Journal of Civil Engineering, Science and Technology
Volume 7, Issue 1, April 2016

INVESTIGATION OF GROUND TEMPERATURE FOR HEAT SINK APPLICATION IN KUCHING, SARAWAK, MALAYSIA

Imran S. Muhammad[1, *], Baharun A.[2], Halipah S. Ibrahim[3,] and Wan A. Wan Z.B.[4,]
[1,2,3,4] Faculty of Engineering, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

Date received: 23/10/2015, Date accepted: 27/2/2016
Corresponding author's email: md.syukri@moh.gov.my

Abstract - Ground Air Heat Exchanger (GAHE) may be a solution to improve thermal comfort in buildings located in Sarawak but no ground survey specifically to examine the potential of GAHE has been done. Ground temperature prediction with computer program did not provide an accurate result for this region. In this study, a few sites with different soil profile in Kuching, Sarawak were selected to determine the soil temperature up to 4 meters depth. For peat soil area with high water table, the ground mean temperature is about 28 °C after 1m depth. For sandy clay type soil which is subjected to tidal activity, the daily soil temperature fluctuates greatly with the highest maximum temperature exceeding 32°C for all depth. This behavior is not really desirable if the ground were to be used as a steady heat sink source. Red podzolic soil gave an almost flat profile between 26°C to 27°C after the depth of 1m which is more desirable as a ground heat sink source. Therefore earth tube application in the state of Sarawak should consider the type of soil profile and optimum depth of to take advantage of the cool ground to provide building cooling.
.

***Keywords*:** Ground temperature, heat sink, Kusuda Formula, earth tube, Sarawak soil temperature

1.0 INTRODUCTION

Several pertinent studies have shown that the indoor thermal condition of a single-storey as well as double-storey terrace houses in Malaysia usually will exceed the recommended thermal comfort range as reported in [1] and [2]. The peak temperature is somewhere between 30 to 35° C in the afternoon which is beyond the thermal comfort range of between 28 °C to 31 °C at air velocity of 0.8m/s for natural ventilation in this climate condition [3]. Studies have been done that showed building could be passively cooled by transferring the heat to the ground [4] - [5]. The ground will act as a heat sink source to offset the peak temperature of the building indoor air. Earth tube application such as Ground Air Heat Exchanger(GAHE) basically cools room air by forcing the ventilation air into the ground via long metal or plastic pipes before entering the building as shown by [6] and [7] in the regions of Peninsular Malaysia. However, the study conducted was site specific and no further tests were done on other types of soil profile in Malaysia and the corresponding optimum depth. No such survey and earth tube application has been implemented in Sarawak so far. Building thermal modelling software such as TRNSYS, Design Builder or Energy Plus could be used to predict vertical soil temperature profile for different categories of soil condition. However the built in Kasuda Formula in the software did not provide an accurate soil temperature profile. This will be elaborated in this paper. The objectives of this study is to obtain soil temperature up to 4m depth in different type of soil profile in Sarawak where the data could be used to accurately study the performance of earth tube technology to passively cool building.

2.0 PREDICTING SOIL TEMPERATURE

The use of building thermal modelling software such as TRNSYS, Design Builder or Energy Plus could help to predict the performance of GAHE on a building. The software requires the average and amplitude of soil surface temperature to be entered manually as part of the input required to calculate the soil temperature surrounding the pipe. The temperature at any depth and time is calculated by using the following formula [8] .

$$T_{soil}(D, t_{year}) = T_{mean} - T_{amp} * \exp\left(-D\sqrt{\frac{\pi}{365*\alpha}}\right) * \cos\left[\frac{2\pi}{365}\left(t_{year} - t_{shift} - \frac{D}{2}\sqrt{\frac{365}{\pi*\alpha}}\right)\right] \quad (1)$$

Where

$T_{soil}(D, t_{year})$	=	Soil temperature at depth D and time t of the year
T_{mean}	=	Mean surface temperature (average air temperature). The temperature at an infinite depth will be this temperature.
T_{amp}	=	Amplitude of surface temperature [(maximum air temperature- minimum air temperature)/2]
D	=	Depth below the surface (surface=0)
α	=	Thermal diffusivity of the ground (soil)
t_{year}	=	Current time (day)
t_{shift}	=	Day of the year of the minimum surface temperature

Figure 1 shows the annual prediction of soil temperature along the outer surface of the earth tube as calculated by Energy Plus (ground surface mean temperature was 30ºC with 3ºC amplitude as input) for a building model located in Kuching, Sarawak. The building model was retrofitted with earth tube at a depth of 1.5m from the ground surface.

