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INVESTIGATION OF EARTH TUBE SYSTEM APPLICATION IN LOW INCOME BUILDING IN KUCHING, SARAWAK

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Abstract

Modern residential building in Malaysia particularly in Sarawak rarely consider the ground as a source of heat sink to cool down the building. This is probably due to the lack of information on surveyed ground temperature and energy modelling of such building. A typical low income residential building in Sarawak with earth tube was modelled in Energy Plus to determine the effect of earth tube to passively cool the building in Sarawak. From the simulation result, the indoor air temperature of the east facing zone of the building could be lowered from 33°C to 29.5°C. A further drop of about 0.6°C could be achieved if the room volume served by the earth tube is reduced. The PMV of the building were greatly reduced from 3 to 1.5 on a thermal sensation scale. The operative temperature is within 80% acceptability limits of 30.3°C operative temperature as per ASHRAE Standard 55 for naturally conditioned spaces.

Keywords: Passive cooling, Earth tube heat exchanger, Low income home, Thermal comfort, Energy simulation,

1. Introduction

Residential house in Sarawak generally are constructed above ground with no basement structure with the exemption of high rise shopping complexes. Building developers nowadays construct residential homes with little regards to indoor thermal comfort and make assumption that the future owner of building will install a mechanical means of cooling the indoor environment. This is true for low income houses in the state of Sarawak where one can find single storey low cost terrace house and low rise low cost flat are the common type of low cost house

Nomenclatures

clo	Clothing insulation value, m^2.K/W
U	Heat transfer coefficient value, W/m^2.K

Abbreviations

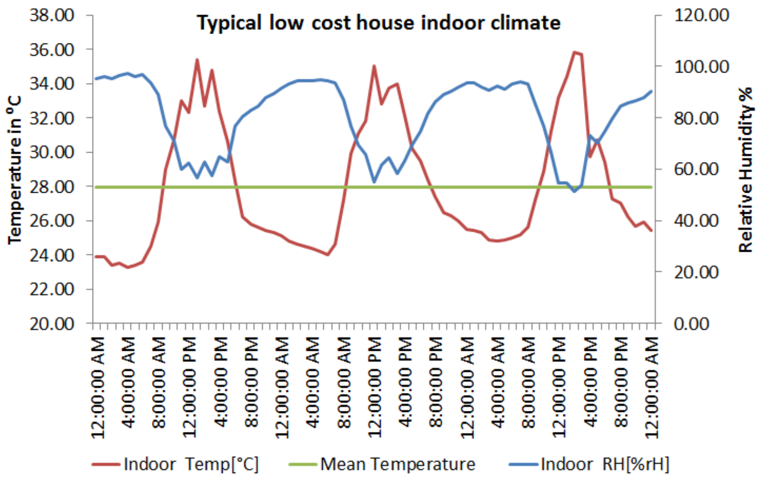
ACH	Air Change per Hour
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
DBT	Dry Bulb Temperature
GAHE	Ground Air Heat Exchanger
ISO	International Standard Organization
OTTV	Overall Thermal Transfer Value
PMV	Predicted Mean Vote

being constructed in Sarawak. The single storey building is mainly for sale to lower income group whereas the low rise flats are normally used as transit house by the government of Sarawak to reduce squatters in the state. However the focus of this study is on single storey low cost house as this type of house is more widely constructed and made available by the government in a huge land reserve of Sarawak. A typical low cost house ranging from RM 50,000 to RM60,000 constructed by Sarawak Housing Development Corporation is available for low earners group with household income of less than RM5000 a month [1]. An example of a constructed low cost house in Sarawak and its measured indoor air temperature is shown in Fig. 1. Measurement was taken in an occupied unit during clear weather to show the internal climate condition of the low cost house.

