2nd International Conference on Emerging Trends in Scientific Research 2014
Pearl International Hotel, Kuala Lumpur 2nd & 3rd November 2014

MATERIALS FOR THE EARTH AIR PIPE HEAT EXCHANGER (EAPHE) SYSTEM AS A PASSIVE GROUND COOLING TECHNOLOGY FOR HOT-HUMID CLIMATE

Noor Aziah Mohd. Ariffin, Aliyah Nur Zafirah Sanusi and Aminuddin Mohd Noor
Department of Architecture
Kulliyyah of Architecture & Environmental Design
International Islamic University Malaysia

Abstract

The implementation of the earth-air pipe heat exchanger (EAPHE) system as a passive cooling technology for both residential and commercial buildings in the hot humid climate of Malaysia is relatively new. To date this technology has not been implemented in Malaysia, although it is proven in many studies particularly in drier climates, that it has the potential to reduce energy consumption for passive cooling. Studies by local researchers on EAPHE are also limited as a passive cooling system for the country. Thinner on the ground are the potentials of the appropriate pipe materials for the EAPHE system. The study investigated the most appropriate pipe materials that will predict the optimum air temperature reduction through computer simulation studies for achieving thermal comfort. The study utilizes the EnergyPlus environmental simulation program to investigate the performances of three pipe materials system: single pipe material, hybrid pipes and insulated hybrid pipes system. Through an exhaustive enumeration process the study found that the insulated hybrid pipes system gave the best temperature reduction indicating promising cooling and energy savings potentials.

Keywords: EAPHE, pipe materials, temperature reduction, ground cooling, environmental simulation.

1. Introduction

Malaysia is currently experiencing increasing temperatures with temperature hikes ranging from 0.5% to 1.5% over the last 40 years. As the country's ambient temperature increases, so do the energy consumption as most Malaysians are resorting to air-conditioning system to ensure that body comfort is achieved. In lieu of this, Chin (2012) confirmed that the growth for electricity increased from 3.1% in 2011 to 3.7% in 2012. Kubota et. al. (2011) established that the total number of households with air-conditioning in Malaysia has tremendously increased up to 16.2% in 2000 from a mere usage in the 1970s. Malaysia has also been recorded as the second highest energy consumer among the ASEAN members and Tang (2008) suggested that a need for studies for alternative provision of cooling for buildings is pertinent in the effort to save energy and to reduce the detrimental effects on the environment. Therefore this paper is looking at one of the passive cooling strategies for buildings that are possible for the hot humid climate of Malaysia through the Earth Air Pipe Heat Exchanger (EAPHE) cooling system.

EAPHE is the cooling the outdoor air through underground pipes buried a few meters deep and using the soil as a heat sink for cooling purposes where the heat is removed and dissipated back into the ground with air as the transfer medium for space cooling. As hot air flows through the length of the EAPHE, heat is transferred from the earth to the air and it gets cooled resulting in the air temperature at the outlet of the earth–air–pipes to be much lower than that of the ambient. The cooler outlet air from the EAPHE can be directly used for space cooling if its temperature is low enough with adequate air flow to provide end user thermal comfort (Santamouris et al., 1995). Alternatively, the outlet air may be cooled further by association with the building's heating, ventilation and air-conditioning (HVAC) system. Since Malaysia has a hot and humid climate with daily temperatures averaging between 24° and 34° C and relative humidity (RH) more than 75% for most times, comfort for occupants is hard to achieve naturally.

According to ASHRAE 55-2004, most people will feel comfortable when the indoor temperature is around 22°C to 27°C and the relative humidity is in the range between 40% and 60%. Even when using the adaptive approach of the thermal comfort where the comfort range can be increased to be between 24°C - 30°C (Noor Aziah, 2008), it is still quite hard for people to be comfortable naturally in the Malaysia climate. Therefore, the use of passive and low energy strategies for cooling of buildings is apposite to be an alternative method for providing not only, comfortable indoor environments but uses low energy as well.

The main contention of this paper is to look for the optimum pipe materials or a pipe system for the EAPHE in hot humid condition of Malaysia. Although many studies on EAPHE have been conducted in many parts of the world, but studies on establishing the most appropriate pipe material for this particular climate is lacking. Most of the pipe materials studied by the researchers are usually based the following criteria, such as, locally and easily available material, cost constraints and durability. Sanusi (2102) conducted a field experiment on EAPHE by using Polyethylene (PE) pipes due to its availability in the market and its durability as compared to PVC pipes. This study will do the same but will also venture to investigate further taking an exhaustive enumeration process on environmental simulation on three pipe systems for the EAPHE: a single-material system; a hybrid-material system and an insulated hybrid-material system to propose the best material and/or system for the EAPHE.

2. Objectives

In realizing the contention as above, the objectives set out are to:

- study the cooling potential of utilizing the three EAPHE pipe systems for a building by means of temperature reduction.
- investigate and assess the best pipe material or combination system of pipe materials for the EAPHE in a hot and humid climate.
- predict the temperature reduction and recommend the optimum pipe material via the Energy Plus environmental simulation program.

