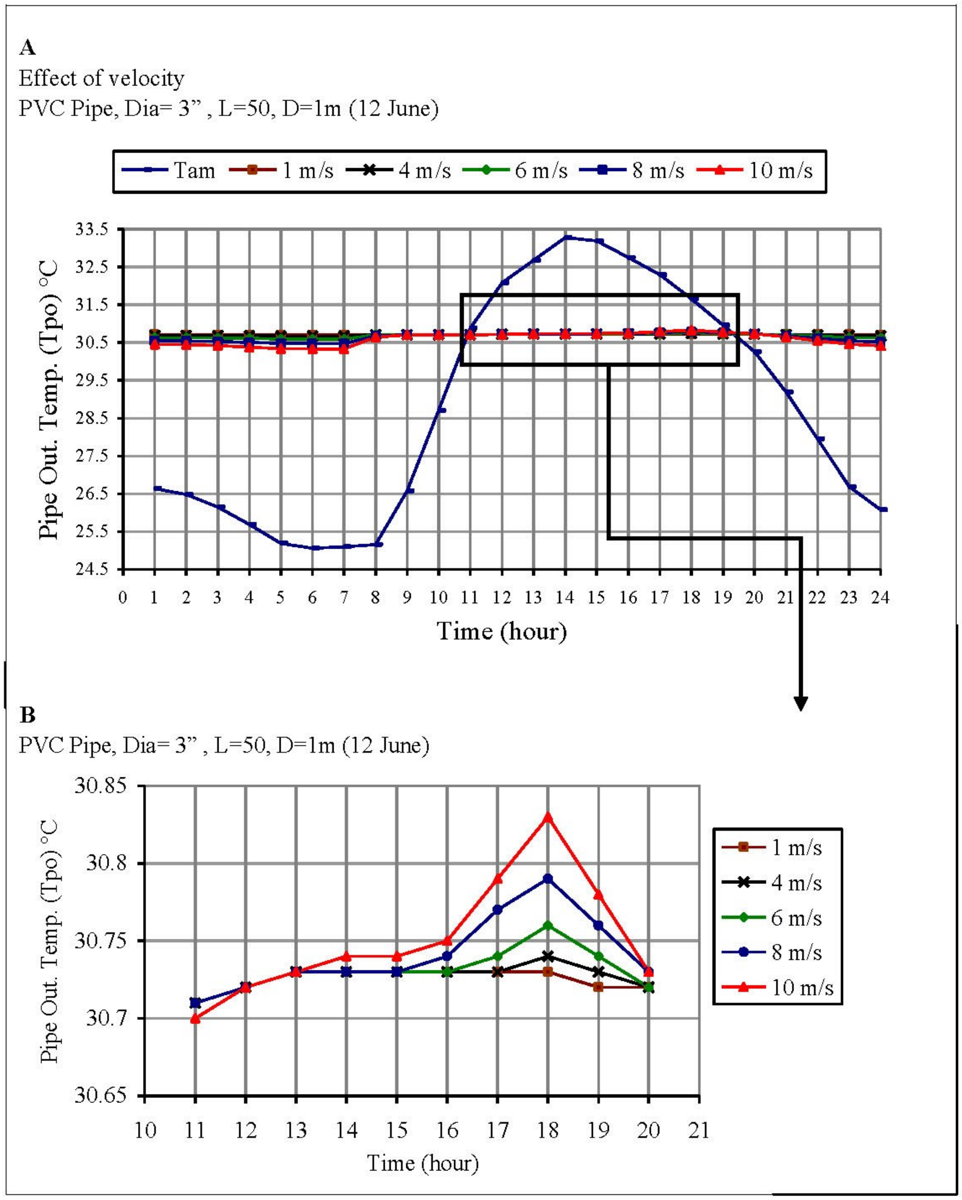

Figure 4.4: Part A, Effect of air velocity on $T_{po}$ for a typical summer day; Part B, is a portion of part A during 11.00am to 8.00pm and without $T_{am}$.