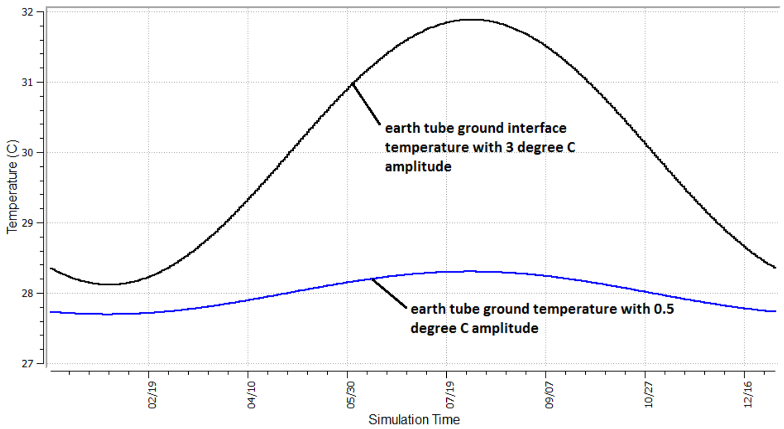


Figure 1 Annual soil temperature profile at earth tube level as calculated by Energy Plus software.

This result, however, is not accurate if we were to compare it to the annual ground survey temperature done by [9] and [10]. The survey plot is as attached in the Appendix. As such Kusuda formula could not be used in region like Malaysia to estimate the ground temperature as Kasuda equation development was based on soil and climate condition which is different than Malaysia [8] . As a result the software user needs to input a lower or flat amplitude value manually so that the annual soil temperature calculated could be close as possible to the actual surveyed annual ground temperature as shown in Figure 1. Even so, to get a similar annual soil temperature profile as per [9] and [10], multiple simulations need to be carried out for each month for different soil surface temperatures so that a more accurate annual earth tube ground interface could be plotted. The predicted soil temperature given by Energy Plus should be calibrated to an actual surveyed data before any study on the impact of earth tube application in any building model could be done. So far, there is only one such study in Malaysia where calibration could be carried out. However the survey data was limited to sandy soil condition and was located in campus site of International Islamic University, Peninsular Malaysia as shown in Figure 2 [7].

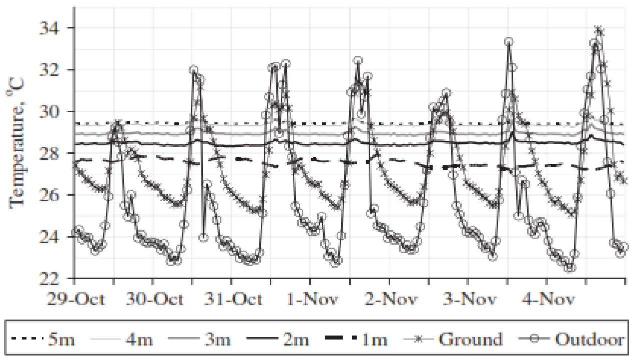


Figure 2 Outdoor ambient, ground surface and underground temperature for sandy soil campus site of International Islamic University, Malaysia [7].

Table 1 shows an example of calibration result before the computer building model can be used as a baseline model. The calibration was done by comparing the simulated temperature of the air entering the thermal zone after passing through the earth tube with an actual experiment conducted by the other study mentioned earlier.

Table 1 Calibration of simulation model with an actual earth tube experiment by others

	Simulation Model	**Study from [7]**	**Error**
Outdoor Air DBT Peak Temperature °C	33.8	34.1	0.9%
Earth Tube Zone Inlet Air Temperature °C*	28.1	28.0	0.4%

*Earth Tube Zone Inlet Air Temperature refers to the temperature of the air entering the zone after passing through the earth tube [C].