3. Background

Air-conditioning has become essential to gain thermal comfort in any building in Malaysia due to the hot and humid climate (Sanusi, 2012; Noor Aziah, 2008). This cooling system is widely installed in most commercial and residential buildings for the comfort of the occupants in the building space. However, of late the excessive use of air conditioning system has led to detrimental effects upon the environment such as disproportionate CO_2 emission to the atmosphere which leads to the reduction of the ozone layer and subsequently, global warming. According to the Ministry of Natural Resources and Environment (MNRE) in the 2nd National Communication (NC2) Report (2011), the Malaysian government is committed to reduce its emissions intensity of gross domestic product (GDP) by up to 40% based on 2005 levels by 2020 during the Conference of Parties 15 (COP 15) in Copenhagen. For that reason alone this study is relevant at looking for passive alternatives to cooling of buildings that will consume less energy and less detrimental to the environment. Although the EAPHE system has always been used in some parts of the globe and has been successful in hotter and drier climates, it is not a common passive design feature here in Malaysia. Therefore, this study investigates the potential of this system in the hot and humid climate with focusing on the different pipe materials or a pipe system for better efficiency.

3.1. Earth Air Piping Heat Exchanger (EAPHE)

The Earth Air Piping Heat Exchanger (EAPHE) is a passive cooling and heating method that uses the constant temperature of the earth to pre-cool outdoor air in the summer and pre-heat incoming air in the winter by passing the air through pipes buried underground before bringing it into the building envelope (Santamouris, et al., 1995). This is actually an ancient technique which has been used for thousands of years with great effect especially in the hotter and drier climates. EAPHE is also a low-technology and sustainable passive geothermal solar heating and solar cooling systems (Lefaucheur, et.al, 2010). Filtered fresh air enters a series of pipes embedded around the interior of a building foundation, absorbing energy from the surrounding soil and moderating the temperature of ambient air at the intake point (usually outside the building). The EAPHE system applies the storage capacity of the earth to condition the air. The magnitude of the heat exchange between air and pipe rely on factors such as, air temperature, soil temperature, air flow rate, pipe dimensions, pipe burial depth, the type of soil and the pipe material thermal properties (density, heat capacity and thermal conductivity) (Ahmed, et.al., 2007). Figure 1 demonstrates the diagrammatic sketch of the EAPHE system undertaken in this study.

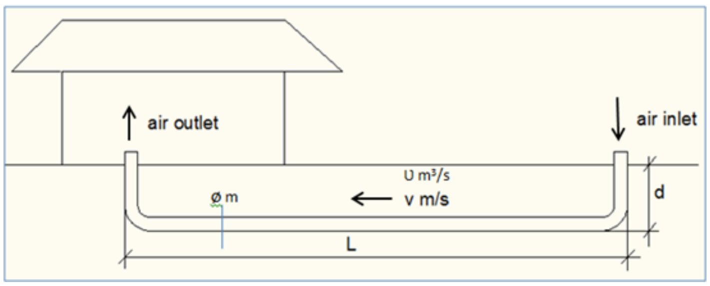

Figure 1: Schematic diagram of the earth-air-pipe heat exchanger.

The hot outdoor air is driven via the length of the earth–air–pipes heat exchangers, where heat gains or heat loss occurs through convection and to a certain extent, conduction between the earth and the air. As a result the moving air becomes either cooler or warmer depending on the moderating nature of the soil. For a hot climate the soil becomes a heat sink for cooling purposes where the heat is removed and dissipated back into the pipes for space cooling. As a result, the outlet air from the EAPHE can be directly used for space cooling or heating if its temperature is low or high enough with adequate air flow to provide end user thermal comfort. Alternatively, the outlet air may be cooled or warmed further by the association with the HVAC system. Both of the above uses of EAPHE can contribute to the reduction in energy demand and consumption.

The EAPHE system also creates better and healthier indoor air environments than conventional system. They are much more energy efficient; provide a stable, comfortable indoor temperature; are exceptionally quiet and emit virtually no carbon pollutants. According to Sharan, et al., (2001), EAPHE does not degrade the environment because they do not use the refrigerants integral in an air-conditioning system. The EAPHE system is also akin to a dual mode air conditioner in that it works as a cooler and a heater in summer and winter respectively (Sharan, et al., 2001). In addition, Sharan et al., (2002) state that although the initial installation costs of this system are likely to be higher as compared to a conventional refrigerant-based system (because this system requires extensive trenching works of soil as the heat sink or heat source), this cost can be offset quickly through a lower or nil operating cost. Recently, the potential of this system was tested in the hot and humid climate by Sanusi (2012) and revealed a good potential for passive cooling with a reduction of outdoor temperatures by up to 6 K.