In previous simulation, Simulation 1, (see Figure 4.3) the maximum ΔT occurs when pipe diameter is small not more than 0.075m (3 inches). Therefore, in this simulation the diameter of the pipes was fixed at 0.075m (3 inches). The other parameters, depth and length were fixed at 1 m and 50m respectively. Air velocities were varied at 1, 4, 6, 8 and 10 m.s$^{-1}$. Two patterns were observed. First, all $T_{po}$ is lower than $T_{am}$ after 11.00am. Second, all $T_{po}$ is higher than $T_{am}$ after 8.00pm.

Part B of Figure 4.4 shows the effect air velocity from 11.00am to 8.00pm on the $T_{po}$ more clearly. It can be seen that during 9 hours at velocity 1m.s$^{-1}$ the pipe-outlet air temperature has more stability. In addition, it is apparent from the results that very little difference noted in $T_{po}$ between minimum and maximum air velocity, which was only 0.10 °C.

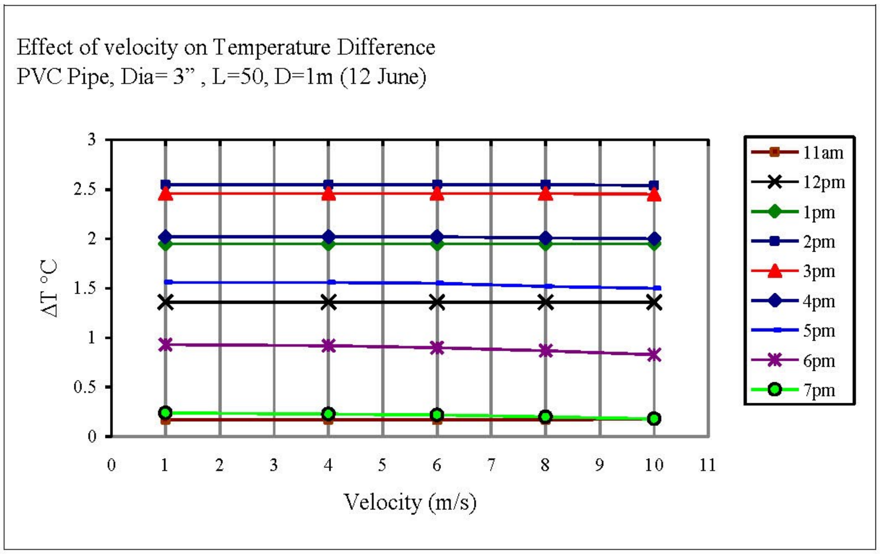

Figure 4.5: Effect of Air velocity on cooling potential (ΔT).

Similar to simulation 1, further analysis was conducted at the period when $T_{po}$ are higher than $T_{am}$ from 11.00am to 8.00pm. The effect of air velocity at peak temperatures is shown in Figure 4.5. The reduction remains 2.55 °C at 2.00pm, and can be seen that $\Delta T$ is almost constant. In terms of air flow, the lower velocity 1 $ms^{-1}$ is the optimum to reduce pressure drop and use a low energy to run the fan.

This finding agrees with previous research. Sanusi (2012) reported that; when the air velocity is $0.5m.s^{-1}$, the pipe-outlet air temperature ($T_{po}$) ranges from 28.2°C to 29.1°C. When the air velocity is increased to 1 $m.s^{-1}$ and 1.5 $m.s^{-1}$, the $T_{po}$ has smaller ranges with values from 28.6°C to 28.7°C and 28.5°C to 28.8°C respectively. Therefore, the best air velocity is 1 $m.s^{-1}$ or 1.5 $m.s^{-1}$ with lower and higher velocities performing less significance in the parametric study, while the air velocity provided in the field work experiment is 5.6 $m.s^{-1}$.

## 4.3 SIMULATION 3: INFLUENCE OF UNDERGROUND PIPE DEPTH

In previous simulation, Simulation 2, $\Delta T$ is independent in terms of air velocity. Therefore the lowest air velocity 1 $ms^{-1}$ selected. Like the previous simulations, Figure 4.6 shows the variation of the $T_{po}$ as a function of pipe underground depth for the same typical day in the month of June. The pipe diameter, air velocity, and pipe length were set at 0.075m (3 inches), 1 $ms^{-1}$, and 50m, respectively. The pipe depth varied from 1 to 4 meters. Three patterns were noticed. First, all $T_{po}$ are lower than $T_{am}$ after 11.00am. Second, all $T_{po}$ is higher than the $T_{am}$ after 8.00pm. Third, the difference in $T_{po}$ found between 1m to 4m depth was only 1.01 °C.