Since there are almost no local data to carry out this calibration, one of the aim of this study is to carry out ground temperature survey for different soil type particularly in the state of Sarawak. Only then, it can the impact of earth tube application on buildings in Sarawak can be accurately studied.

3.0 METHODOLOGY

The measurements were carried out at 3 different residential locations around Kuching, Sarawak with different types of soil profile defined by the Minerals Geoscience Department of Malaysia as summarized in Table 2. These soil profiles are the major ones typically found in the state of Sarawak [11]

Table 2 Distinctive soil profile at 3 test location

No	Location	Soil Profile	Filling Material	Ground level (ft) from sea level
1	Jalan Ketitir, Batu Kawa	Peat soil overlaying riverine alluvium	Offsite earth fill	43
2	Jalan Sultan Tengah, Petra Jaya	Sandy clay overlaying riverine alluvium subject to salty water flooding	Offsite river sand fill	36
3	Taman Genesis, Matang	Red yellow podzolic soil overlaying sandstone formation	Cut and fill	70

Thermocouples attached to metal rods were used to carry out measurement from one site to another in succession. The metal rods were driven with hammer at five separate points to a depth of 0.02m, 0.2m, 1m, 2m and 4m for each site except site No.3. Deeper depth is not possible due to limitation of instrument used. As for site No. 3, no measurement were taken beyond 2m depth due to the stiffness and hardness of the soil layer which did not permit the metal rods and the driving hammer to go further into the ground. The measurements were logged with a multiple channel data logger on hourly basis. Minimum of 3 days data were taken sometime in month of November and December 2014 for all sites except site No. 3. Measurement for site No. 3 was taken in middle of March 2015. Ambient and water level were also observed for all sites and recorded. A simple shallow pit was dug to allow water level to be observed. The pit also serves to confirm the type of soil present at site. It should be noted that at location No. 1, all the metal rods were deliberately driven under shaded area to observe the effect of tree shading on ground temperature. The effects of covering the ground to further reduce the ground temperature were also presented by [9] . The experiment showed that the ground temperature at 1m and 1.5m were further reduced from 28.5 °C to about 27°C when the ground surface was insulated with timber palette and tyres. Due to limitation in time and equipment availability, annual measurement cannot be carried out.

4.0 RESULTS

Site No 1 (Jalan Ketitir, Batu Kawa)

The data recorded for this site were analyzed and presented in Figure 3. The temperature swings near the surface of the ground (0.02m) follows closely the ground temperature (ambient). As expected, the graph shows that the diurnal temperature starts to decrease after about a feet from the ground and it does not reach the depth of more than 1 meter. This is in agreement with the finding from other studies by [9] and [10]. However the soil temperature does not increase with depth as stated by [9] for this particular soil type.

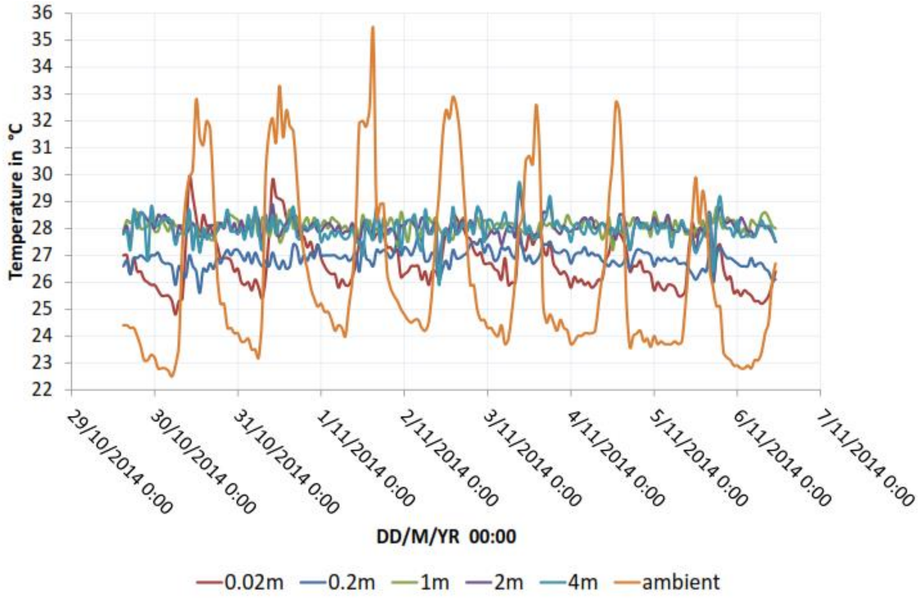


Figure 3 Soil temperature profile at site No. 1 (30th October – 6th November 2014)