3.2. EAPHE studies

As mentioned previously, one of the parameters that determine the effectiveness of the EAPHE system is the materials of the pipes. Many studies seldom indicate the main reasons for their selection of the material of the pipes in their studies. However it can be inferred that local availability and cost of the materials are the main reasons for the choice of pipe materials. Explained below is a summary of studies undertaken on the materials used for the pipes for the studies of the EAPHE system.

Goswami and Biseli (1993), developed an EAPHE system consisted of 12 inch (305 mm) diameter, 100 ft (30.5 m) long corrugated plastic pipe and buried at a depth of 9 ft (2.7 m). They claimed that the EAPHE system can minimize the ambient air temperature from 4°C to 5.5°C of temperature reduction in the dry climate of Western India. Sharan and Jadhav, (2002) used two parallel mild steel pipes of 200 mm diameter and 4 mm thickness at 30 m long, for the EAPHE system for tiger dwellings at the Kamala Nehru Zoological Garden, Ahmedabad, India. Both pipe were buried at a depth of 2 m and separated at 1.5 m from each other. The system managed to warm up the ambient air by 10°C at night in winter and cool the air by 8°C to 10°C during the day in summer time. Sharan and Jadhav, (2003) further studied the performance for both cooling and heating of the earth-tube-heat exchanger (ETHE) at the village of Thor in Ahmedabad, India. They experimented on a single pass ETHE with mild steel pipes with nominal diameter of 100 mm and 3 mm thickness; at a length of 50 m and 3 m deep. They found that the ETHE cools and heats the ambient air by about 14°C in May and January, respectively. The air velocity applied in this system was 11 m/s.

Bansal et al., (2009) investigated the EAPHE system performance during winter in Ajmeer (Western India). The pipes were buried at a depth of 2.7 m in a flat land with dry soil. They experimented on steel and PVC pipe materials with the air velocity ranging from 2 m/s to 5 m/s which flow through 23.42 m length of 150 mm diameter pipe. The result showed that the system gives heating in the range of 4.1°C to 4.8°C. In another study, Bansal et al., (2010) further analyzed the EAPHE system performance during summer with similar parameters and showed that the system gives a cooling range of 8°C to 12.7°C in temperature reduction from the ambient. Onyango (2012), using a prediction method using computer simulation studied the EAHE system using four parallel PE pipes with the pipe diameter at 200 mm and 11 m long. The pipes were buried at 1 m deep in the ground. The model space of the outlet was an insulated office space measuring 6.1 m long, 2.4 m wide and 2.4 m in height and located at the Miami University, in hot-humid Florida. The simulation studies, reveals that the temperature reduction between 2.7°C and 8.9°C was obtained by using this passive cooling technique.

The most recent study on EAPHE was that conducted in Malaysia was by Sanusi, et al., (2013) studying on the potential of this system in the hot-humid climate. The study uses 3 polyethylene (PE) pipes with 76 mm in diameter and 30 m long. All three pipes were buried separately at depths of 0.5 m, 1.0 m and 1.5 m. Fan blowers were installed at each inlet of the pipes which provided air velocity at 5.6 m/s. The result showed the best reduction of temperature of up to 6.4°C during the wet season and 6.9°C during the hot and dry season, was when the pipes were buried at 1 m depth underground. Meanwhile, 30m long PVC pipes were also buried at 0.5m, 1.0m and 1.5m depth underground at the same time. However, due to the increasing weight of the soil as it goes deeper underground, the PVC pipes below 0.6m were found broken just before measurements were taken. It concluded that the PVC pipes have low durability as compared to PE pipes. Furthermore, a parametric study was carried out in EnergyPlus in comparing other pipe materials; PVC, PE, Brick and Clay (Sanusi, 2012). The results had shown that Clay pipes provide the lowest pipe outlet air temperature among the four pipes. This research extends the type of buried pipes for its parametric analysis on buried pipe materials.

Table 1 shows the summary of the all studies mentioned above.

Researcher	Location	Material	Temp. Reduction °C
Gowami & Biseli,1993	Florida, USA.	Plastic (PVC)	4 – 6
Sharan & Jadhav, 2002 & 2003	Ahmedabad, India. Thor, Ahmedabad.	Mild steel	8 – 10 14
Bansal et al., 2009 & 2010	Ajmer, India	Steel	4 – 5 (Heating) 8 – 13 (Cooling)
Onyango, 2012	Florida, USA.	Polyethylene (PE)	3 - 9
Sanusi, et.al, 2013	Selangor, Malaysia.	Polyethylene (PE)	6 - 7

Table 1: Summary of studies on EAPHE systems

4. The Methodology

This paper intends to systematically find the best pipe material for the EAPHE system for the hot and humid climate. Through the process of the elimination using exhaustive enumeration, six (6) possible pipe materials commonly available in Malaysia: PVC (polyvinyl chloride), PE (polyethylene), steel, clay, concrete and copper, were investigated. The computer simulation used the EnergyPlus (http://apps1.eere.energy.gov/buildings/energyplus) software to evaluate the performances of the various types of pipe materials in order to obtain optimum outlet temperature reduction. EnergyPlus is an energy analysis and thermal load simulation program that calculates the heating and cooling loads of a building necessary to maintain thermal control and comfort in buildings. The main feature of this software is that it gives an integrated and comprehensive simultaneous solution as would the real building. The expected output for this study is in the form of temperature difference between the intake (outdoor ambient temperature) and the eventual temperature of the air that flow through the EAPHE system to the outlet inside of the building.