The peak temperature is somewhere between 34 to 36° 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 in this climate condition as shown by Candido et al. [2] as well as beyond than what have been set by ASHRAE Standard 55 [3] and ISO 7730 [4]. Investigation by other local researcher such as Halipah and Tinker [5], Rajeh [6], Nugroho [7], Kamar et al. [8] as well as Normah et al. [9] have showed that typical Malaysian residential house including low income house failed to provide the minimum thermal comfort target. Study by Djamila et al. [10] in a similar regional condition located in Sabah have showed from a survey that the thermal comfort temperature was at 30.2 ºC. Another study by Hussein et al. [11] have given an upper limit of 30.7 ºC for an unconditioned building in Malaysia. Similarly study by Nguyen et al. [12] have put not more than 30ºC as an upper limit for building in a hot and humid region. This strongly requires a strategy to allow for cheap and practical means to cool the low income house without passing over the burden of domestic cooling to lower income citizens.

Studies have been done that showed building could be passively cooled by transferring the heat to the ground in several ways. The ground will act as a heat sink source to offset the peak temperature of the building indoor environment. Among other technology is the Ground Air Heat Exchanger (GAHE) which basically cools room air by forcing the ventilation air into the ground via pipes before entering the building. This method if building cooling have been showed to be a promising method outside of Malaysia as explained by Woodson et al. [13], Ascione et al. [14], Florides and Kalogirou [15], Leong et al. [16], Man et al. [17], Sharan and Jadhav [18], Yu et al. [19], Yusof et al. [20] as well as Zimmermann and Andersson [21].

(a) Typical low cost house for low income earners in Sarawak [1]**.**



(b) Typical low income house indoor climate measure from 30/10/2014 to 1/11/2014.

Fig. 1. Typical low cost housing indoor climate in Kuching Sarawak.

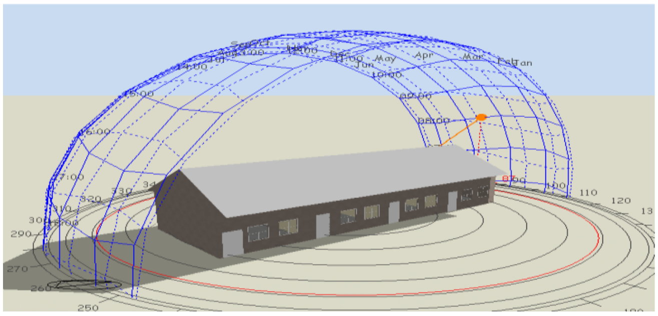
This technology was first tested by Reimann et al. [22] and Sanusi et al. [23] at the Peninsular region of Malaysia. Reimann et al. [22] showed that forced ventilation air via ground pipes could deliver 27.2°C of air at the outlet when the outdoor air is about 30° C while Sanusi et al. [23] showed that ambient air between 35°C to 37°C pumped through earth tube could be reduced to as much as 6.4°C to 6.9°C as measured at the outlet of pipe buried at 1 m depth. While both studies do show temperature drop after travelling through earth tube in the ground however, performance of earth tube application towards indoor thermal comfort of a full scale building was not demonstrated. Both studies were restricted to determine the outlet temperature of the earth tube system and there were no simulation or experiment conducted to find out the impact of earth tube installation on thermal comfort of any residential building in Malaysia. Furthermore Tin et al. [24] have shown that other method of cooling is still preferable in Malaysia such as building envelope, roof design and solar chimneys over ground cooling method.

Ground cooling method has yet to capture the interest of local home builders where study and research on the application and performance of the technology in this region is still limited and still rare. Survey of the ground temperature for this purpose is also rare where 5m deep ground survey was done by Sanusi et al. [23] in the peninsular so far. The aim of this study is to give some insight on the applicability to utilise the ground as a heat sink source to cool down low income building in Sarawak to a thermally acceptable level.

