Parametric Study of Earth-to-Air Heat Exchanger in Malaysian Climate

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Abstract

The technology, where the ground was used as a heat sink to produce cooler air, has been an area of interest in Malaysia even before National Green Technology Policy was launched in 2009. This simulation study is based on ASHRAE Weather database, local data collected in previous field studies at Universiti Teknologi Malaysia Skudai Campus in Johor and International Islamic University Malaysia Gombak Campus in Selangor. This study investigates the parameters influencing the cooling potential of Earth-to-Air Heat Exchanger (EAHE).

Keywords: ground cooling, green technology

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1 INTRODUCTION

Green technology is a top priority in Malaysia. The 2013 Budget gave an additional RM2 billion for green technology projects under the Green Technology Financing Scheme (Intan Farhana Shazwan (2013). Since January 2010, a total of RM1.5 billion has been made available for soft loans to interested parties with low interest rates. One of the less explored green technologies is earth cooling.

Heating and cooling needs of building can be significantly reduced by utilization of the stored energy derived from the earth. Earth-to-Air Heat Exchanger (EAHE) is a metal or plastic pipe buried underground through which the air passes from one end to another. EAHE is also known as Earth-air-pipe system (Huijun et al., 2007), Earth tube heat exchanger (Miroslaw, 2011; Trombe et al., 1991), Earth tube system (Jacovides et al., 1995; Kwang and Richard, 2008), Earth–air–tunnel system (Rakesh et al, 2003), and underground air pipe air conditioning system (Sawhney et al., 1999). During heating season the ambient air that flow through EAHE is pre-warmed before entering building. The direction of heat transfer is reversed that the ambient air is pre-cooled in summertime.

This earth pipe cooling technology has been explored by many researchers and used by building designers as cooling means for various building types in temperate countries as well as hot and arid countries, where the results have been significant and positive. Min (2004) analyzed application of EAHE in Montreal, Canadian climate. 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). Fabrizio et al. (2011) evaluated the energy performances achievable using EAHE in different Italian climates (i.e. Naples, Rome, & Milan). Ghosal and Tiwari (2006) integrated the EAHE with the greenhouse located in Delhi, India. Vikas et al., (2010) analyzed the performance of the system in dry climate of the Western India . Darkwa (2011) evaluated the EAHE system as an energy saving technology for a typical hot and humid location in Ningbo, China. Al-Ajmia et al., (2006) predicted the outlet air temperature and cooling potential of EAHE in a hot and arid climate in Kuwait.

However, information on earth pipe cooling technology in Malaysia is scarce. The first known research to study viability of earth cooling in the country was funded by Universiti Teknologi Malaysia (UTM) and was conducted in its Skudai Campus, in a suburban area18 km from Johor Bahru City (Md Najib Ibrahim, 1988). The field measurements were conducted in 1986 near one of its buildings. At that time the 1,222 hectare new campus, a former rubber estate, was occupied by only a small number of buildings, therefore the microclimate of the campus was different from Johor Bahru, Malaysia. In the morning of rainy season temperature as low as 24^{o}C were recorded. At that time it was found the cooling potential of earth cooling was not significant since ambient temperature was relative low.