The research methodology was designed as such that the parametric studies evaluate the performance of the various types of pipe materials that can be used for EAPHE in order to obtain the optimum outlet temperature reduction. EnergyPlus simulation software was used because it has been validated with field experiments by Sanusi, Li and Ibrahim (2012) which showed similar results. The study was conducted for four different experiment steps to determine the optimum pipe and pipe system through the process of elimination, as shown in Figure 2.

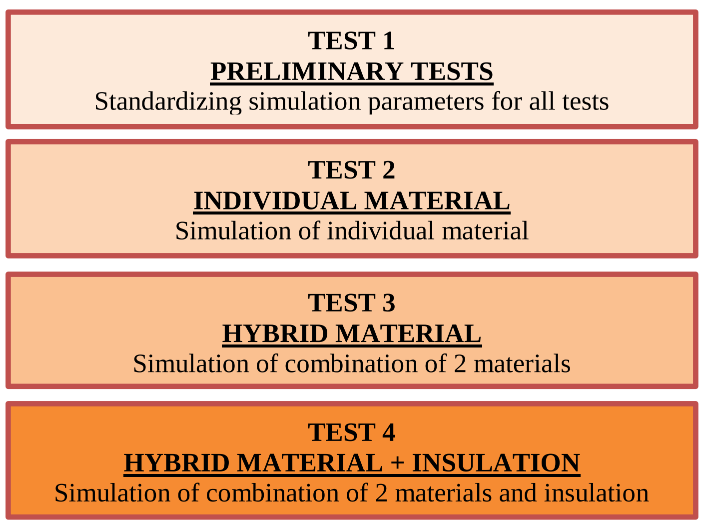

Figure 2: Parametric steps undertaken for the computer simulation tests

4.1. TEST 1 - Preliminary Tests

In this step, the design parameters of the EAPHE system were determined to be standardized as the common factors for the next 3 simulation tests. The design parameters to be standardized for the EnergyPlus simulation are: the ambient temperature, air velocity, length of pipe, diameter of pipe and the buried depth. These tests were done for each of the parameters above to look at the optimum values. The values above were tested based on validated and recommended literatures. The standardized variables for each parameter established by TEST 1 and will be used for the next simulation tests are as follows:

- Max. ambient inlet temperature: 36.46 °C
- Air velocity: 0.5 m/s
- Pipe length: 25 m
- Pipe size (diameter): 50 mm
- Buried depth: 1 m

4.2. TEST 2 - Individual Materials

The next set of tests investigated performances of the single pipe material. In this test, six (6) different pipe materials have been selected and will be simulated individually. Using the standardized parameters from TEST 1, each pipe material was subjected to the computer simulation in establishing the best material that gave the best temperature reduction through the EAPHE system. The pipes were selected based on the size availability in the market and of those commonly used in the Malaysian industries. The pipe materials concerned were: polyvinyl chloride (PVC); polyethylene (PE); copper (Cu); concrete (Conc); clay (Cl) and steel (St). Simulated data was compiled, transferred into line graph charts and analyzed. The concrete and clay pipes are available in the market, but because of their limited sizes (only >100mm diameter) these pipes will not be used in this study. Each data must be correctly keyed in or fatal error will occur in the program and cannot be processed precisely. The results obtained will determine the best material performance and will be used for the next test.

4.3. TEST 3: Combination of Materials (Hybrid)

In the previous exercise, single pipes were tested to find out which one would perform the best for the EAPHE system in hot and humid context. In this test, a combination of 2 pipes (hybrid) materials were simulated – one inside of the other, as shown in Figure 3.