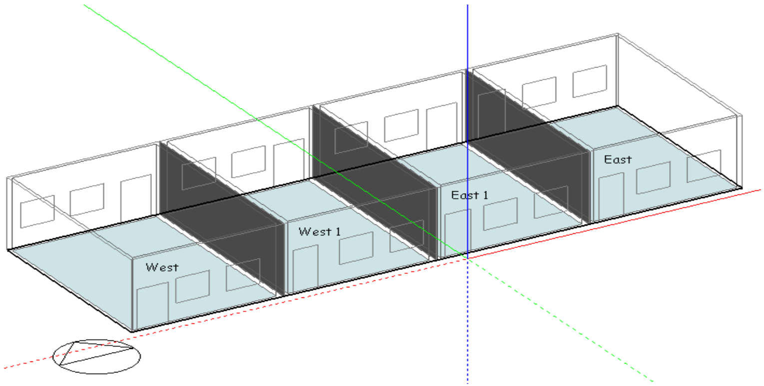
2. Earth Tube in Building Simulation using Design Builder V4.2.

2.1. Model set up

This study involves building energy simulation program that access the use of earth tube installed in a low income building model with 4 unit of houses as shown in Fig. 2. Building shorter side was oriented to the east where the east wall is expected to receive the highest amount of solar radiation and therefore will experience the highest peak indoor air temperature. Each home unit was treated as a separate thermal zone as shown in Fig. 2 with an area of 41.25m^2 for every home unit.



(a) Four unit home building model with short side orientated to the east.



(b) Four units home building with separate thermal zone for each unit.

Fig. 2. Low income building model and its corresponding thermal zone.

For the purpose of this simulation the building thermal properties were set to a minimum requirement as per building energy standard of Malaysia [25] as shown in Table 1. Detail of the earth tube installation within the building is shown in Table 2 and will be treated as the baseline model.

Table 1. Building envelope U value and overall thermal transfer value (OTTV) of model.

Building component U value	**W/m^2 K**
Wall	3.21
Roof	0.27
Window	5.89
Door	3.13
Floor	1.58
Building overall U value	**W/m^2**
Model OTTV	30
MS1525 recommended OTTV	50

Table 2. Detail of earth tube installation in each unit of the building model.

Field	**Units**	**Model**
Earth tube type		Exhaust
Pipe Material		Polyvinylchloride (PVC)
Pipe Radius	m	0.04
Pipe Thickness	m	0.003
Pipe Length	m	30
Pipe Thermal Conductivity	W/m.K	0.2
Pipe Depth Under Ground Surface	m	1.5
Design Flowrate	m^3/s	0.026
Soil Temperature	°C	28.2

2.2. Computer programme: Validation and verification

Before the model can be used as a baseline model, it was validated and calibrated at the same time by comparing the simulated temperature of the air entering the thermal zone after passing through the earth tube with an actual experiment conducted by another study by Sanusi et al. [23]. The ground interface temperature was set to 28°C based on the finding of the same study. Calibration result is shown in Table 3 and Fig. 3.

Table 3. Calibration of simulation model with an actual earth tube experiment by others.

Calibrated parameter	Simulation Model	Study from [23]	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].

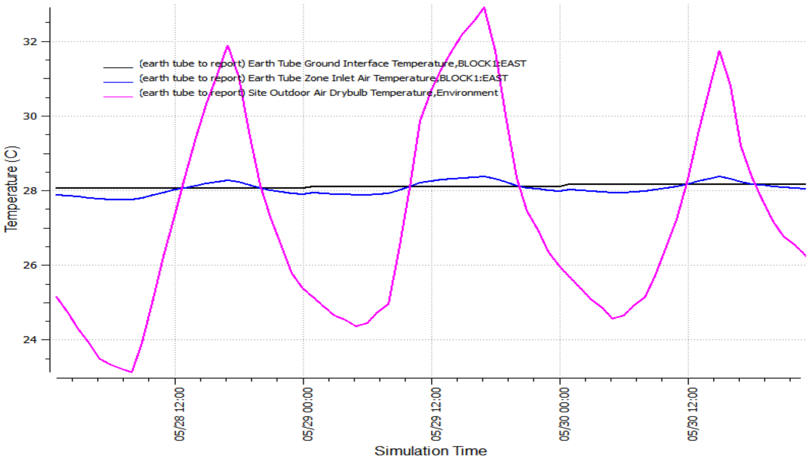


Fig. 3. Design ground temperature and air temperature with the resulting zone inlet temperature for validation purpose.