Further analysis shows that beyond 1m, the ground temperature remains unchanged up to 4m depth. This may due to the underlying peat layer with high water table where high moisture content or saturated ground has a higher heat storage capacity. This homogeneous and isotropic saturated soil layer have a high latent heat capacity where the diurnal air temperature variation seem to have little effect on this layer of wet soil. Study by [12] has described the effect of soil type and moisture content to soil thermal conductivity as well as to ground heat pump performance. Moist soil allows more heat to be extracted or introduced without affecting the soil temperature that much. This is also in agreement with soil thermal properties studied by [13]. According to the study, heat capacity and thermal diffusivity are greatly affected by water content because of the high heat capacity of water compared to air and solids.

Ambient temperatures were recorded at 2 different locations both in tree shaded and open area. It was observed that the ambient temperature under the shade is lower by 1.6 °C in comparison to the open area. This is primarily due to lower direct radiation from the sun and surrounding trees transpiration process which lowers the maximum ambient temperature. One would expect a much lower ambient temperature in a denser recreational park or a jungle floor and experience a cooler environment even under a hot afternoon sun. Table 3 summarizes the preceding points.

Table 3 Mean and Diurnal Temperature at Various Depth for site No.1

Depth (m)	Mean Temperature °C	Highest Max Temp °C	Lowest Min Temp °C
0.02	26.8	29.9	24.8
0.2	26.9	28.0	25.6
1	28.1	28.8	27.2
2	28.1	29.4	26.7
4	28.0	29.7	25.9
Ambient (shaded)	26.2	35.4	22.5
Ambient (open)	27.8	36.4	23.3

Due to the lower mean ambient temperature under tree shaded area, the ground mean temperature at depth of 0.02m and 0.5m is also affected. However at depth beyond 1 m the mean ground temperature follows closely the mean open air ambient temperature. The mean soil temperature value of about 28°C measured in the month of November above also correspond to MARDI mean monthly and annual soil temperature in Kuching for month of November as shown in Table 4.

Table 4 Mean Monthly and Annual Soil Temperature in °C [10]

Station :	Kuching	
Month	Depth in cm	
	30	122
Jan	27.6	28.1
Feb	27.6	27.9
Mar	28.5	28.2
Apr	29.3	28.9
May	29.5	29.2
Jun	29.5	29.4
Jul	29.1	29.2
Aug	29.1	29.2
Sep	29.3	29.2
Oct	28.8	29.1
Nov	28.7	28.9
Dec	28.1	28.5
Annual	28.7	28.8

The ground water level was measured in the shallow pit and fluctuates between 1 and 2 feet below ground surface with the water temperature almost constant between 27° C and 28° C. It can be concluded that the ground water temperature is generally governed by the ground temperature itself where both body will try to reach an equilibrium state.

Site No 2: (Jalan Sultan Tengah, Petra Jaya)

Site No. 2 is located on a saline gley soil which is typical soil type near coastal area or deltaic area subject to salty water flooding [14]. The site is located less than 100m away from a river subjected to daily tide fluctuation. Measurements were taken as described in preceding pages and are presented in Figure 4.