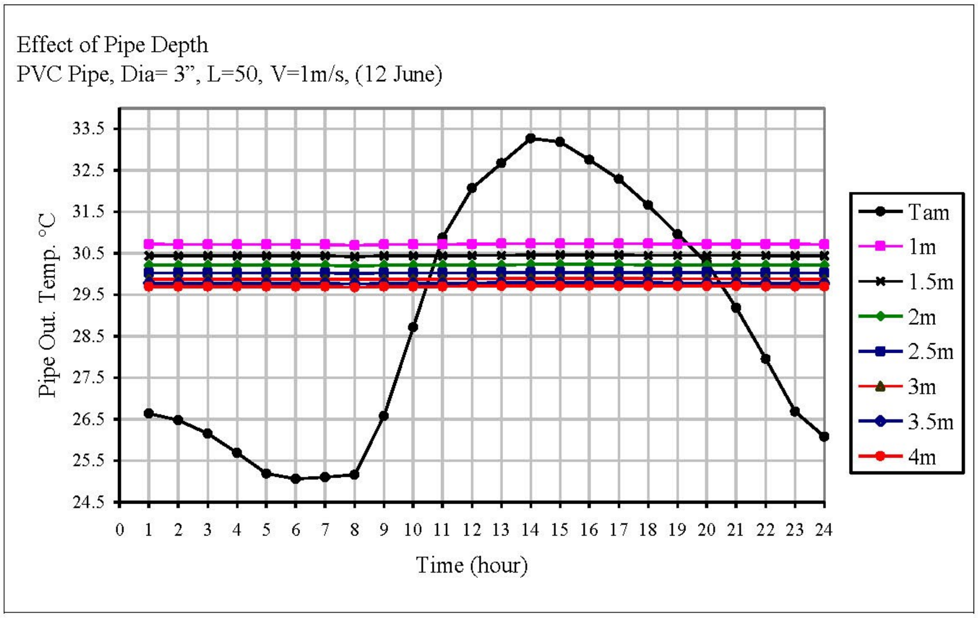

Figure 4.6: Effect of pipe underground depth on $T_{po}$ for a typical summer day.

The last observation on the graph in Figure 4.6 is that all $T_{po}$ during 24 hours were almost constant. The reason behind this phenomenon is the soil temperature at the depth between 1 m to 4 m is stable and constant throughout the year around as noted by previous researcher Sanusi, (2012) reported in a site experiment investigation in Malaysia, that the soil temperature at the 1.0 m depth underground were stable when measured in two days ranges from 29.9°C to 30.0°C (see Chapter 2 section 2.4.4.3.2).