The simulation was then initiated with values shown in previous Table 1 and Table 2 as a baseline model. A parametric analysis was conducted based on this baseline model by varying the parameter shown in Table 4. Different value was tested to access the performance of the earth tube in the building model. For the purpose of thermal comfort analysis, the simulation considers an underfloor air diffuser with a comfort height of 1.1m above floor level. The following criteria were used for the simulation: (i) there is no envelope infiltration and only allows variable flow ventilation through the earth tube, (ii) air flow is induced by air fan and located at downstream of tube where fan heat is not added to the air stream, (iii) typical summer design week where outdoor air temperature ranges from 32°C to 34°C.

Table 4. Variable that was regulated in the simulation.

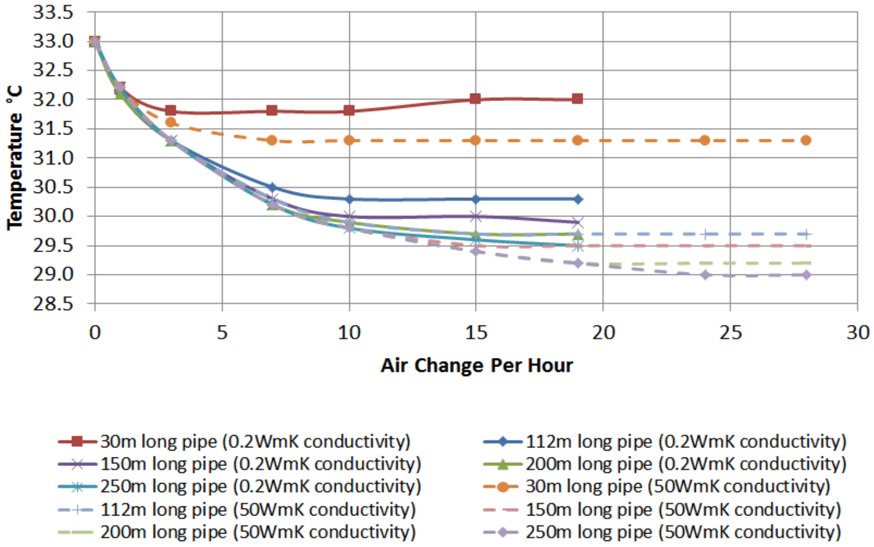
Field	Units	Tested value
Pipe Length	m	30-250
Pipe Radius	m	0.025-0.08
Air flowrate	m^3/s	0.04-0.6
Pipe Thermal Conductivity	W/m.K	0.2-50 (PVC to Steel)

3. Simulation Result

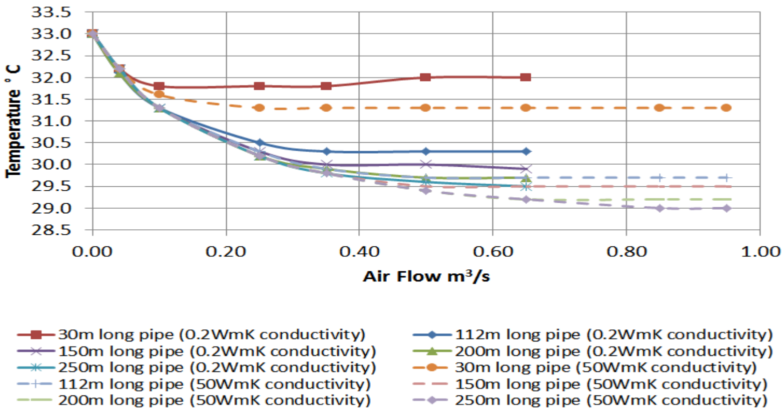
Baseline model was tested for variable tube distance from 30m to 250m long and the effect to each home unit was observed under different Air Change per Hour (ACH). Figure 4 shows the East zone temperature drop from 33°C to 29.5°C (a total of 3.5°C drop) by using tube distance of 250m long and 0.04m radius PVC pipe.