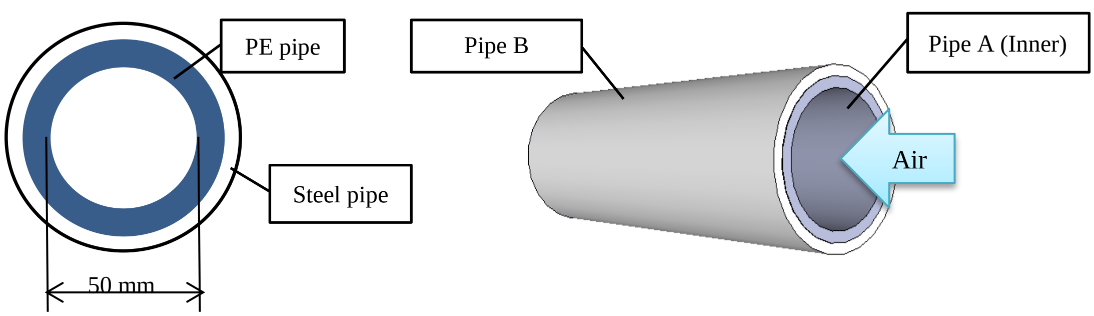

Figure 3: A cross section of two pipes in a hybrid pipe system

In this test, the inner diameter (ø) of 50 mm will be kept at a constant as with the previous simulation and the outer layer is the 100mm pipe. The combination of the two different materials will be calculated and simulated accordingly. The air from inlet point flows along the pipe before entering the building space. Table 2 shows the total thermal conductivity of the combination of the two different types of material.

Table 2: Thermal Conductivity (W/mK) of the combined pipe materials

Material	Clay	Copper	Steel	PVC	Concrete	PE
Clay		385.25	50.45	0.44	1.05	0.67
Copper	385.25		435.2	385.19	385.8	385.42
Steel	50.45	435.2		50.39	51	50.62
PVC	0.44	385.19	50.39		0.99	0.61
Concrete	1.05	385.8	51	0.99		1.22
PE	0.67	385.42	50.62	0.61	1.22	

As an example, the combination of Copper and PVC (Cu+PVC) pipes will give the total thermal conductivity of 385.19 W/mK and and PE and PVC (PE+PVC) and the best hybrid pipes of this test will be used in Test 4.

4.4. TEST 4: Hybrid Material + Insulation

In the final test of the exhaustive enumeration process, 2 types of simulation processes were undertaken, as follows:

- Test 4A – hybrid system + water
- Test 4B – hybrid system + Rockwool insulation

The aim of these tests are to investigate whether insulation filled in between the 25mm gaps has any effect in reducing further the air temperature inside the EAPHE pipes, as shown in Figure 5. The results of these tests are elucidated in the next section.

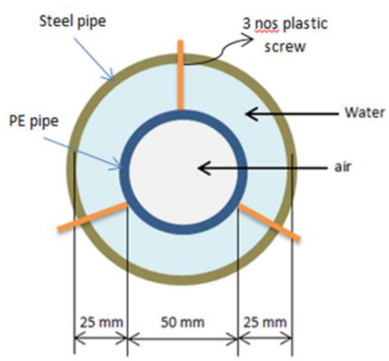

Figure 4: A cross-section of the insulated hybrid materials.

At the outlet, the ends of the hybrid pipes faced upward and were closed by using an end cap to prevent the medium such as water and air from spilling out the pipe, as shown in Figure 6.

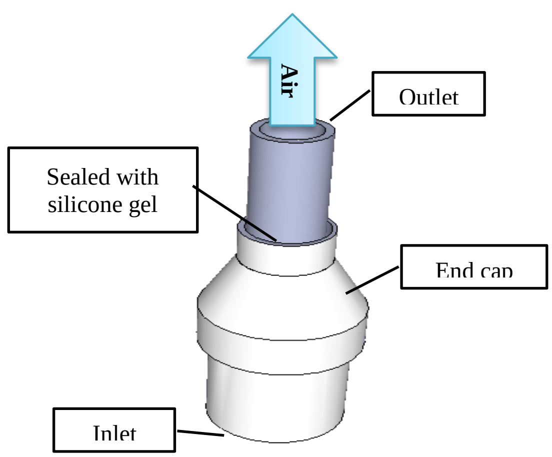

Figure 5: The schematic diagram of the end cap assembly

In order to ensure that the inner pipe stays in the middle of the outer pipe, plastic screws are used to tie the 2 pipes together, as shown in Figure 7. These are then sealed with silicone gel to prevent the water and air from sipping out.

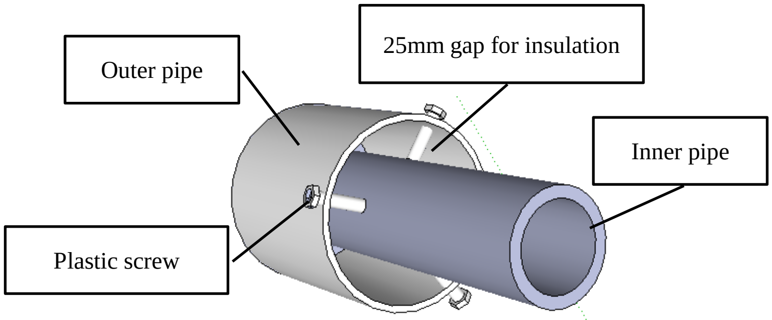

Figure 6: The schematic diagram of the hybrid pipe system.

5. Analysis, Results and Findings

In this section results of all tests are explained accordingly. All tests were simulated with the constant variables as determined in Test 1 in regards to the ambient temperature, air velocity, length of pipe, diameter of pipe and the buried depth.