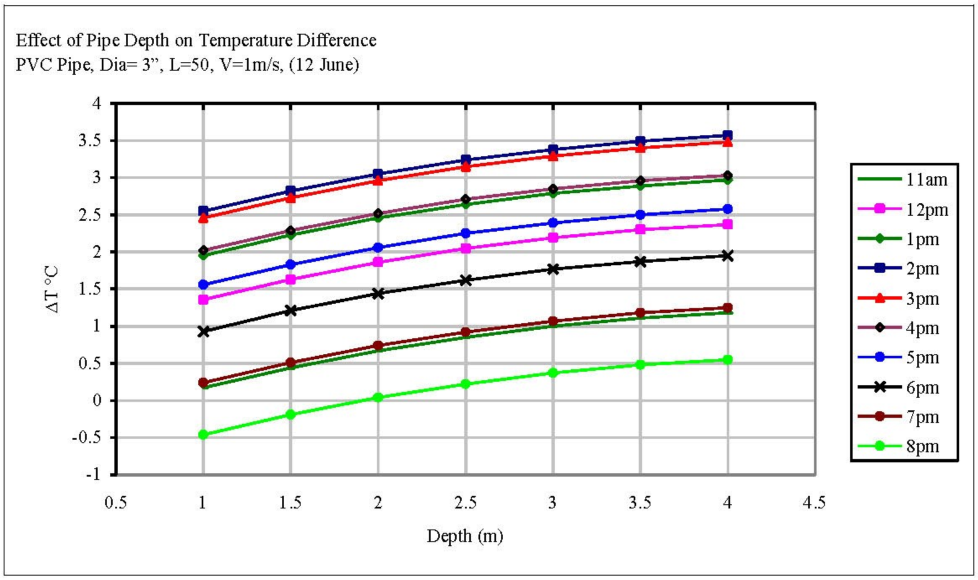

Figure 4.7: Effect of pipe depth on cooling potential (ΔT).

Further analysis conducted on the influence of pipe depth. As shown in Figure 4.8, the effect of pipe depth on the cooling potential has been presented. It can be seen that an increase in depth results in lower pipe-outlet air temperatures and higher ΔT. The maximum reduction in temperature (ΔT) was 3.57 °C and occurred at 4m depth, indicating that the earth tube should be placed as deeply as possible. However, the trenching cost and other economic factors should be considered when installing EAHE.

## 4.4 SIMULATION 4: INFLUENCE OF PIPE LENGTH

The last parametric study is the effect of different pipe lengths, to investigate the minimum requirement for the buried pipe length and to achieve maximum cooling potential. Based on the previous simulations, the other variables were fixed. The diameter at 3inches (75mm) and the air velocity at 1ms$^{-1}$, and the depth of the buried pipe at 4m, then the pipe length varied from 12.5m to 80m length.

Figure 4.8 shows typical daily profile of $T_{am}$ and the variation of $T_{po}$ as it functions under the variation of pipe length. It can be seen that, first, all $T_{po}$ is lower than $T_{am}$ after 10.30am. Second, all $T_{po}$ is higher than $T_{am}$ after 8.30pm. The study results of different length have shown that when the length is increase results in lower in outlet air temperature (see Figure 4.9). This indicates that when the buried pipe is long, heat transfer process underground takes more time since the air flow inside the buried pipe stays longer in the soil, which let the air inside the buried pipe to transfer heat more to the surrounding soil.

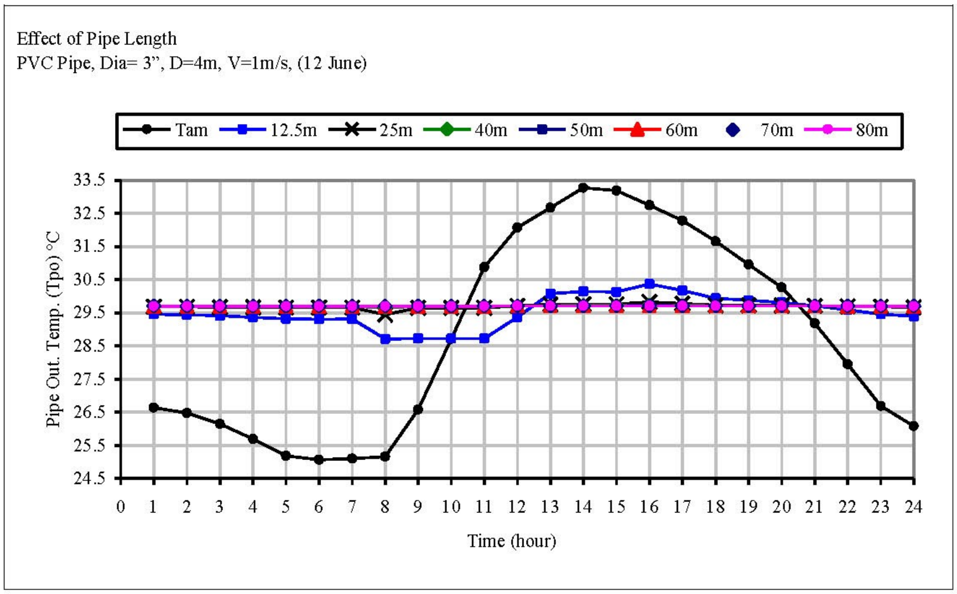

Figure 4.8: Effect of pipe length on hourly variations of $T_{po}$ for a typical summer day.