However it should be noted that the longer the distance of the tube the less impact it will give to the resulting conditioned air entering the zone after passing through the earth tube. The result was in agreement with the study by Sharan and Jadhav [18]. They studied the performance of a 50m long pipe at 3m depth (soil temperature of 26.6°C) and measured the temperature drop at the middle point and outlet of the pipe. Given the air temperature of about 40°C in India

Ahmedabad around noon, most of the cooling occurred in the first half of the tube where the temperature drop from 40.8°C to 29.7°C (11°C drop) At the outlet of the tube the lowest temperature recorded was 27.2°C (another 2.5°C drop). The plot in Fig. 4 shows how manipulation of the pipe length can have an impact to the zone air temperature. Figure 5 shows how much cooling a 250m long pipe could provide under variable flowrate.



(a)



(b)

Fig. 4. Effect of variable ACH/air flowrate for different length of earth tube on East zone air temperature reduction during outdoor peak temperature of 33.2°C. Baseline East zone indoor temperature is 33°C.

As a reference with regards to hourly air change (ACH), ASHRAE have suggested ACH of about 1 ACH for whole house ventilation, minimum 5 ACH for kitchen area and 2 ACH for bathroom or lavatory. Another point worth mentioning here is that for short pipe (30m), increasing the air flowrate will slightly increase the air temperature as shown in Fig. 4. This could likely be due to the fact that under higher flowrate more air mass is being forced into the pipe but the cooling power of the earth tube remains the same therefore insufficient to cool down the extra volume of air which led to higher net temperature. The baseline model was further tested by dividing the East zone into three smaller thermal zones with two additional rooms located on the east side as shown in Fig. 6. Each of the 3 smaller thermal zones in East unit was still being served by earth tube of the same length and size from the previous result. Figure 6 shows that a further air temperature reduction of 0.6°C could be achieved due to the smaller room volume served by the earth tube. The east north and east south room temperature was at about 28.9°C.

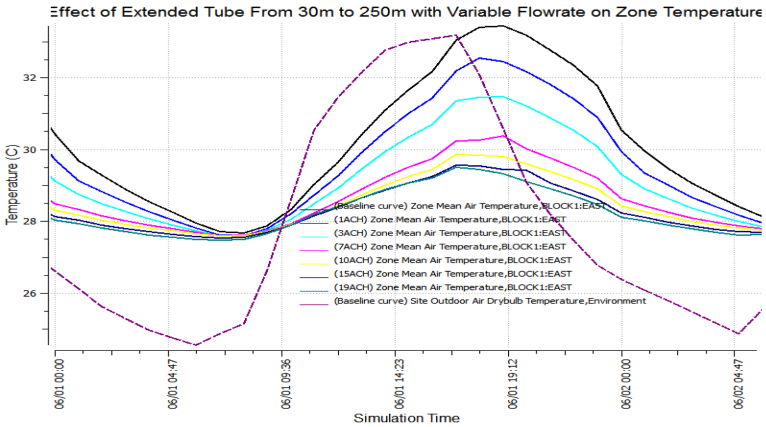
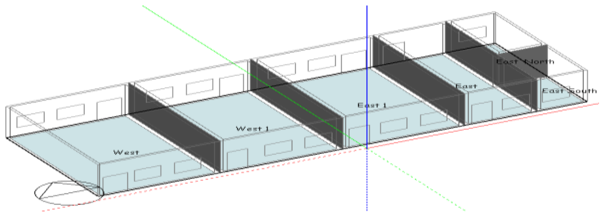
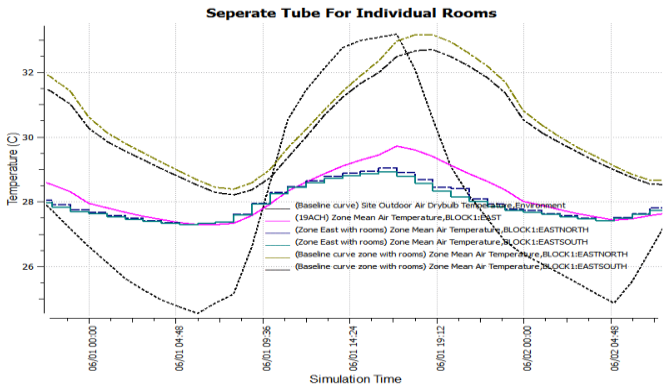