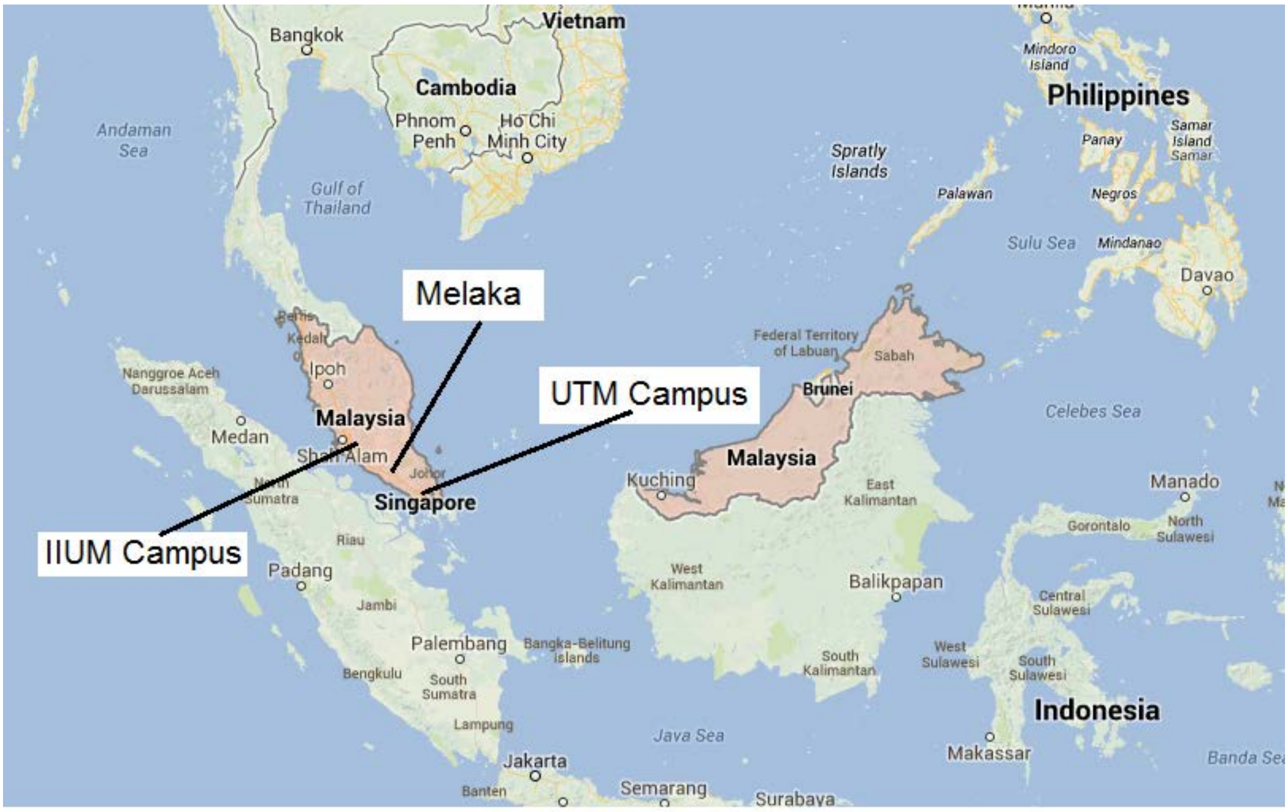

Fig. 1 Location of Ground Cooling Studies in Malaysia

Reimann, Boswell & Bacon (2007) reported earth cooling was incorporated into CoolTek house, in Melaka, Malaysia. The earth cooling system consists of a sub-soil chamber and a sub-soil duct. The sub-soil chamber was constructed from 50 mm thick 1000 mm diameter concrete culvert, containing five concrete filled ceramic pipes standing on a concrete plinth of 300 mm depth with heavy concrete, surface insulated lid. It was connected with 10 meter sub-soil duct with an air intake opening. It was generally concluded that the potential for earth cooled ventilation was relatively small.

Aliyah Sanusi, Li Shao and Md Najib Ibrahim (2013) reported a field investigation of earth pipe cooling technology, conducted in International Islamic University Malaysia (IIUM), Gombak Campus, Kuala Lumpur. It was found at 1 m underground, the result is most significant, where the soil temperature is 6^{o}C and 9^{o}C lower than the maximum ambient temperature during wet and hot and dry season, respectively. It was also found Energy Plus simulation results correlate well with the field work.

This paper presents a more detail simulation study on the parameters influencing the cooling potential of earth pipe cooling in Malaysia. Specifically the objectives of study are as follows:

1. To determine when outlet air temperatures T_{PO} is lower than ambient air temperature T_A
2. To determine when the cooling potential ΔT (the difference between T_A and T_{PO}) is maximum

3. To determine the influence of diameter, air velocity, and pipe length on the ΔT

2 SIMULATION METHOD AND RESULTS

An EAHE model (known in the software as earth tube) was created in EnergyPlus Version7.1. Three simulations were conducted on the model. In Simulation 1, air velocity and pipe length were set as constant while pipe diameter is varied. In Simulation 2, pipe diameter and pipe length were set as constant while air velocity is varied. In Simulation 3, pipe diameter and air velocity were set as constant while pipe length is varied. The weather **DATA FOR KUALA LUMPUR** from ASHRAE database and soil data taken from an experimental site at IIUM Campus Gombak were used in the simulations.