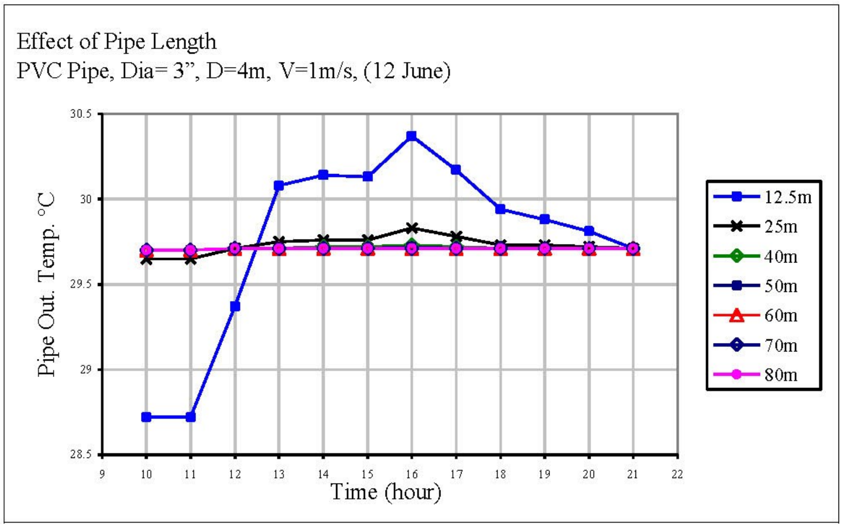

Figure 4.9: Effect of pipe length on $T_{po}$ for a typical summer day from 10.00am to 9.00pm.

To observe the effect of pipe length on the pipe-outlet air temperature obviously the Figure 4.9 presented at different temperature range during 10.00am until 9.00pm and without ambient temperature. In addition, from the simulation result data the difference in $T_{po}$ for minimum and maximum pipe length was only 0.65 °C.

The effect of pipe length at peak temperatures on EAHE cooling system is shown in Figure 4.10. It shows $\Delta T$ increases with an increase of pipe length until 50m length. After a certain point around 50–80 m increasing the length does not result in much better performance and the improvements begin to level off. At longer pipe length beyond 50m length $\Delta T$ remains constant, indicating that this value can be the optimal design value at which the maximum $\Delta T$ takes place and 3.57 °C at 2.00 pm. This result conforming to the results obtained by Kwang & Richard, 2008, and Ghosal et al, 2006 as well. Sanusi also stated that when the length of the earth pipe is incresed to 50m long, the pipe-outlet air temperature range reduced and the outlet temperature becomes more stable (Sanusi, 2012). Based on these results, pipe length appears to have as large of an influence on EAHE performance as pipe diameter and pipe depth.