Fig. 5. East zone air temperature reduction after pipe length of 250 m.



(a) Adding more thermal zones on the East unit with two additional rooms (east north and east south)



(b) Further air temperature reduction of 0.6°C.
Fig. 6. Further air temperature reduction due to smaller thermal zone served by the same pipe length and size.

Another variable that was looked into to try further lower this temperature is the size and material of the pipe used. The baseline pipe size was 0.04m and reducing the radius size to 0.025m will only increase the zone temperature slightly as shown in Fig. 7.

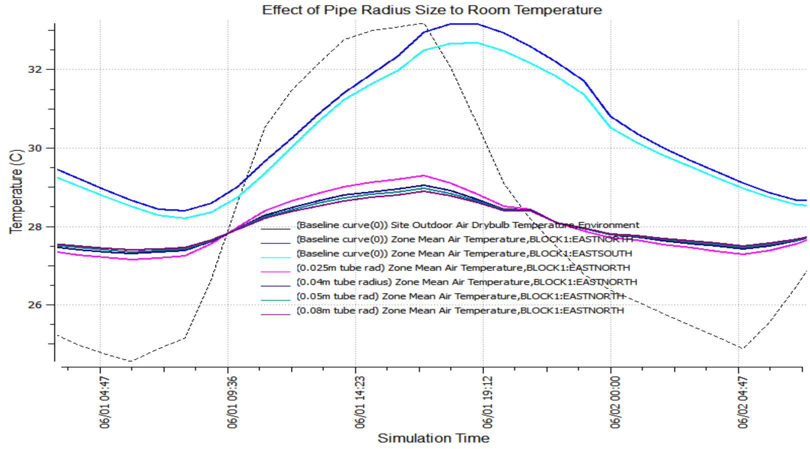


Fig. 7. Limited effect of variable tube size to further lowering the air temperature.

On the other hand, increasing the size gradually to double its size will only lower the temperature slightly down to only about 0.2°C. This may be due to the fact that the resulting earth tube zone inlet air temperature is nearly close to the ground temperature of 28°C and to further lower the inlet temperature would require a cooler ground temperature. A separate study by Yu et al. [19] have conducted experiment of an Earth Air Heat Exchanger in the Nebraska US, buried 3 meters deep underground with ground temperature between 18°C to 20°C and channelled this cool air into a room (20m L x5m W x3m H) to produce an indoor air temperature of between 21°C to 24°C. To get a lower cool air would require a lower ground temperature. Furthermore at this stage changing the material type from PVC to steel pipe does not give much additional cooling as shown in Fig. 8. The same is also true for any other pipe length as shown in Fig. 9.

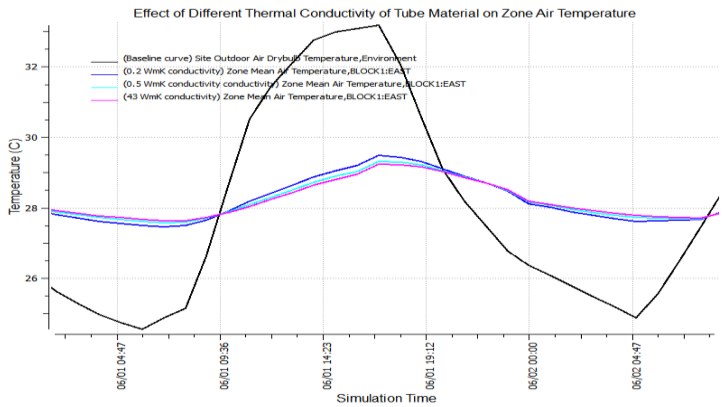


Fig. 8. Effect of pipe material change to zone temperature.