2.1 Simulation 1: Influence of pipe diameter

Fig. 2 shows typical daily profile of ambient air temperature T_A and outlet air temperatures T_{PO} in June (hot season) when the air velocity, length and depth are set at 4 ms^{-1}, 50 m and 1m respectively and pipe diameter is varied from 1 to 14 inches. Three patterns were observed. First, all T_{PO} are lower than T_A after 11.00am. Second, all T_{PO} is higher than the T_A after 7.30pm. Third, T_A as well as T_{PO} peaks at around 2.00 to 3.00pm

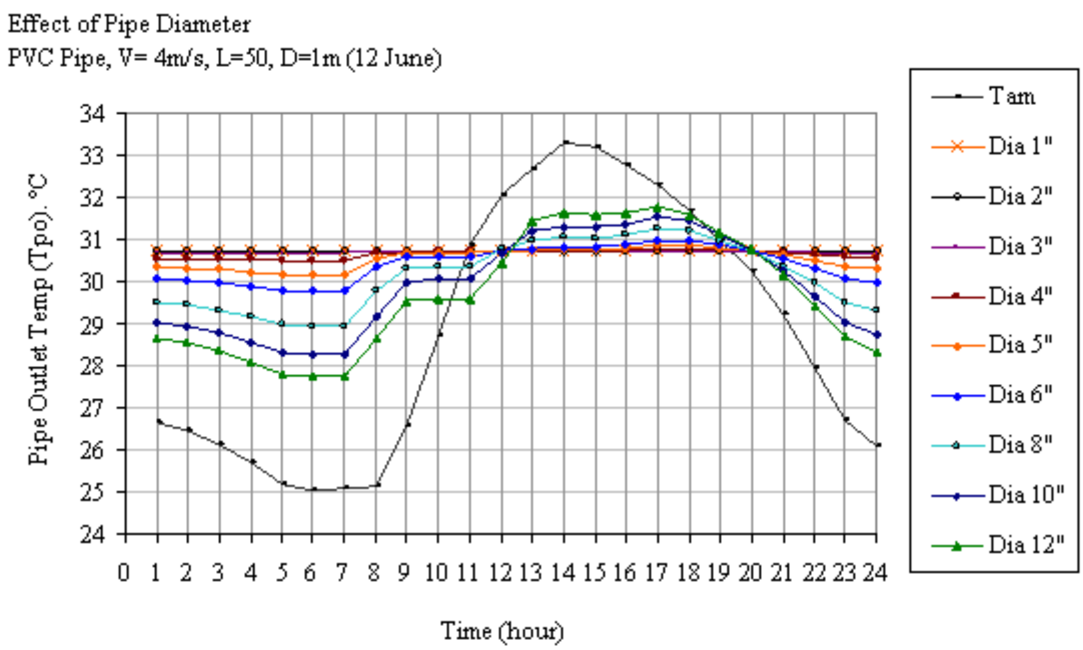

Fig 2 Profile of ambient air temperature TA and outlet air temperatures TPO

The effect of pipe diameter between 1 pm to 7 pm is further analysed and is shown in Fig. 3. The cooling potential is represented by ΔT. $\Delta T = T_A - T_{PO}$. Two patterns were observed. First, ΔT is almost constant at for small pipes up to 4 inches. Second, for pipes larger than 4 inches, ΔT decreases with an increase in pipe diameter.

2.2 Simulation 2: Influence of air velocity

Simulation 1 shows maximum ΔT occurs when pipe diameter is below 4 inches. In this simulation the pipe diameter was set at 3 inches. The pipe length was set at 50 m. Fig. 4 shows typical daily profile of T_A and T_{PO} in June (hot season) when the air velocity is varied from 1 to 10 ms^{-1}. Two patterns were observed. First, all T_{PO} is lower than T_A after 11.00am. Second, all T_{PO} is higher than T_A after 7.30pm.