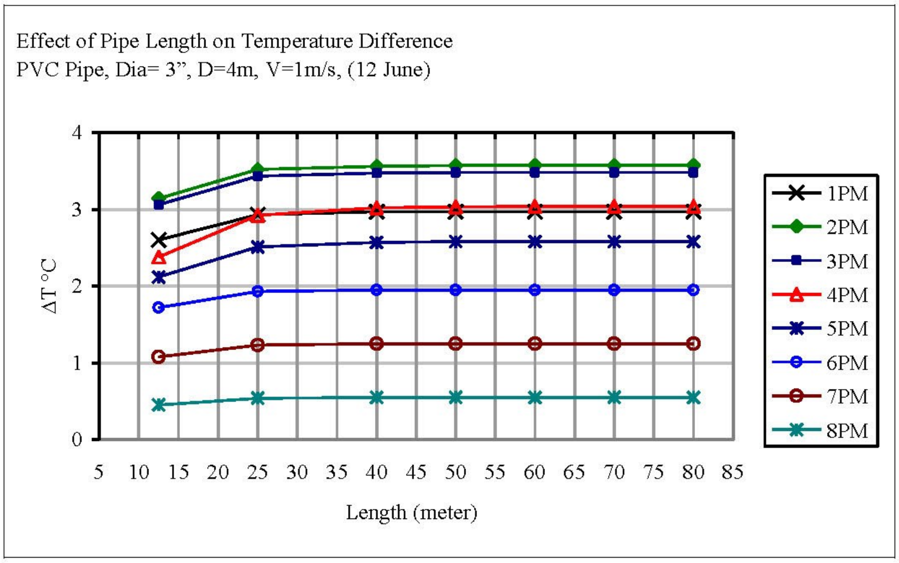

Figure 4.10: Effect of pipe length on cooling potential (ΔT).

## 4.5 CONCLUSIONS

Base on all the simulation results, the parameters that influence the performance of EAHE significantly are the pipe diameter, pipe depth and pipe length, while the air velocity did not showed any significant effect.

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

This chapter will discuss the extent to which the objectives of the study were achieved. Some recommendations for further investigation in future research-work on similar systems in Malaysia will also be covered in this chapter.

## 5.1 PARAMETRIC STUDY

i. The first objective of this study was to determine the time when pipe-outlet air temperature ($T_{po}$) is lower than ambient air temperature ($T_{am}$). It was generally observed that the $T_{po}$ are lower than the $T_{am}$ from 11.00am to 8.00pm.

ii. The second objective of this study was to know the influence of: a) pipe diameter, b) pipe depth, c) pipe length, and d) air velocity on the cooling potential ($\Delta T$). Two aspects of the influence were noted. First, $\Delta T$ is inversely proportional to pipe diameter and air velocity, however, the relationship between air velocity and $T_{po}$ was not significant. Second, $\Delta T$ is directly proportional to pipe depth and pipe length; $\Delta T$ remained the same for pipe lengths beyond 50 m.

iii. The third objective of this study was to determine the configuration of the Earth-to-Air Heat Exchanger that would achieve the optimum cooling potential ($\Delta T$). The research found that the optimum cooling potential $\Delta T$

was 3.57 °C at 2.00 pm, when the pipe diameter is 0.075m (3inches), air velocity is 1 $m.s^{-1}$, pipe depth is 4m, and pipe length is 50m.

## 5.2 RECOMMENDATIONS FOR FURTHER STUDY

The following recommendations are to be considered for future studies:

i. Investigating the effects of different types of soil on $\Delta T$.

ii. Investigating the potential of using the Earth-to-Air Heat Exchanger technique to pre-cool fresh air for Fresh Air Handling Units (FAHU) in a typical office building.

# BIBLIOGRAPHY

Al-Ajmia, F., Loveday, D.L., & Hanby, V.I. (2006). The cooling potential of earth–air heat exchangers for domestic buildings in a desert climate. *Building and Environment*, Volume 41, Issue 3, pp. 235–244.

Banks, D. (2008). *An Introduction to Thermogeology: Ground Source Heating and Cooling*. Blackwell Publishing Ltd.

Chan, S. A. (2004) Energy Efficiency, Designing Low Energy Buildings Using Energy 10. Pertubuhan Arkitek Malaysia. CPD Seminar 7th August 2004. Kuala Lumpur.

Contrasting the capabilities of building energy performance simulation programs. (n.d). Retrieved October 23, 2012. http://apps1.eere.energy.gov/buildings/tools_directory/pdfs/contrasting_the_capabilities_of_building_energy_performance_simulation_programs_v1.0.pdf.

Darkwa, J., Kokogiannakis, G., Magadzire C.L., & Yuan K. (2011). Theoretical and practical evaluation of an earth-tube (E-tube) ventilation system. *Energy and Buildings,* 43, pp. 728–736.

Egg, J., & Clark, H. B. (2011). Geothermal HVAC Green Heating and Cooling. McGraw-Hill Companies, Inc.

EnergyPlus Energy Simulation Software, version 7.1.0; 2012. U.S. Department of Energy, Energy Efficiency and Renewable Energy.

EnergyPlus Engineering Reference (2012). The Board of Trustees of the University of Illinois and the Regents of the University of California through the Ernest Orlando Lawrence Berkeley National Laboratory.US Department of Energy.