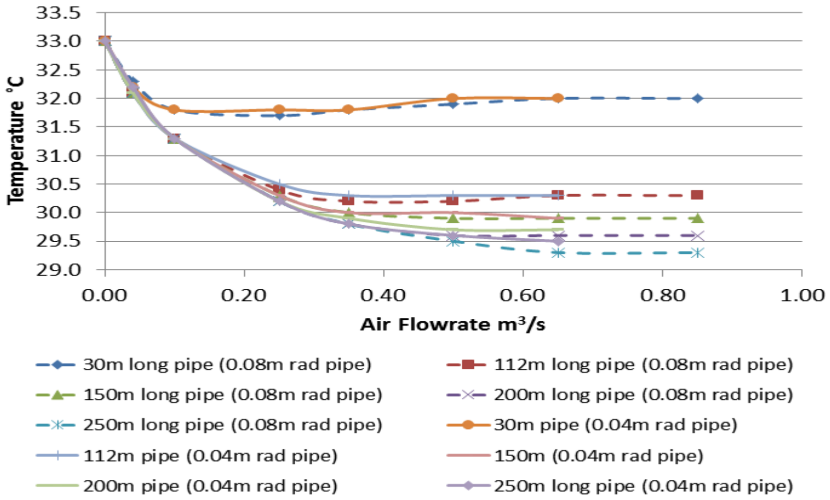


Fig. 9. Effect of pipe diameter sizes to zone temperature.

The baseline model clothing value was 0.5 (clo) with a 1.2 (met) metabolic rate value typical for dwelling setup. The Fanger PMV (calculated according to ISO 7730, 2007) improvement was observed for all four units of the low income house building as shown in Fig. 10. (ASHRAE has set a PMV range of -0.5< PMV < +0.5 for a mechanical conditioned building whereas ISO 7730 has set lower range quality category C of -0.7 < PMV < +0.7)

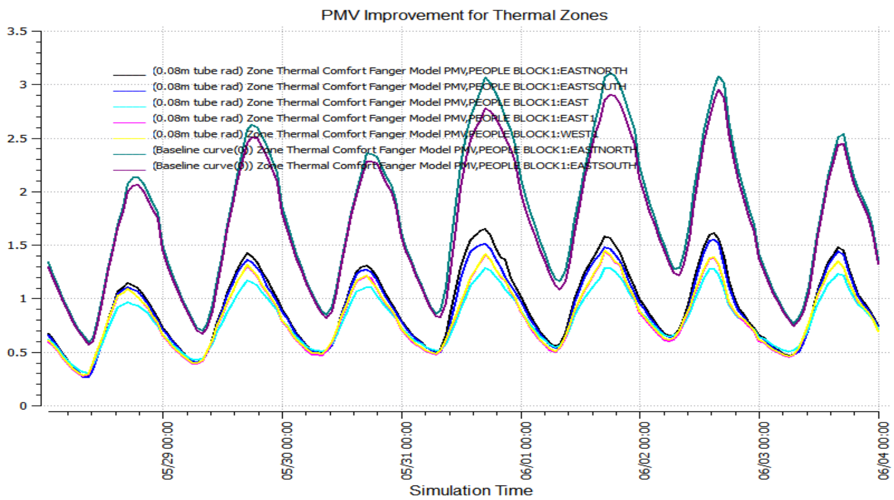


Fig. 10. PMV improvements for all thermal zones.

Although the building PMV was still beyond the set standard, the operative temperature in the building nevertheless was able to be lowered to less than 30°C where the significances are explained in the following para. In a summer design week, the daily peak zone operative temperature for end unit (facing east) and middle unit of the building with earth tube cooling is shown in Fig. 11.