5.1. TEST 2

Test 2 was conducted to find out the optimum pipe material for the EAPHE system. The air speed (m/s), under-ground depth and pipe length were set as constants of 0.5 m/s, 1 meter and 25 m respectively. All diameters of pipe material were set at 50 mm as decided in Test P.1 previously. Only four (4) different pipe materials (PVC, Steel, Cu and PE) with different material thermal conductivity (W/m²K) were simulated. The reason is that, the size of 50 mm diameter for clay and concrete pipes are not available in the market. Therefore, the clay and concrete pipe will be used in the (Test 3) insulated hybrid pipe classification as an outer pipe during the test and simulation.

Table 3 shows results that the outlet temperature of the four materials ranging between 30.231°C and 30.25°C when the maximum ambient temperature was 36.46°C at 2 pm.

Table 3: Temperature reduction of different type of materials for TEST 2

T_{am}	PE	PVC	ST	Cu
36.463	30.231	30.345	30.248	30.250
ΔT	6.23	6.12	6.22	6.21

The results indicated that the PE (polyethylene) has the maximum temperature reduction followed by ST (steel), Cu (copper) and PVC (polyvinyl chloride). Therefore the best reduction between the ambient temperature and pipe outlet temperature was 6.23°C for the PE pipe material. Although PVC shows the poorest performance, this material will still be further tested as a combination with other pipe materials. Therefore all 4 pipes above with the addition of concrete and clay pipes will be tested further in TEST 3.

5.2. TEST 3

The aim of this set of Test 3 is to examine the potential for temperature reduction via a combination of two (2) pipe materials (hybrid). With the same design variables remaining fixed as the above test, the thickness and thermal conductivity value of hybrid material are the ones that changes and as calculated by the software. The combinations of the pipes gave rise to 30 permutations and the results show slight variances between them. Thus the following findings for Test 2 are reported in Table 4, which shows an example of the significant variations only.

Table 4: Temperature variances of the combination pipe materials (hybrid) for TEST 3.

T_{am}	Cu+St	PVC+Cu	PVC+St	PE+Cu	PE+St	PVC+PVC	PE+PE	PE+PVC
	Metal	Metal+Non-Metal				Non-Metal		
36.463	30.229	30.229	30.229	30.229	30.229	30.234	30.230	30.231
Δ T	6.233	6.233	6.234	6.233	6.234	6.228	6.233	6.232

In this test, the temperature reduction at pipe outlet of the different combinations ranges around 6.23 K and the differences between them are between 0.001K and 0.01K. However, the combination of metal and non-metal elicit better temperature reduction than the metal and non-metal only combinations. This would infer that combining the thermal conductivities between metal and non-metal has better impact on the temperature reduction performance of the pipes. Since the temperature reduction difference between all combinations is small then the combination of the non-metallic pipes are recommended to be simulated for the next process of elimination. This is due to the cost benefit and versatility of the materials for metallic materials is more expensive. However the results of TEST 4 also show findings of metal and non-metal combinations as a comparison.

5.3. TEST 4

5.3.1. Result Test 4A - Hybrid Material with Water as insulation

In this simulation instead of air in the gap, another two (2) types of insulation medium were tested to be in the 25mm space between the two materials. Water (W) and Rockwool (RW) insulation were used and simulated with the two pipe materials in order to obtain the best performance of temperature reduction at pipe outlet. The inner pipe diameter (50 mm), outer pipe (100 mm), air flow rate (0.00098 m^3/s), underground depth (1 m), air velocity (0.5 m/s), and pipe length (25 m) were set as the fixed variables. Other variables that are also essential are the pipe thickness (m) and the thermal conductivity (W/mK) were also input into the simulation. TEST 4A elicit 30 permutations and the significant results only are displayed in Table 5.

Table 5: Temperature reduction of Water-insulated hybrid system

T_{am}	St+St	Cu+Cu	PE+St	PVC+Cu	St+ Cl	PE+Cu	PVC+PVC	PVC+ PE	PE+ PE
	Metal		Metal+Non-Metal				Non-Metal		
36.463	30.328	30.326	30.218	30.228	30.228	30.228	30.230	30.230	30.231
Δ T	6.135	6.137	6.245	6.234	6.234	6.234	6.232	6.232	6.232

The simulation results show that the differences in the temperature reduction between the water-insulated pipes at the pipe outlet are in the range between 6.14°C to 6.25°C. The best water-hybrid system is the combination of Steel and PE (St+PE) and the lowest are the combination of steel + steel (ST+ ST) with a 0.1K temperature reduction difference between the pipes at the pipe outlets. Although the metal+non-metal show better result the difference is very slight. Therefore, the non-metal combination pipe material is a better buried pipe alternative for the EAPHE passive cooling system because it is the cheaper. PE + PE pipe is recommended for the selection since they are more durable, flexible and easier to handle as compared to the other pipe materials.