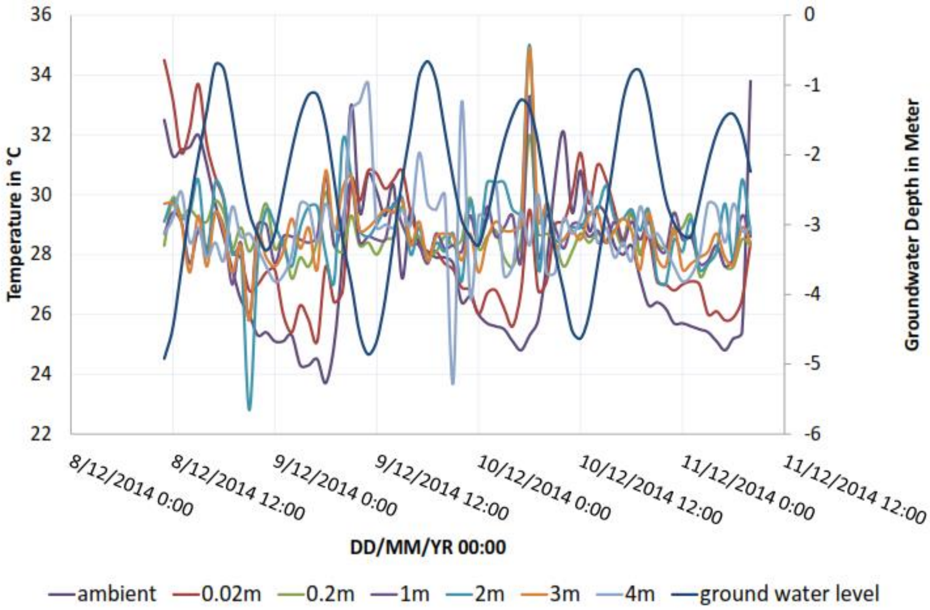


Figure 4 Soil temperature profile at site No. 2 (8th – 11th Dec 2014)

One would notice the more inconsistent pattern for all ground depth from the figure shown. Ground water level which corresponds to daily tide level is also superimposed on the chart. Immediately beyond 1 foot from the ground surface the soil temperature fluctuate generally between 27°C and 30°C. Even at 4m depth the ground temperature fluctuate somewhere between 24°C and 33°C.

This behavior of erratic soil temperature could be attributed to the sandy soil profile with highly fluctuating moisture content. The fluctuating moisture content is a result of sea tidal activity taking place in the area where the water level data could be obtained from Drainage Irrigation Department Sarawak official website . Due to low specific heat of dry sand, heat rises or drops rapidly compare to saturated sand [12]. The rate of heat transfer is dependent on the moisture content of the sand. This may explain the erratic soil temperature profile at site No 2. In general water added to soil greatly increase the thermal conductivity as well as increasing its diffusivity 2 to 3 times the dry value [16]. However the mean ground temperature for all depths is almost the same and corresponds to the mean ambient temperature at about 28°C as shown in Table 5. The mean soil temperature value of about 28°C measured in the month of November above also corresponds to MARDI mean monthly and annual soil temperature in Kuching for month of November as shown in Table 4.

Table 5 Mean and Diurnal Temperature at Various Depths for site No.2

Depth (m)	Mean Temperature °C	Highest Max Temp °C	Lowest Min Temp °C
0.02	28.3	34.5	25.1
0.2	28.6	32.0	27.2
1	28.7	33.3	25.8
2	28.9	35.0	22.8
4	28.9	33.7	23.7
Ambient	28.1	33.8	23.7

Site No 3: (Taman Genesis, Matang)

The third test site is located at Taman Genesis, Matang a hilly area in Kuching Sarawak. The residential area was a cut and fill area where red podzolic soil overlaying sandstone is the main soil profile of the area. Figure 5 shows the nearly stable temperature profile after 1m depth as compared to the first two sites.

Figure 5 Soil temperature profile at site No. 3 (14th – 17th March 2015)

The mean ground temperature for all depth is between 26°C to 27°C as shown in Table 6 which is nearly equal to the mean ambient temperature taken in that 3 days survey period for site No 3.

Table 6 Mean and Diurnal Temperature at Various Depths for site No.3

Depth (m)	Mean Temperature °C	Highest Max Temp °C	Lowest Min Temp °C
0.02	26.6	33.1	24.3
0.2	26.1	27.7	25.2
1	27.0	27.8	26.5
2	27.0	28.0	26.5
Ambient	26.0	32.6	23.7

Table 7 shows the standard deviation of the data collected for all sites. Soil type for site No1 and No 3 shows smaller deviation where the ground temperature experience small deviation after 0.2m depth whereas soil type for site No 3 shows a bigger deviation instead.