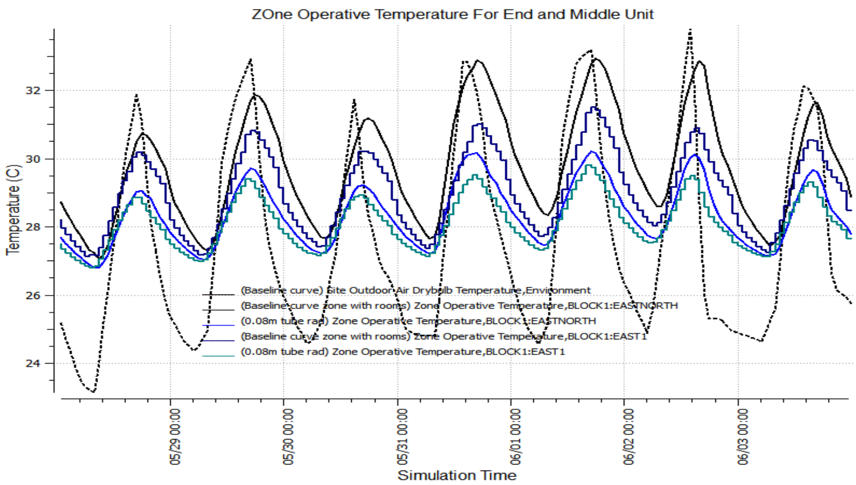


Fig. 11. Zone operative temperature for end house unit (smooth plot line) and middle house unit (stair plot line).

The operative temperature of the middle unit is below 30°C. This range is within acceptable operative temperature of 80% acceptability limits of 30.29 ° as per ASHRAE Standard 55 (2013) for naturally conditioned spaces as shown in Fig. 12 (for mean outdoor temperature of 29°C).

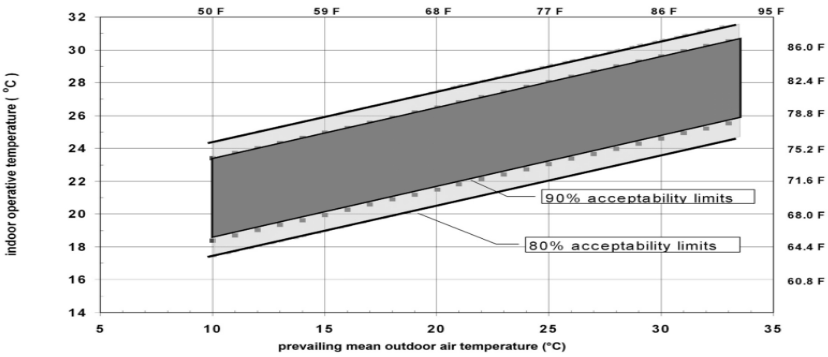


Fig. 12. Acceptable operative temperature ranges for naturally conditioned spaces (ASHRAE Standard 55, 2013).

This operative temperature is also within the recommended operative temperature of 29°C-31°C for air movement of 0.6 to 0.7 m/s of 80% acceptability for naturally ventilated building in tropical climate [2]. As for the end unit of the building which is the warmest unit of all, the peak operative temperature of 30.2°C is also still within the acceptable 80% limit as mentioned above. One should bear in mind that the simulation model provides a preconditioned air through earth tube before entering the indoor zone thus result in operative temperature which is within the limit set above without air movement induced by occupant controlled air fan in the room. Any movement of air created by the air fan should further improve the PMV.

4. Conclusion

Earth tube application in a Sarawak low cost single storey house was simulated in Design Builder V 4.2 to find out how much cooling the earth tube system could provide. From the simulation it can be seen that retrofitting a low cost house with earth tube at a certain boundary condition could improve the indoor thermal comfort. The improvement of the thermal comfort expressed as operative temperature is within the acceptable ranges for naturally conditioned spaces specified by ASHRAE as well as most of the published research acceptable temperature range which seldom exceed 30ºC. The PMV was significantly improved even though it is still short of meeting the specified standard and could still be enhanced with the use of force air movement or fan.

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