EnergyPlus Input Output Reference (2012). The Board of Trustees of the University of Illinois and the Regents of the University of California through the Ernest Orlando Lawrence Berkeley National Laboratory. US Department of Energy.

Fabrizio Ascione, Laura Bellia, & Francesco Minichiello.(2011). Earth-to-air heat exchangers for Italian climates. *Renewable Energy,* 36, pp. 2177-2188.

Getting Started with EnergyPlus (2012). The Board of Trustees of the University of Illinois and the Regents of the University of California through the Ernest Orlando Lawrence Berkeley National Laboratory.US Department of Energy.

Ghosal, M.K., & Tiwari G.N. (2006). Modeling and parametric studies for thermal performance of an earth to air heat exchanger integrated with a greenhouse. *Energy Conversion and Management*, 47, pp. 1779–1798.

Ghosal, M.K., Tiwari G.N., & Srivastava N.S.L. (2004). Thermal modeling of a greenhouse with an integrated earth to air heat exchanger: an experimental validation. *Energy and Buildings,* 36, pp. 219–227.

Goswami, D.Y., & Biseli K. M. (1993) Use of Underground Air Tunnels for Heating and Cooling Agricultural and Residential Buildings. Fact Sheet EES 78. Florida Energy Extension Service, University of Florida, pp 1-4.

Gyuyoung Yoon, Hideki Tanaka, & Masaya Okumiya. (2009). Study on the design procedure for a multi-cool/heat tube system. *Solar Energy*, 83, pp. 1415–1424.

Hollmuller, P., & Lachal, B. (2000). Cooling and preheating with buried pipe systems: monitoring, simulation and economic aspects. *Energy and Buildings*, 1295 pp. 1-10.

Hollmuller, P., & Lachal, B. (2005). Buried pipe systems with sensible and latent heat exchange: validation of numerical simulation against analytical solution and long-term monitoring. Conference of International Building Performance Simulation Association August 15-18 2005, Ecole polytechnique de Montréal.

Hollmuller, P. (2002). Utilisation Des changeurs Air/Sol Pour Le Chauffage Et Le Rafraîchissement Des Bâtiments Mesures in Situ, Modélisation Analytique, Simulation Numérique Et Analyse Systémique [Use of Air / Ground Exchanger for Heating and Cooling of Buildings in situ Measurements, Analytical Modeling, Numerical Simulation and Systemic Analysis], PhD Thesis, Université de Genève, Genève.

Huijun Wu, Shengwei Wang, & Dongsheng Zhu. (2007). Modelling and evaluation of cooling capacity of earth–air–pipe systems. Energy Conversion and Management 48 (2007) 1462–1471.

IEA-ECBCS Annex 28. (1998). Low Energy Cooling. Aalborg University, Department of Civil Engineering. DCE Technical Report No. 051.

Jacovides C. P., & Mihalakakou G. (1995). An underground pipe system as an energy source for cooling/heating purposes. *Renewable Energy*, Vol. 6, No. 8, pp. 893 900, 1995.

Jian Zhang, & Fariborz Haghighat. (2005). Simulation of earth-to-air heat exchangers in hybrid ventilation systems. Ninth International IBPSA Conference Montréal, Canada August 15-18, 2005.

Jian Zhang. (2009). Investigation of airflow and heat transfer in earth-tube-air heat exchanger. (PhD. Thesis, Concordia University, Canada, 2009) Retrieved from ProQuest Digital Dissertations.

Kwang Ho Lee, & Richard K. Strand. (2008). The cooling and heating potential of an earth tube system in buildings. *Energy and Buildings*, Volume 40, Issue 4, pp. 486–494.

Kyoto Protocol to the United Nations Framework Convention on Climate Change (1998). Retrieved November 10, 2012. http://unfccc.int/resource/docs/convkp/kpeng.pdf.

Liddarnent, M. W. (2000). Technical Synthesis Report, IEA-ECBCS Annex 28. Low Energy Cooling. ESSU (ExCo Support Services Unit ), Coventry, U.K.