Table 7 Standard Deviation for Temperature Data

Site	No 1: Peat Soil	No 2: Sandy Clay Soil	No 3: Red Podzolic Soil
Depth (m)			
0.05	0.99	2.29	2.15
0.2	0.35	1.16	0.55
1	0.27	1.23	0.19
2	0.34	1.75	0.20
4	0.46	1.51	-
Ambient (shaded)	3.14	-	-
Ambient (open)	3.11	2.90	2.77

5.0 CONCLUSION

Using Kusuda Equation to estimate ground temperature in this hot and humid region will not give an accurate result. Ground temperature was surveyed at 3 different locations representing different composition of soil type in the state of Sarawak. For all locations, the diurnal temperature does not reach the depth more than 1m deep. For peat soil area with high water table, the ground mean temperature after 1m depth is about 28 °C. However a lower mean temperature of 26°C could be achieved if the ground is heavily shaded. For sandy clay type soil which is subjected to tidal activity, the daily soil temperature fluctuate greatly with the highest maximum temperature exceeding 32°C for all depth. This behavior is not really desirable if the ground were to be used as a steady heat sink source. Among all three sites, site no 3 where cut and fill area of red podzolic soil overlaying sandstone gave an almost flat ground temperature profile between 26°C to 27°C after the depth of 1m which is more desirable as a ground heat sink source. Therefore earth tube application in the state of Sarawak should consider the type of soil profile and optimum depth of pipe where it is found that red podzolic soil overlaying sandstone and peat soil both have the heat sink source potential to allow for the application of Ground Air Heat Exchanger in local building. Due to the limitation in time and equipment availability the annual measurement of soil temperature was not possible, therefore further survey is recommended so that annual simulation of the earth tube application in building in Sarawak could be studied.

6.0 REFERENCES

[1] M. G. Normah, K. Y. Lau, and S. Mohd.Yusoff, "Thermal analysis of Malaysian double storey housing - low/medium cost unit," 2012. [Online]. Available: http://scitation.aip.org/content/aip/proceeding/aipcp/10.1063/1.4704257. [Accessed: 30-Jan-2015].

[2] S. H. Ibrahim and J. A. Tinker, "Improvements to thermal comfort in low-income housing in Malaysia," in *Conference on Sustainable Building South East Asia*, 2005.

[3] C. Cândido, R. J. de Dear, R. Lamberts, and L. Bittencourt, "Air movement acceptability limits and thermal comfort in Brazil's hot humid climate zone," *Build. Environ.*, vol. 45, pp. 222–229, 2010.

[4] G. Florides and S. Kalogirou, "Ground heat exchangers—A review of systems, models and applications," *Renew. Energy*, vol. 32, no. 15, pp. 2461–2478, Dec. 2007.

[5] F. Ascione, L. Bellia, and F. Minichiello, "Earth-to-air heat exchangers for Italian climates," *Renew. Energy*, vol. 36, no. 8, pp. 2177–2188, Aug. 2011.

[6] G. Reimann, H. Boswell, and S. Bacon, "Ground cooling of ventilation air for energy efficient house in malaysia : A case study of the cooltek house," in *Conference on Sustainable Building South East Asia*, 2007, no. 5–7 November.

[7] A. N. Z. Sanusi, L. Shao, and N. Ibrahim, "Passive ground cooling system for low energy buildings in Malaysia (hot and humid climates)," *Renew. Energy*, vol. 49, pp. 193–196, 2013.

[8] T. Kusuda and P. Achenbach, "Earth Temperature And Thermal Diffusivity At Selected Stations In The United States," 1965. [Online]. Available: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=AD0472916.

[9] A. Nur, Z. Sanusi, A. Azlan, and A. Zamri, "Seeking Underground for Potential Heat Sink in Malaysia for Earth Air Heat Exchanger (EAHE) Application," in *Proceedings Book of ICETSR,Malaysia*, 2014, pp. 542–546.

[10] The Malaysian Agricultural Research and Development Institute, "MARDI REPORT: Soil Temperature In Malaysia," 1980. [Online]. Available: http://www.mardi.gov.my/.

[11] Minerals Geoscience Department Malaysia, *Geological Map Of Sarawak*. Kuching Sarawak: Minerals Geoscience Department Malaysia, 2013.

[12] W. H. Leong, V. R. Tarnawski, A. Aittoma, N. B. Unit, and M. Group, "Effect of soil type and moisture content on ground heat pump performance," *Int. J. Refrig.*, vol. 21, no. 8, pp. 595–606, 1998.