5.3.2. Result Test 4B - Hybrid Material with Rockwool as insulation

Test 4B probed whether installing fiber insulation material like Rockwool could provide a better flow of cooled air and temperature difference. The simulation variables were similar with the test above and done for 30 permutations. The results are shown in Table 6.

Table 6: Temperature reduction of Rockwool-insulated hybrid system

T_{am}	St+St	Cu+Cu	PE+St	PVC+Cu	St+Cl	PVC+PVC	PVC+PE	PE+PE	PVC+Conc
	Metal		Metal + Non-Metal			Non-Metal			
36.463	30.234	30.232	30.225	30.228	30.228	30.234	30.231	30.229	30.434
Δ T	6.226	6.228	6.235	6.232	6.232	6.226	6.229	6.231	6.028

The temperature reduction of the system is in the range between 6.03^{o}C to 6.23^{o}C. The optimum Rockwool-hybrid system is also the combination of Steel and PE (St+PE) and the lowest are the combination of PVC and concrete (PVC+Conc) with a 0.2 K temperature reduction difference between the pipes at the pipe outlets.

4.5 Summary of all test results.

To summarize the results from all four (4) tests conducted, Table 7 presents the performances from the single pipe material system to the hybrid pipe system to the insulated hybrid system.

Table 7: Summary of performances of the best results from all tests

T_{am}	PE	PE+St	PE+PE	PE+W+St	PE+RW+ St
	Individual	Hybrid 2 pipes		Hybrid 2 pipes+insulation	
36.463	30.231	30.229	30.230	30.228	30.228
Δ T	6.232	6.234	6.233	6.235	6.235

Through the series of simulations conducted this study the results show that when the ambient is at 36.46^{o}C the optimum pipe material for the individual pipe test is the polyethylene (PE) and the best combination pipe system is the hybrid of PE+st (Polyethylene + Steel). The best hybrid pipe systems with insulation for the EAPHE are the PE+W+St (polyethylene + Water + steel) and PE+RW+St (polyethylene + Rockwool + steel) with similar temperature reductions of 6.235^{o}C. All the findings indicate that the best pipe material for EAPHE system and common to all three tests is the PE pipe material. The PE performance is optimum for the individual as well as the combination systems. The inclusion of insulation in the gaps of the hybrid system proved to be of no consequence to the temperature reduction performance.

4.6 Cost Analysis of the EAPHE Piping System

This section explains on the cost analysis related to the materials required for the field experiment of EAPHE system based on the parametric studies. The total length required in the system is 25 meter length, and pipe size of 50 mm diameter. Cost factor is the most crucial thing to be considered when developing the system. The cost of each pipe material as of the date of this study in 2014 is shown in Table 8. The costs may fluctuate with the economy of the country.

Table 8: Cost of pipe materials as of 2014

Pipe Material (50 mm)	Price RM/m length	USD equivalent (OANDA Currency converter)	Length (m)	Total RM	USD equivalent (OANDA Currency converter)
Copper	206.00	63	25	5,150.00	1,576.60
Steel (Class B)	44.20	13.50	25	1,105.00	338.30
PE	21.70	6.60	25	542.50	166
PVC	20.00	6.10	25	500.00	153

The cost shown is the cost of the pipes only, excluding the joints, transportation, trenching and labour charges. For a 25 m length the copper pipe material will cost RM 5,150.00 which is 11times, 8 times and 5 times more expensive than PVC, PE and Steel respectively. Steel pipe is more or less 2 times more expensive than PVC and PE pipes. Therefore the better options would be to either use PVC or PE material for the EAPHE system. Although the PVC is much cheaper than the PE, suggestions by the contractors were that PE tends to be more durable, flexible, easier to work with and lasts longer.

6. Conclusion

This paper was researched and written on the premise that to help save energy in the building sector passive cooling design and strategies are necessary to be integrated into buildings. There are various other passive design strategies that are utilized in the hot and humid context but not much has been researched on the EAPHE system. This paper contended that there is potential for temperature reduction from cooled air from earth buried pipes into indoor spaces of building to reduce the building's dependency on mechanical cooling alone. This paper was set out to investigate the optimum pipe material to be used, especially in the tropical situation. Utilizing a predictive method using the environmental simulation software EnergyPlus, which has been used and validated by numerous researches on environmental studies, the authors used an exhaustive enumeration process to eliminate the types of pipe materials tested by other studies and also those that are locally available in Malaysia. Six different pipe materials were identified and tested rigorously individually, as a combination of two-pipes system and finally, incorporating insulation in between the gaps in the combination of the two-pipe system. The findings revealed that there was not much difference in terms of temperature reduction between all three pipe systems tested.

From the studies done several findings are revealed: the temperature reduction in the EAPHE system ranges from 3-6 K depending on the variations of the maximum ambient temperatures. The result of this study also affirms the temperature reduction to that undertaken by Sanusi in 2012. Although all pipes have only slight differences in temperature reduction between them but the best pipe material is the Polyethylene (PE) which gave optimum temperature reduction individually and in the combination or hybrid systems with other pipes. Even though not the cheapest material, this study maintains that PE is the better material because it is more versatile, durable and favoured by most contractors. Although it is slightly more expensive (8% more) than PVC the savings would be in the form of maintenance and replacement costs as PVC pipes are more prone to wear and tear during the construction period and over time..