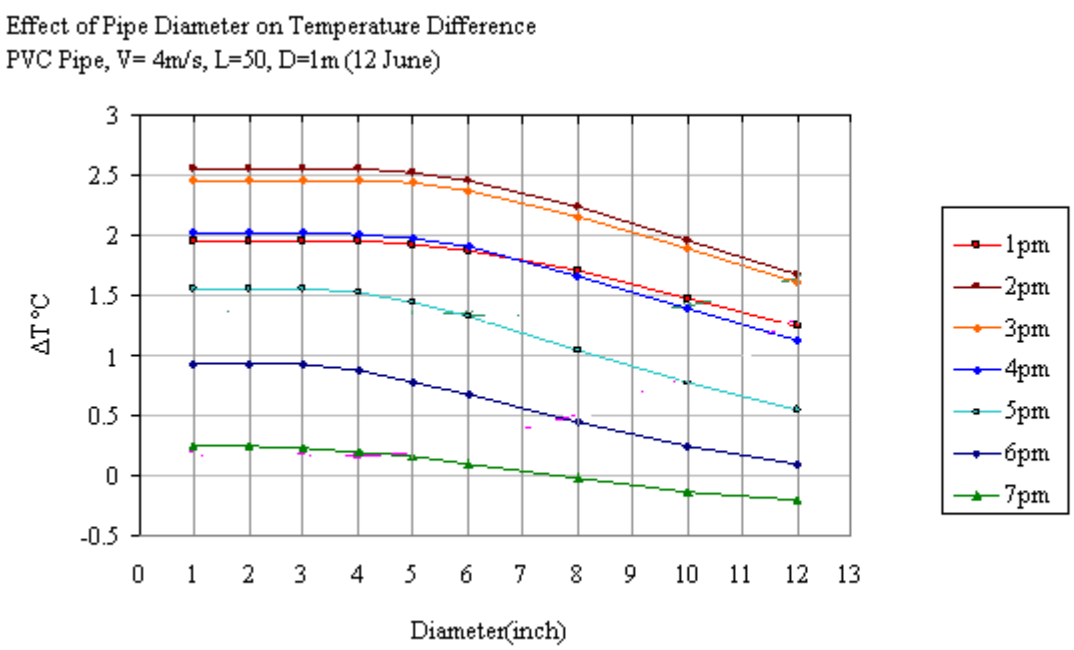

Fig. 3 Profile of Cooling Potential

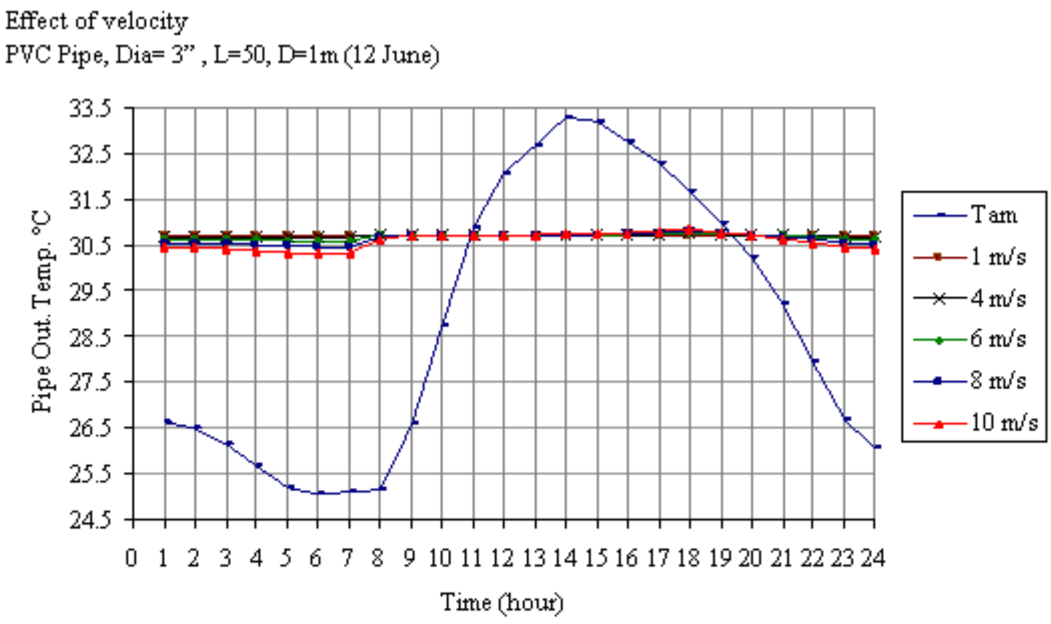

Fig.4. Profile of Outlet Air Temperatures and Ambient Temperature

Further analysis was conducted between 11.00 am to 7.00 pm. The effect of air velocity at peak temperatures on EAHE cooling is shown in Fig. 5. It shows Cooling Potential, ΔT, is constant.

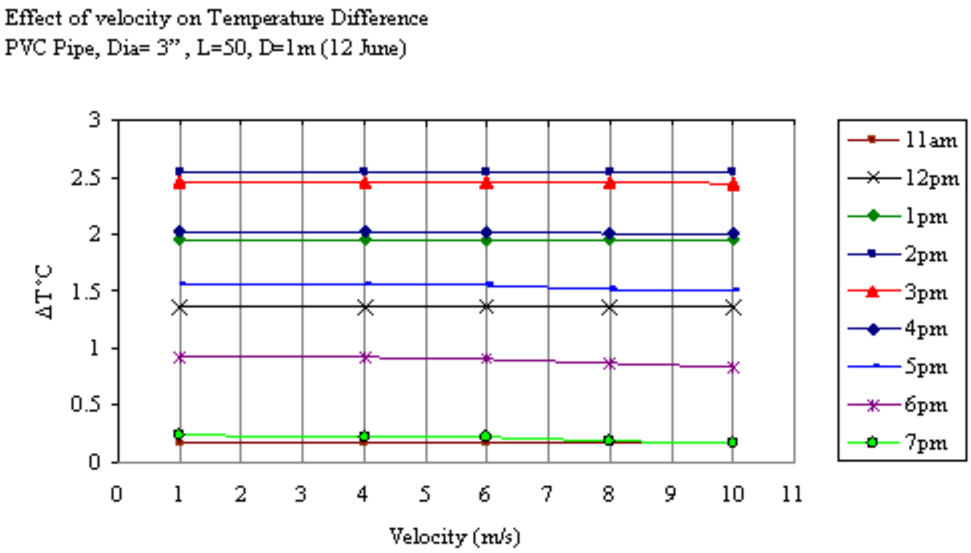

Fig. 5 Profile of Cooling Potential

2.3 Simulation3: Influence of pipe length

Simulation 2 shows ΔT is independent of air velocity. Therefore the lowest air velocity 1 ms^{-1} is used. Fig. 6 shows typical daily profile of T_A and T_{PO} in June (hot season) when the pipe length is varied from 25 to 80 m. Two patterns were observed. First, all T_{PO} is lower than T_A after 10.30am. Second, all T_{PO} is higher than T_A after 8.30pm.