[13] J. L. Hanson, T. B. Edi, and N.Yesiller, "Thermal Properties of High Water Content Materials," 1994. .

[14] Agriculture Department Sarawak Malaysia, "Soil Map of Sarawak," 1968. [Online]. Available: http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/asia/lists/y2_cmy.htm.

[15] Drainage Irrigation Department Sarawak, "Sarawak Online Water Level Data." [Online]. Available: http://www.did.sarawak.gov.my/.

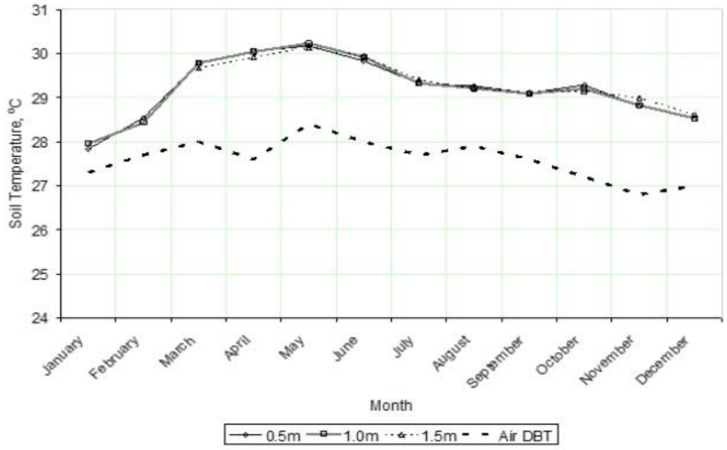
[16] H. Carslaw and J. Jaeger, *Conduction of Heat in Solids*, Second edi. Oxford University Press, 1959.

[17] M. R. Alam, "Energy Efficient Green Building Based On Geo Cooling System In Sustainable Construction Of Malaysia," vol. 3, no. 2, pp. 96–105, 2012.

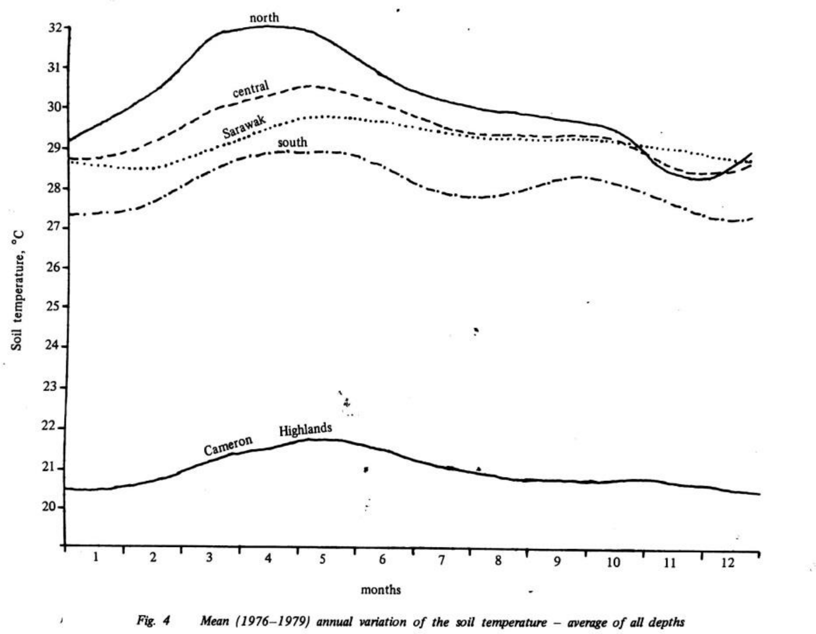
[18] Y. Yu, H. Li, F. Niu, and D. Yu, "Investigation of a coupled geothermal cooling system with earth tube and solar chimney," *Appl. Energy*, vol. 114, pp. 209–217, 2014.

[19] A. Sanusi, "Low Energy Ground Cooling System for Buildings in Hot and Humid Malaysia," De Montfort University, 2012.

APPENDIX



Average air and soil temperature at different depth underground, [9]



Mean (1976-1979) annual variation of the soil temperature – average of all depth, [10]