This study affirmed that the choice of materials that most researchers undertake for the study of EAPHE is dependent on the affordability and local availability of the materials. In addition it is opined that the choice of the pipe material does not have any significant consequence on the temperature reduction by the EAPHE system in hot and humid climate. Future research for this system would be to investigate the parameters of reducing the ambient temperature over the ground of the EAPHE system be means of shading and cooling the ground from trees and bushes and also inside water or wet covered areas. The notion is that if the soil temperature is cooler then the air passing through the pipes inside the soil can be cooled considerably to have a more favorable temperature reduction at the outlet.

References:

Ahmed A., Miller A. and Kenneth Ip., (2007). The potential of earth-air heat exchangers for low energy cooling of buildings. PLEA2007. The 24th Conference on Passive and Low Energy Architecture

ANSI/ASHRAE 55-2004, Thermal environmental conditions for human occupancy, American Society of Heating Refrigerating and Air-conditioning Engineers Inc., Atlanta, USA, 2004.

Bansal V., Misra R., Agrawal G.D. and Mathur J., (2009). Performance analysis of earth–pipe–air heat exchanger for winter heating. Energy and Buildings. Vol. 41(2009), pp. 1151-1154

Bansal V., Misra R., Agrawal G.D. and Mathur J., (2010). Performance analysis of earth–pipe–air heat exchanger for summer cooling. Energy and Buildings Volume 42, Issue 5, May 2010, Pages 645–64

Chin F.K., (2012). The Future of Energy In Malaysia. Minister of Energy, Green Technology and Water at the Malaysian International Chamber of Commerce & Industry (Micci). 24th April 2012.

Goswami D.Y. and Biseli K.M., (1993). Use of underground air tunnels for heating n cooling agriculture and residential buildings. Fact sheet EES 78, Florida Cooperative Extension Services, University of Florida, May1993 pp.1-4

Kubota. T., Jeong S., Toe D.H.C. and. Ossen D.R., (2011). Energy Consumption and Air conditioning usage in Residential building of Malaysia. Journals of International Development and Cooperation, volume 17, No.3 pp. 61-69.

Lefaucheur J.L, Tamrakologos M., Karnezi S., Tsironis I. and Rodi F., (2010). Hybrid Energy Susytem in Future Low Carbon Building. Univ. Strathclyde, Glassgow.

Ministry of Natural Resources & Environment Malaysia (MNRE) (April, 2011), Malaysia’s 2nd National Communication (NC2) to the United Nations Framework Convention on Climate Change (UNFCCC). ISBN 978-983-44294-9-2.

Noor Aziah MA, (2008). Energy efficient design towards energy conservation for terraced housing in Malaysia. PHD thessis (unpublished). Curtin University of Technology, Perth, Australia.

Onyango J.O., (2012). Simulation of passive ground-coupled cooling system for a house in hot humid climate. WIT Transactions on Ecology and The Environment, Vol. 160, ISSN

Santamouris M., Mihalakakou G., Argiriou A. and Asimakopoulos D.N. (a), (1995). On the performance of building coupled with earth to air heat exchangers. Solar Energy 54 (6):375-80.

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

Sanusi A.N.Z, and Li S. and Ibrahim M.N. (a), (2012). The potential of low energy earth pipe cooling in hot and humid Malaysia. In: International Conference on Green in the Built Environment (ICGBE) 2012, 29 - 30 May 2012.

Sanusi A.N.Z, Li S. and Ibrahim M.N. (2013). Passive ground cooling system for low energy buildings in Malaysia (hot and humid climates). Renewable Energy, 49 , pp:193-196.

Sharan G., Sahu R.K. and Jadhav R., (2001). Earth Tube Heat Exchanger Based Air-conditioning for Tiger Dwellings. Zoos' Print, 16:5, May, (RNI 2:8).

Sharan G. and Jadhav R., (2002). Soil temperature regime at Ahmedabad. Journal of Agricultural Engineering, 39:1, January-March.

Sharan G., Jadhav R., (2003). Performance of single pass earth-tube heat exchanger: An experimental study. Journal of Agricultural Engineering (forthcoming).

Tang, C.F.,(2008). A re-examination of the relationship between electricity consumption and economic growth in Malaysia, Energy Policy 36, 3077 – 3085.

.

T_{am}	PE+St	PE+Cu	PVC+ PE	PE+ PE
36.463	30.218	30.228	30.230	30.231
Δ T	6.245	6.234	6.232	6.232

T_{am}	PE+St	PVC+PE	PE+PE
36.463	30.225	30.231	30.229
Δ T	6.235	6.229	6.231