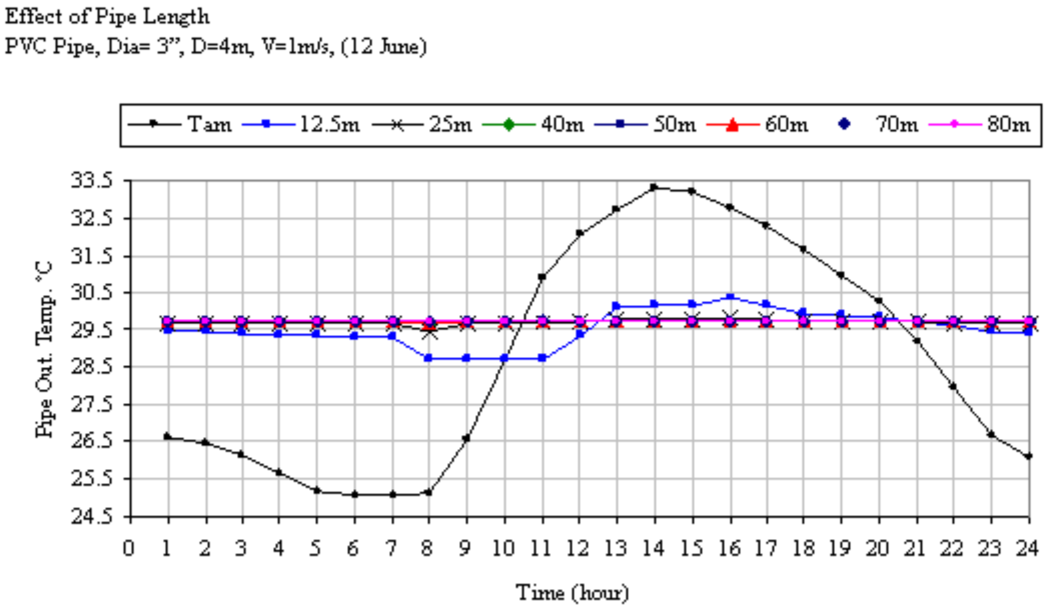

Fig. 6 Profile Outlet Air and Ambient Temperatures

Further analysis was conducted at 1.00pm and 8.00 pm. The effect of pipe length at peak temperatures on EAHE cooling potential is shown in Fig. 7. It shows ΔT is increases with an increase of pipe length until 50m length. At longer pipe length ΔT remains constant.

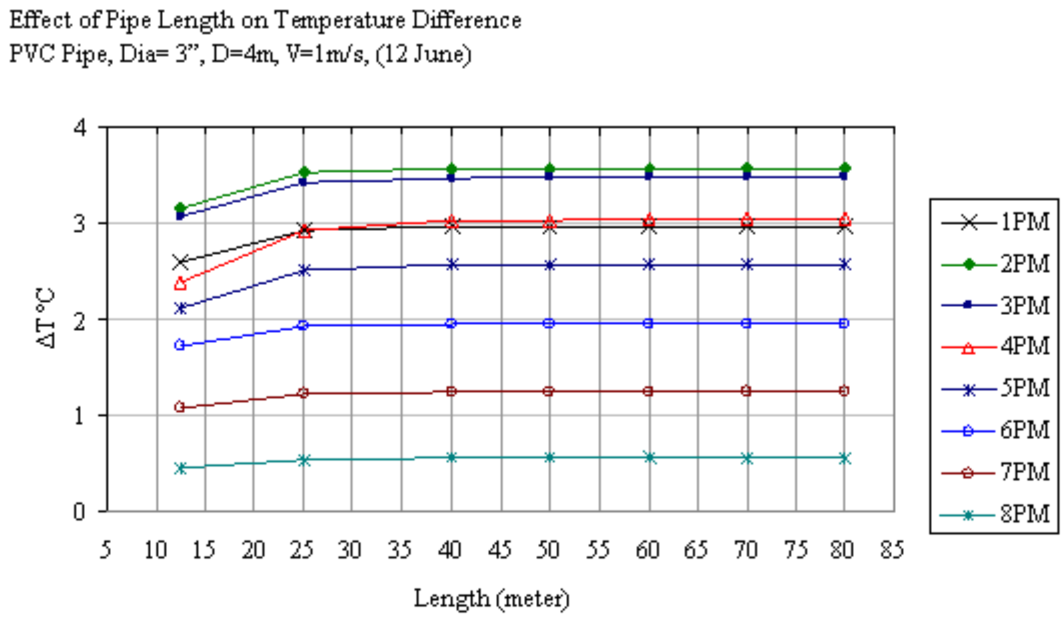

Fig. 7 Profile of Cooling Potential

3 DISCUSSION

It is interesting to note the cooling potential, ΔT, observed in the simulations is smaller than that observed in field investigation. Aliyah Sanusi, Li Shao and Md Najib Ibrahim (2013) reported ΔT through field investigation was between 6^{o}C and 9^{o}C. Whereas ΔT observed in simulation was less than 3.5^{o}C. The disagreement is expected since in this study EnergyPlus was used without any modification in algorithm or standard data in library. For example, 'soil condition' in basic set up was 'heavy and damp'. In this case,

4 CONCLUSION

The simulation results show that the cooling potential, ΔT, is influenced by pipe diameter only. It is independent of pipe length and air velocity

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