Mark Zimmermann, & Johnny Andersson. (1998). Case Studies of Low Energy Cooling Technologies. International Energy Agency, Energy Conservation in Buildings and Community Systems Programme, Annex 28 – Low Energy Cooling.

Mihalakakou, G., Santamouris, M., Asimakopoulos, D., & Tselepidaki, I. (1995). Parametric prediction of the buried pipes cooling potential for passive cooling applications. *Solar Energy*, Volume 55, Issue 3, pp. 163–173.

Min Zhong Zhao. (2004). Simulation of earth-to-air heat exchanger system. (Master Thesis, Concordia University, Canada, 2004) Retrieved from ProQuest Digital Dissertations.

Miroslaw Zukowski, Beata Sadowska, & Wieslaw Sarosiek. (2011). Assessment of the cooling potential of an earth-tube heat exchanger in residential buildings. The 8th International Conference, Vilnius, Lithuania.

Paolo Principi, & Roberto Fioretti, (2009). Expert Guide–Part 2 Responsive Building Elements, IEA-ECBCS Annex 44 Integrating Environmentally Responsive Elements in Buildings.

Rakesh K., Rameshb S., & Kaushika S.C. (2003). Performance evaluation and energy conservation potential of earth–air–tunnel system coupled with non-air-conditioned building. *Building and Environment*, Volume 38, Issue 6, pp. 807–813.

Richard, K. S., Crawley, D. B., Pedersen, C. O, Richard, .J. L., Linda, K. L., Winkelmann, F.C., Buhl, W.F., Huang, Y. J., & Fisher, D. E. (2000). EnergyPlus: A New-Generation Energy Analysis and Load Calculation Engine for Building Design.

Santamouris, M., & Asimakopoulos, D. (1996). Passive Cooling of Buildings. James and James (Science Publishers) Ltd.

Santamouris, M., Mihalakakou, G., Balaras, C. A., Argiriou, A., Asimakopoulos, D. & Vallindras, M. (1995). Use-of-buried-pipes-for-energy-conservation-in-cooling-of-agricultural-greenhouses. *Solar Energy*, Vol. 55, No. 2, pp. 111-124.

Sanusi, A.N.Z. (2012). Low energy ground cooling system for buildings in hot and humid Malaysia. (PhD. Thesis, International Islamic University Malaysia and De Montfort University, UK, 2012).

Sanusi, A.N.Z., Li Shao, & Najib Ibrahim. (2012). Passive ground cooling system for low energy buildings in Malaysia (hot and humid climates). Renewable Energy (2012). *Renewable Energy*, Volume 49, pp. 193‑196.

Sawhney, R.L., Buddhi, D., & Thanu, N.M. (1999). An experimental study of summer performance of a recirculation type underground air pipe air conditioning system. *Building and Environment*, 34, pp. 189-196.

Sergio Altomonte (n.d). CSET - Centre for Sustainable Energy Technologies, Ningbo, China. Retrieved January 12, 2013. https://www.educate-sustainability.eu/kb/content/cset-centre-sustainable-energy-technologies-ningbo-china.

Standard dimensions and weight of PVC - Polyvinyl Chloride - and CPVC - Chlorinated Polyvinyl Chloride - pipes according ASTM D1785. Retrieved October 17, 2013. http://www.engineeringtoolbox.com/pvc-cpvc-pipes-dimensions-d_795.html.

The Centre for Sustainable Energy Technologies (n.d). Retrieved January 12, 2013. http://www.nottingham.ac.uk/shared/shared_built/documents/PDF_Documents/CSET_Sept08_opening_brochure.pdf

Tjelflaat, P.O. (2000). Pilot Study Report - Media School. IEA ECBCS Annex-35 (HybVent) Technical Report.

Trombe, A., Pettit M., & Bourret B. (1991). Air cooling by earth tube heat exchanger: experimental approach. *Renewable Energy*, Vol. 1, No. 5/6, pp. 699-707.

Vikas Bansal, Rohit Misra, Ghanshyam Das Agrawal, & Jyotirmay Mathur. (2010). Performance analysis of earth–pipe–air heat exchanger for summer cooling. *Energy and Buildings*, Volume 42, Issue 5, pp. 645–64.